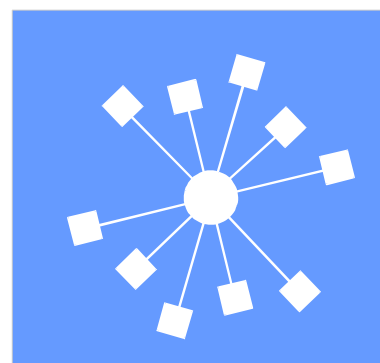
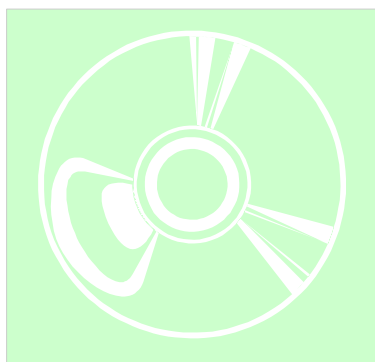


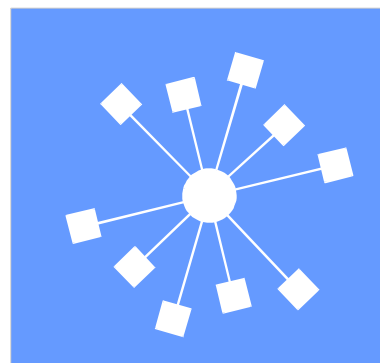
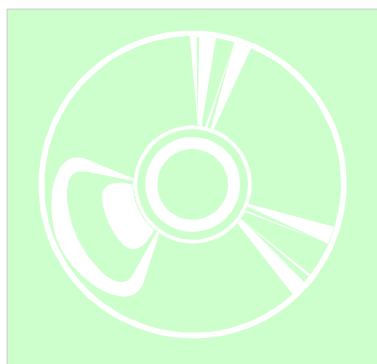
System Guide



Mark VI Control

System Guide, Volume I

System Guide



Mark VI Control

System Guide, Volume I

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Safety Symbol Legend



Indicates a procedure, condition, or statement that, if not strictly observed, could result in personal injury or death.

Warning



Indicates a procedure, condition, or statement that, if not strictly observed, could result in damage to or destruction of equipment.

Caution



Indicates a procedure, condition, or statement that should be strictly followed in order to optimize these applications.

Attention

Note Indicates an essential or important procedure, condition, or statement.



This equipment contains a potential hazard of electric shock or burn. Only personnel who are adequately trained and thoroughly familiar with the equipment and the instructions should install, operate, or maintain this equipment.

Isolation of test equipment from the equipment under test presents potential electrical hazards. If the test equipment cannot be grounded to the equipment under test, the test equipment's case must be shielded to prevent contact by personnel.

To minimize hazard of electrical shock or burn, approved grounding practices and procedures must be strictly followed.



To prevent personal injury or equipment damage caused by equipment malfunction, only adequately trained personnel should modify any programmable machine.

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Introduction

This document describes the SPEEDTRONIC™ Mark VI turbine control system. Mark VI is used for the control and protection of steam and gas turbines in electrical generation and process plant applications.

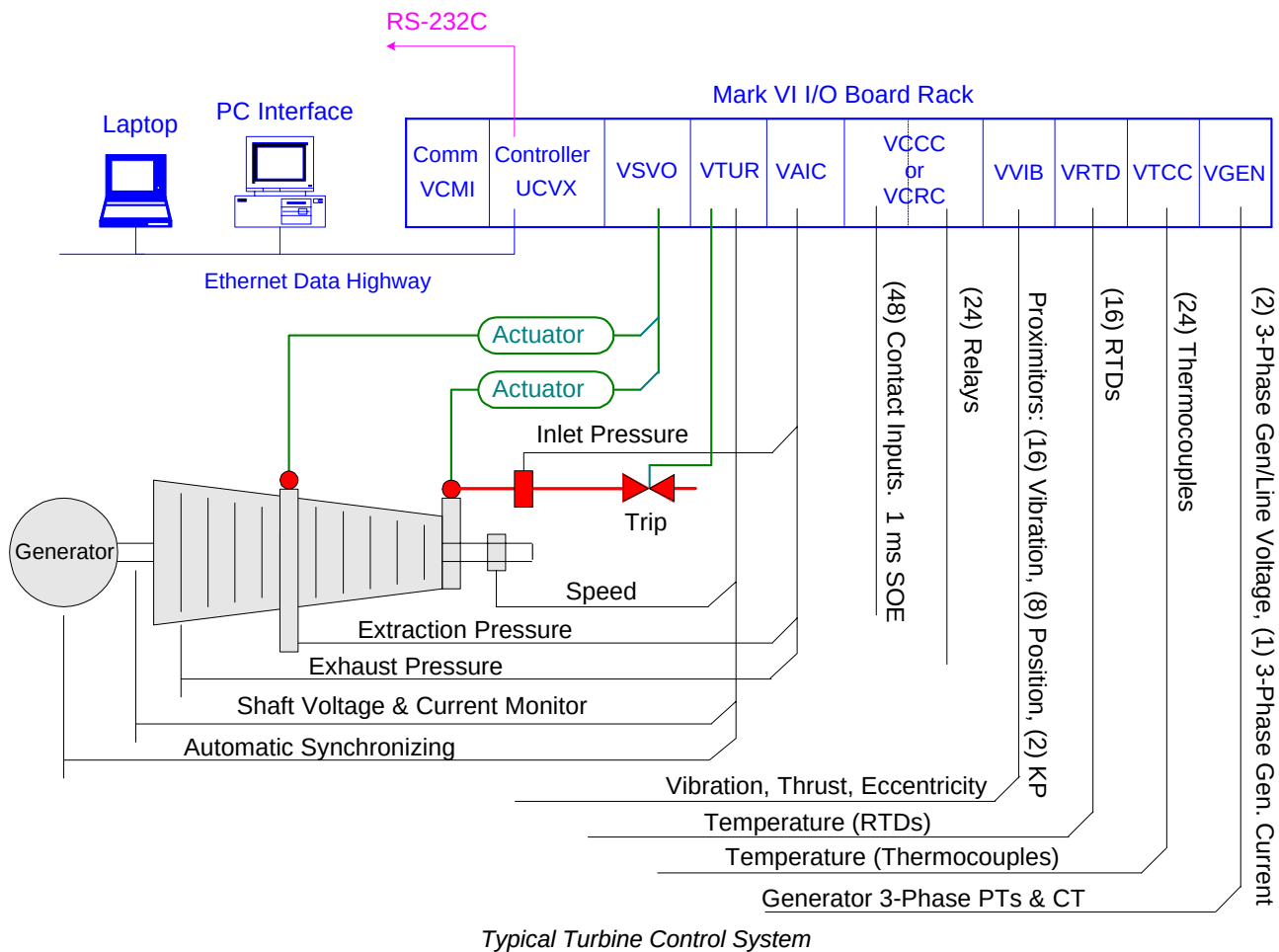
The main functions of the Mark VI turbine control system are as follows:

- Speed control during turbine startup
- Automatic generator synchronization
- Turbine load control during normal operation on the grid
- Protection against turbine overspeed on loss of load

The Mark VI system is available as a simplex control or a triple modular redundant (TMR) control with single or multiple racks, and local or remote I/O. The I/O interface is designed for direct interface to the sensors and actuators on the turbine, to eliminate the need for interposing instrumentation, and to avoid the reliability and maintenance issues associated with that instrumentation.

Note To obtain the highest reliability, Mark VI uses a TMR architecture with sophisticated signal voting techniques.

The following figure shows a typical Mark VI control system for a steam turbine with the important inputs and control outputs.



Related Documents

For additional information, refer to the following documents:

- GEH-6403 *Control System Toolbox for a Mark VI Controller* (for details of configuring and downloading the control system)
- GEH-6422 *Turbine Historian System Guide* (for details of configuring and using the Historian)
- GEH-6408 *Control System Toolbox for Configuring the Trend Recorder* (for details of configuring the toolbox trend displays)
- GEI-100534, *Control Operator Interface (COI) for Mark VI and EX2100 Systems*
- GEI-100535, *Modbus Communications*
- GEI-100536, *Profibus Communications*
- GEI-100189, *System Database (SDB) Server User's Guide*
- GEI-100271, *System Database (SDB) Browser*

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Acronyms and Abbreviations

ADL	Asynchronous Device Language
ASCII	America Standard Code for Information Interchange
BOP	Balance of Plant
BIOS	Basic Input/Output System
CCR	Central Control Room
CMOS	Complementary Metal-Oxide Semiconductor
COI	Computer Operator Interface
CPCI	CompactPCI
CPU	Central Processing Unit
CRC	Cyclic Redundancy Code/Check
CT	Current Transformer
DCE	Data Communication Equipment
DCS	Distributed Control System
DDE	Data Distribution Equipment
DHCP	Dynamic Host Configuration Protocol
DRAM	Dynamic Random Access Memory
DTD	Data Terminal Equipment Device
EGD	Ethernet Global Data
EMC	Electromagnetic Capability
EMI	Electro-Magnetic Interference
EVA	Early Valve Actuation
FE	Functional Earth
FFT	Fast Fourier Transform
FIT	Failures in Time
GPS	Global Position System
GSM	GE Standard Messaging
GTS	Global Time Source
HMI	Human-Machine Interface

HRSG	Heat Recovery Steam Generator
ICS	Integrated Control System
IEEE	Institute of Electrical and Electronics Engineers
KP	KeyPhasor®
LAN	Local Area Network
MPU	Magnetic Pickup
MTBF	Mean Time Between Failures
MTBFO	Mean Time Between Forced Outage
MTTR	Mean Time To Repair
NEC	National Electrical Code
NEMA	National Electrical Manufacturer's Association
NFPA	National Fire Protection Association
NTP	Network Time Protocol
PDH	Plant Data Highway
PE	Protective Earth
PLU	Power Load Unbalance
PDM	Power Distribution Module
PLC	Programmable Logic Controller
PPS	Pulse per Second
PT	Potential Transformer
RFI	Radio Frequency Interference
RLD	Relay Ladder Diagram
RPM	Revolutions Per Minute
RPSM	Redundant Power Supply Module
RTD	Resistance Temperature Device
RTU	Remote Terminal Unit
SDB	Systems Database
SIFT	Software Implemented Fault Tolerance
SOE	Sequence of Events
SOF	Start of Frame
SRS	Single Reference Structure
TMR	Triple Modular Redundant
UART	Universal Asynchronous Receiver/Transmitter
UDH	Unit Data Highway
UTC	Coordinated Universal Time
VLAN	Virtual Local Area Network
WAN	Wide Area Network

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Introduction

This chapter defines the architecture of the Mark VI turbine control system, including the system components, the three communication networks, and the various levels of redundancy that are possible. It also discusses system reliability and availability, and third-party connectivity to plant distributed control systems.

System Components

This section summarizes the main subsystems that make up the Mark VI control system. These include the controllers, I/O boards, terminal boards, power distribution, cabinets, networks, operator interfaces, and the protection module.

Control Cabinet

The control cabinet contains either a single (simplex) Mark VI control module or three TMR control modules. These are linked to their remote I/O by a single or triple high speed I/O network called IONet, and are linked to the UDH by their controller Ethernet port. Local or remote I/O is possible. The control cabinet requires 120/240 V ac and/or 125 V dc power. This is converted to 125 V dc to supply the modules.

I/O Cabinet

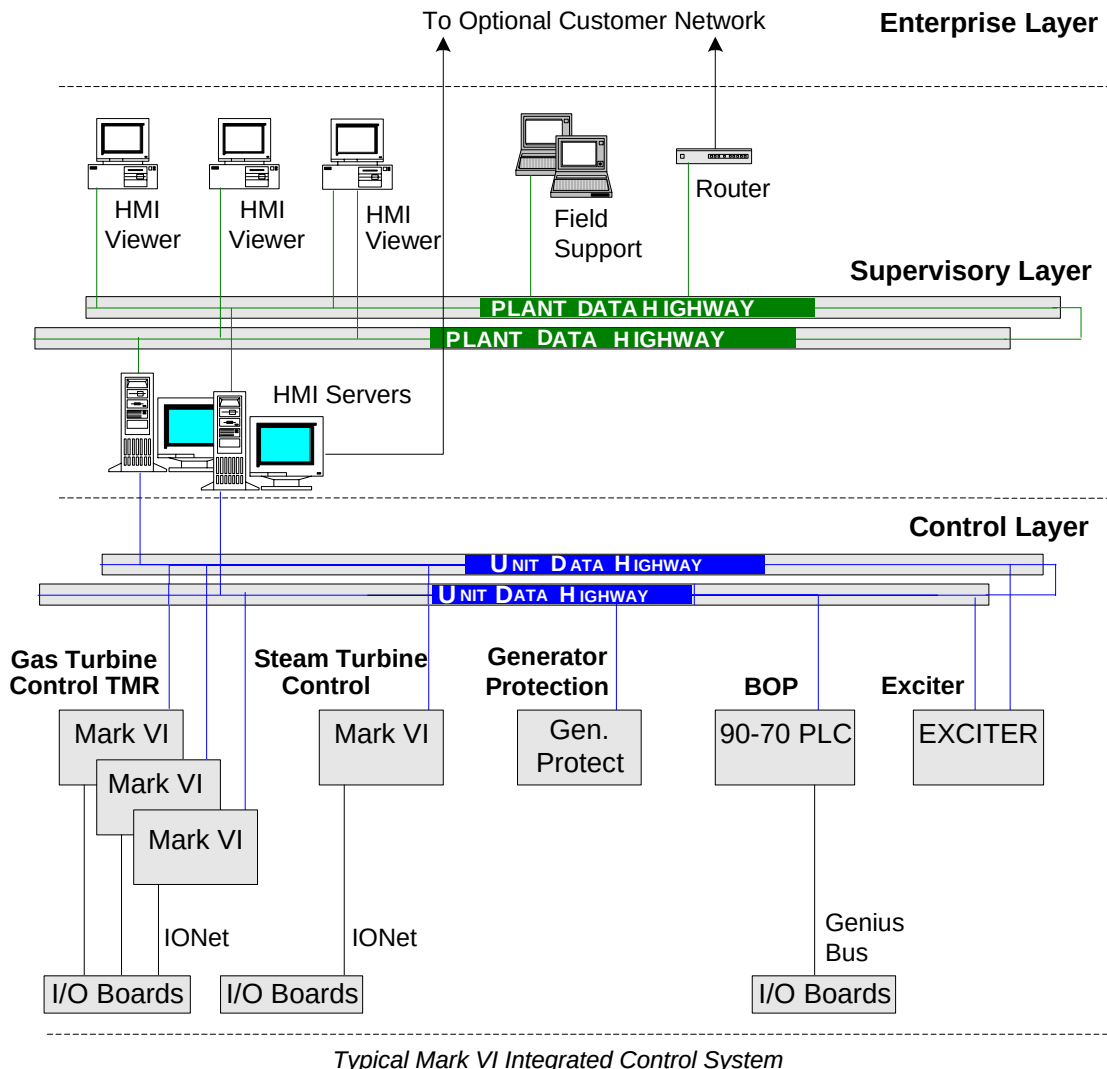
The I/O cabinet contains either single or triple interface modules. These are linked to the controllers by IONet, and to the terminal boards by dedicated cables. The terminal boards are in the I/O cabinet close to the interface modules. Power requirements are 120/240 V ac and/or 125 V dc power.

Unit Data Highway (UDH)

The UDH connects the Mark VI control panels with the HMI or HMI/Data Server. The network media is UTP or fiber-optic Ethernet. Redundant cable operation is optional and, if supplied, unit operation continues even if one cable is faulted. Dual cable networks still comprise one logical network. Similar to the plant data highway (PDH), the UDH can have redundant, separately powered network switches, and fiber optic communication.

UDH command data is replicated to all three controllers. This data is read by the Master communication controller board (VCMC) and transmitted to the other controllers. Only the UDH communicator transmits UDH data (refer to the section, UDH Communicator).

Note The UDH network supports the Ethernet Global Data (EGD) protocol for communication with other Mark VIs, HRSG, Exciter, Static Starter, and Balance of Plant (BOP) control.



Human-Machine Interface (HMI)

Typical HMI's are computers running Windows operating system with communication drivers for the data highways, and CIMPLICITY operator display software. The operator initiates commands from the real time graphic displays, and can view real time turbine data and alarms on the CIMPLICITY graphic displays. Detailed I/O diagnostics and system configuration are available using the toolbox software. An HMI can be configured as a server or viewer, and can contain tools and utility programs.

An HMI may be linked to one data highway, or redundant network interface boards can be used to link the HMI to both data highways for greater reliability. The HMI can be cabinet, control console or table-mounted.

Servers

CIMPLICITY servers collect data on the UDH and use the PDH to communicate with viewers. Multiple servers can be used to provide redundancy.

Note Redundant data servers are optional, and if supplied, communication with the viewers continues even if one server fails.

Computer Operator Interface (COI)

The Computer Operator Interface (COI) consists of a set of product and application specific operator displays running on a small cabinet computer (10.4 or 12.1 inch touch screen) hosting Embedded Windows operating system. The COI is used where the full capability of a CIMPLICITY HMI is not required. Embedded Windows operating system uses only the components of the operating system required for a specific application. This results in all the power and development advantages of a Windows operating system. Development, installation or modification of requisition content requires the toolbox. For details, refer to the appropriate toolbox documentation.

The COI can be installed in many different configurations, depending on the product line and specific requisition requirements. The only cabling requirements are for power and for the Ethernet connection to the UDH. Network communication is via the integrated auto-sensing 10/100BaseT Ethernet connection. Expansion possibilities for the computer are limited, although it does support connection of external devices through FDD, IDE, and USB connections.

The COI can be directly connected to the Mark VI or Excitation Control System, or it can be connected through an EGD Ethernet switch. A redundant topology is available when the controller is ordered with a second Ethernet port.

Interface Features

EGD pages transmitted by the controller are used to drive numeric data displays. The refresh rate depends both on the rate at which the controller transmits the pages, and the rate at which the COI refreshes the fields. Both are set at configuration time in the toolbox.

The COI uses a touch screen, and no keyboard or mouse is provided. The color of pushbuttons is driven by state feedback conditions. To change the state or condition, press the button. The color of the button changes if the command is accepted and the change implemented by the controller.

Touching an input numeric field on the COI touch screen displays a numeric keypad and the desired number can be entered.

An Alarm Window is provided and an alarm is selected by touching it. Then Ack, Silence, Lock, or Unlock the alarm by pressing the corresponding button. Multiple alarms can be selected by dragging through the alarm list. Pressing the button then applies to all selected alarms. For complete information, refer to *GEI-10043, Computer Operator Interface (COI) for Mark VI or EX2100 Systems*.

Link to Distributed Control System (DCS)

External communication links are available to communicate with the plant distributed control system. A serial communication link, using Modbus protocol (RTU binary), can be supplied from an HMI or from a gateway controller. This allows the DCS operator access to real time Mark VI data, and provides for discrete and analog commands to be passed to the Mark VI control. In addition, an Ethernet link from the HMI supports periodic data messages at rates consistent with operator response, plus sequence of events (SOE) messages with data time tagged at a 1 ms resolution.

Plant Data Highway (PDH)

The optional PDH connects the CIMPLICITY HMI/Data Server with remote operator stations, printers, historians, and other customer computers. It does not connect with the Mark VI directly. The media is UTP or fiber-optic Ethernet running at 10/100 Mbps, using the TCP/IP protocol. Redundant cables are required by some systems, but these form part of one single logical network. The hardware consists of two redundant Ethernet switches with optional fiber-optic outputs for longer distances, such as to the central control room. On small systems, the PDH and the Unit Data Highway (UDH) may physically be the same network, as long as there is no peer-to-peer control on the UDH.

Operator Console

The turbine control console is a modular design, which can be expanded from two monitors, with space for one operator, to four monitors, with space for three operators. Printers can be table-mounted, or on pedestals under the counter. The full size console is 5507.04 mm (18 ft 0 13/16 in) long, and 2233.6 mm (7 ft 3 15/16 in) wide. The center section, with space for two monitors and a phone/printer bay, is a small console 1828.8 mm (6 ft) wide.

Excitation Control System

The excitation control system supplies dc power to the field of the synchronous generator. The exciter controls the generator ac terminal voltage and/or the reactive volt-amperes by means of the field current.

The exciter is supplied in NEMA 1 freestanding floor-mounted indoor type metal cabinets. The cabinet lineup consists of several cabinets bolted together. Cable entry can be through the top or bottom.

Generator Protection

The generator protection system is mounted in a single, indoor, freestanding cabinet. The enclosure is NEMA 1, and weighs 1133 kg (2500 lbs). The generator cabinet interfaces to the Mark VI with hard-wired I/O, and has an optional Modbus interface to the HMI.

Static Starter Control System

The static starter control system is used to start a gas turbine by running the generator as a starting motor. The static starter system is integrated into the control system along with the excitation control system. The control supplies the run, torque, and speed setpoint signals to the static starter, which operates in a closed loop control mode to supply variable frequency power to the generator stator. The excitation control system is controlled by the static starter to regulate the field current during startup.

The control cabinet contains an Innovation Series™ controller in a Versa Module Eurocard (VME) control rack. The controller provides the Ethernet link to the UDH and the HMI, and communication ports for field control I/O and Modbus. The field control I/O are used for temperature inputs and diagnostic variables.

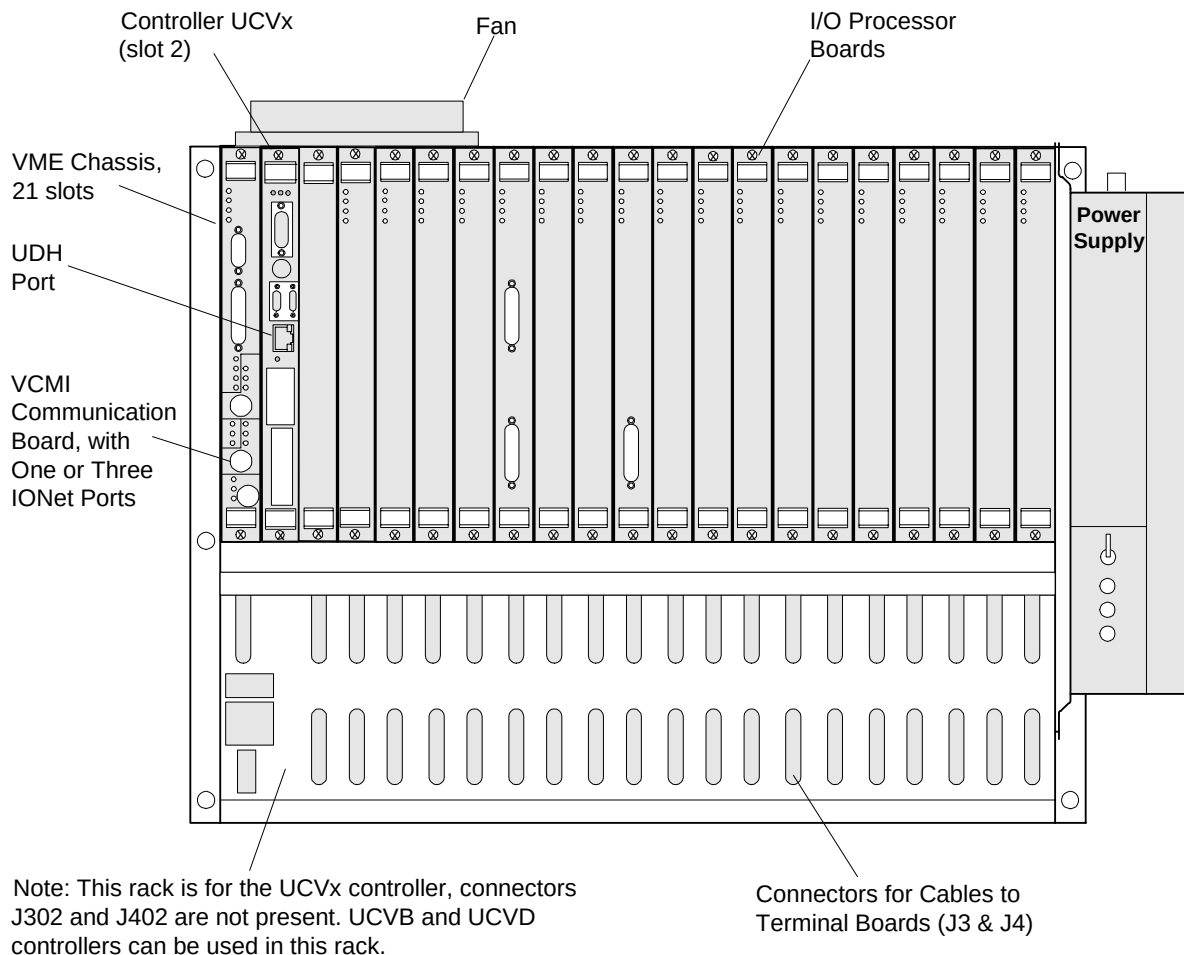
The static starter cabinet is a ventilated NEMA 1 free standing enclosure made of 12-gauge sheet steel on a rigid steel frame designed for indoor mounting.

Control Module

The control module is available as an integrated control and I/O module, or as a stand-alone control module only. The integrated control and I/O rack can be either a 21-slot or 13-slot VME size. The 13-slot rack can accommodate all the boards for control of a small turbine. The backplane has P1 and P2 connectors for the VME boards. The P1 connectors communicate data across the backplane, and the P2 connectors communicate data between the board and 37-pin J3 and J4 connectors located directly beneath each board. Cables run from the J3 and J4 connectors to the terminal boards.

There can be one control module (simplex) or three triple modular redundant (TMR) control modules. Each of these configurations supports remote I/O over IONet. The simplex control modules can be configured to support up to three independent parallel IONet systems for higher I/O throughput. Multiple communication boards may be used in a control module to increase the IONet throughput.

The following figure shows a 21-slot rack with a three-IONet VCMC communication board, and a UCVx controller. The UCVx must go in slot 2. The remaining slots are filled with I/O boards.



Control Module with Control, Communication, and I/O Boards

The I/O racks and the I/O processor boards are shielded to control EMI/RFI emissions. This shielding also protects the processor boards against interference from external sources.

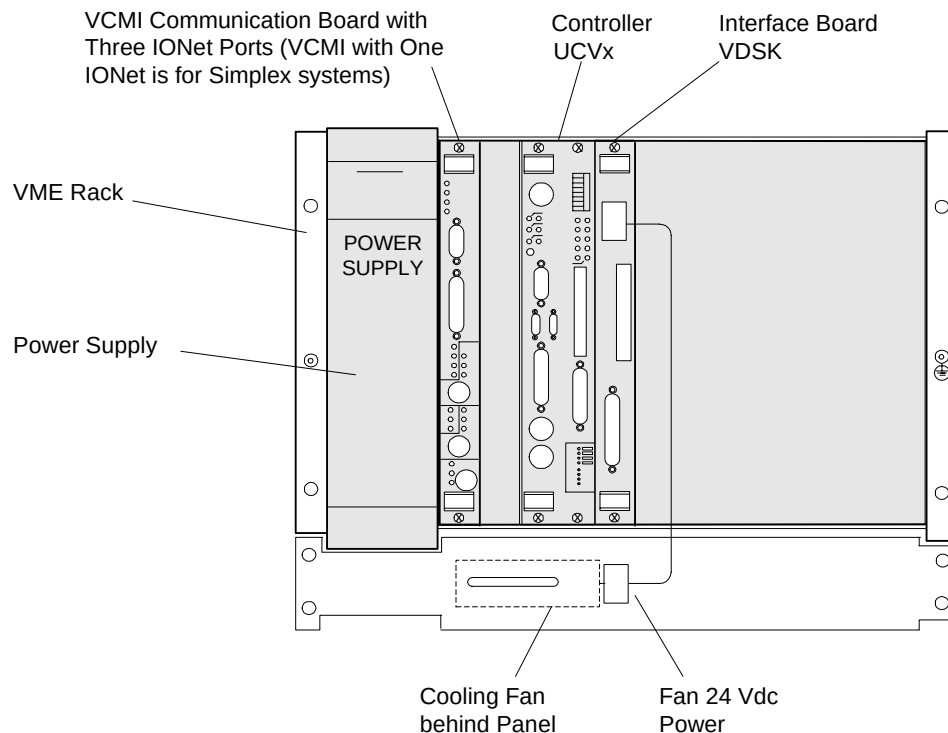


Do not plug the UCVx controller into any rack that has J302 and J402 connectors.

Warning

The stand-alone controller module is a VME rack with the UCVx controller board, VCMi communication board, and VDSK interface board as shown in the following figure. This version is for remote I/O systems. The rack is powered by an integrated power supply.

VDSK supplies 24 V dc to the cooling fan mounted under the rack, and monitors the Power Distribution Module (PDM) through the 37-pin connector on the front. The VDSK board is ribbon cabled in the back to the VCMi to transmit the PDM diagnostics.

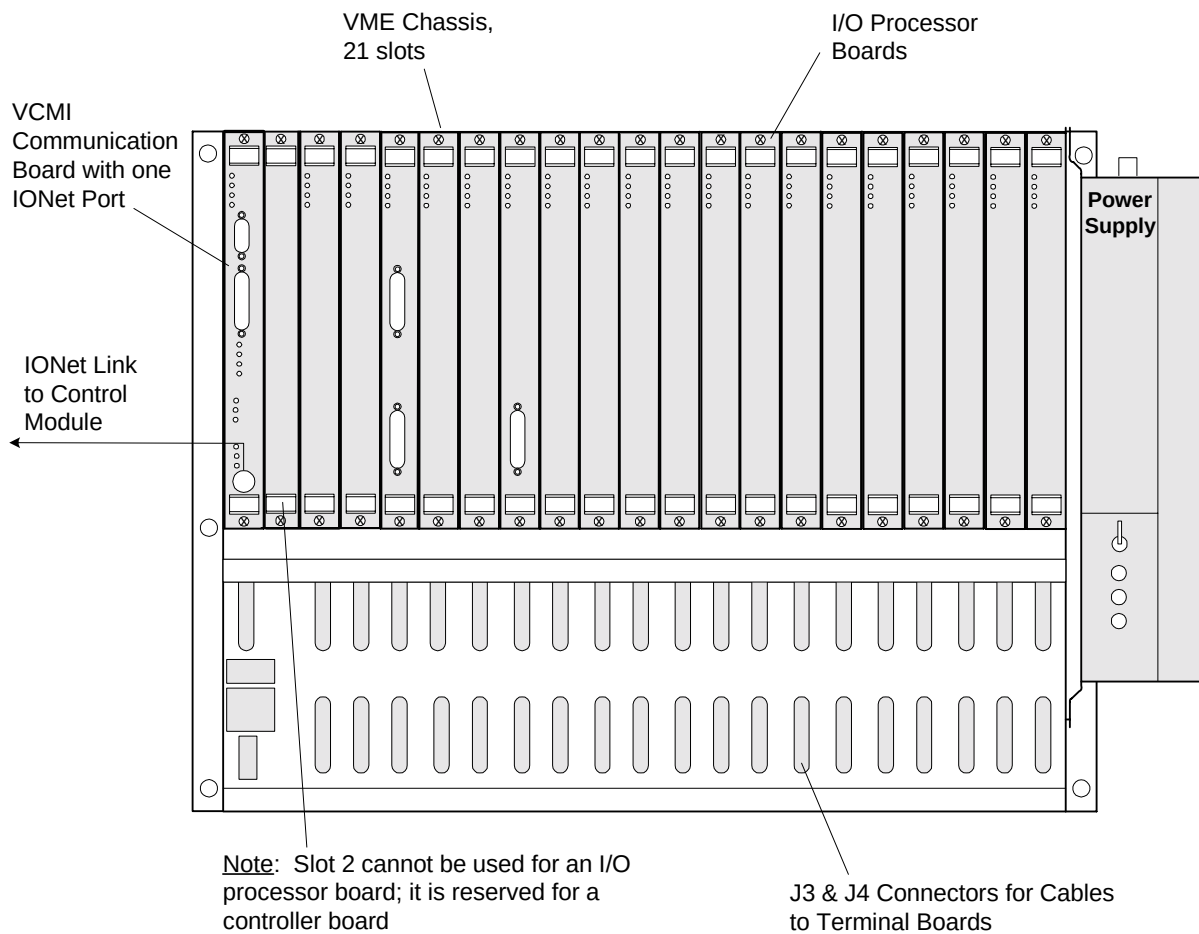


Rack with Controller, VCMi, and VDSK (No I/O Boards)

Interface Module

The interface module houses the I/O boards remote from the control module. The rack, shown in the following figure is similar to the control module VME rack, but without the controller, interface board VDSK, and cooling fan. Each I/O board occupies one or two slots in the module and has a backplane connection to a pair of 37-pin D connectors mounted on an apron beneath the VME rack. Cables run from the 37-pin connectors to the terminal boards. Most I/O boards can be removed, with power removed, and replaced without disconnecting any signal or power cable.

Communication with the module is via a VCMC communication board with a single IONet port, located in the left slot. The module backplane contains a plug wired to slot 1, which is read by the communication board to obtain the identity of the module on the IONet.



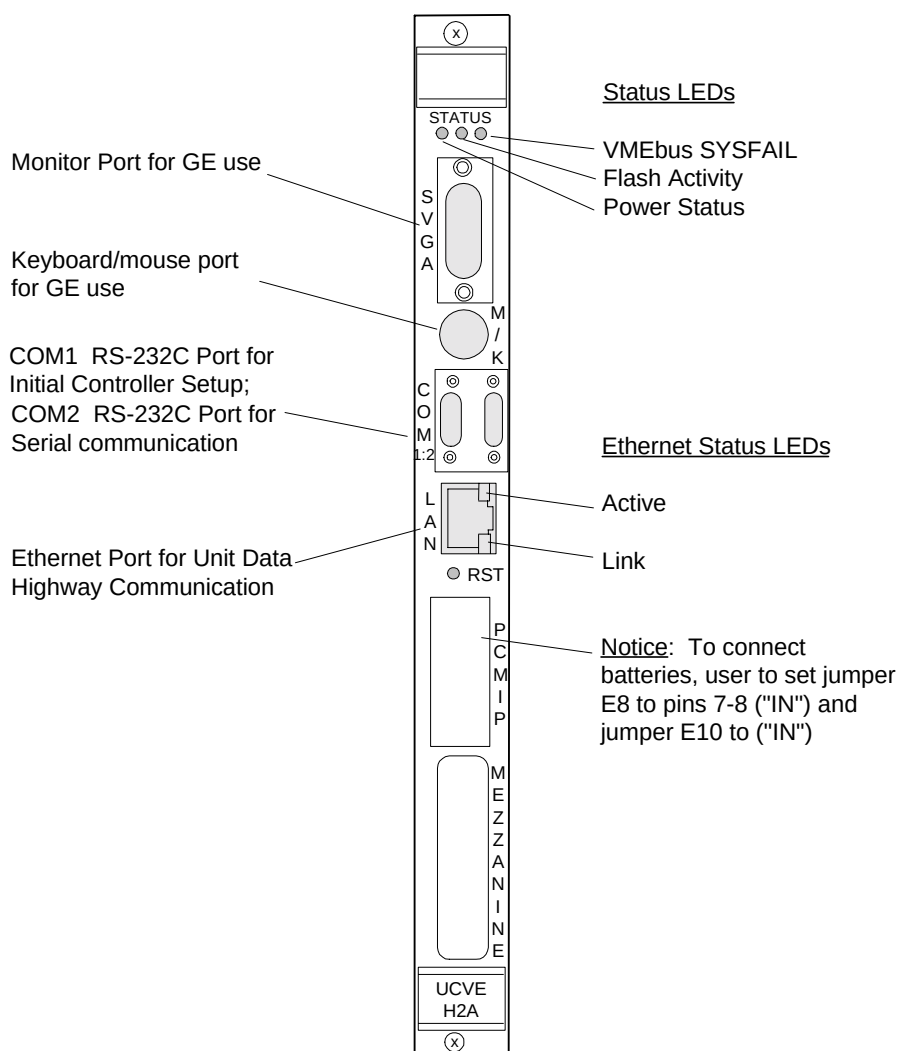
Interface Module with VCMC and I/O Boards

Controller

The controller is a single-slot VME board, housing a high-speed processor, DRAM, flash memory, cache, an Ethernet port, and two serial RS-232C ports. It must always be inserted in slot 2 of an I/O rack designed to accommodate it. These racks can be identified by the fact that there are no J3 and J4 connectors under slot 2. The controller provides communication with the UDH through the Ethernet port, and supports a low-level diagnostic monitor on the COM1 serial port. The base software includes appropriate portions of the existing Turbine Block Library of control functions for the steam, gas, and Land-Marine aero-derivative (LM) products. The controller can run its program at up to 100 Hz, (10 ms frame rate), depending on the size of the system configuration.

External data is transferred to/from the controller over the VME bus by the VCMI communication board. In a simplex system, the data consists of the process I/O from the I/O boards, and in a TMR system, it consists of voted I/O. Refer to *GEH-6421, Volume II*.

Typical Mark VI Controller (UCVx)

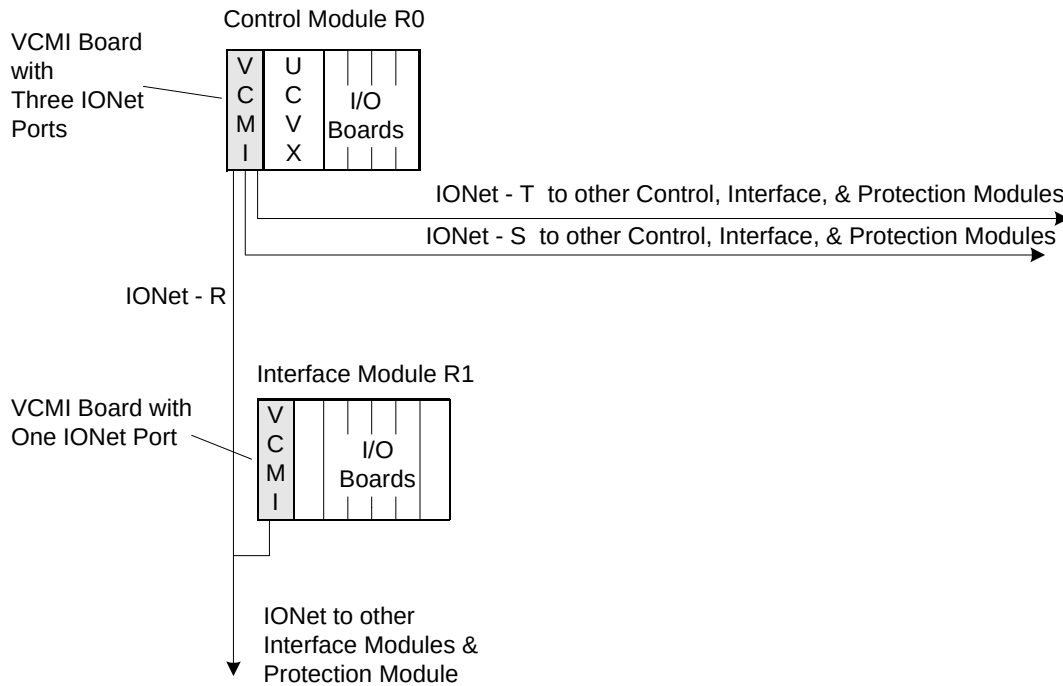


UCVx Controller Front Cabinet

VCMI Communication Board

The VCMI board in the control and interface module communicates internally to the I/O boards in its rack, and to the other VCMI cards through the IONet. There are two versions, one with one Ethernet IONet port for simplex systems, and the other with three Ethernet ports for TMR systems. Simplex systems have one control module connected to one or more interface modules using a single cable. The VCMI with three separate IONet ports is used in TMR systems for communication with the three I/O channels Rx, Sx, and Tx, and with the two other control modules. This is shown in the following figure.

Software Implemented Fault Tolerance (SIFT) voting is implemented in the VCMI board. Input data from each of the IONet connections is voted in each of the R, S, and T VCMI boards. The results are passed to the control signal database in the controllers (labeled UCVx in the diagram) through the backplane VME bus.



VCMI Boards providing I/O Communication and I/O Voting

In TMR mode, the VCMI voter in the control module is always the Master of the IONet and also provides the IONet clock. Time synch messages from the time source on the UDH are sent to the controllers and then to the VCMI. All input data from a single rack is sent in one or more IONet packets (approximately 1500 bytes per packet maximum). The VCMI in the control module broadcasts all data for all remote racks in one packet, and each VCMI in the remote rack extracts the appropriate data from the packet.

IONet

The IONet connection on the VCMi is a BNC for 10Base2 Ethernet. The interface circuit is high impedance allowing “T” tap connections with 50 Ω terminal at the first and last node. The cabling distances are restricted to 185 meters per segment with up to eight nodes, using RG-58C/U or equivalent cable.

The Link Layer protocol is IEEE 802.3 standard Ethernet. The application layer protocol uses Asynchronous Device Language (ADL) messaging with special adaptations for the input/output handling and the state exchanges.

The VCMi board acts as IONet Master and polls the remote interface module for data. The VCMi Master broadcasts a command to all slave stations on a single IONet causing them to respond with their message in a consecutive manner. To avoid collisions on the media, each station is told how long to delay before attempting to transmit. Utilizing this Master/slave mechanism, and running at 10 Mb/s, the IONet is capable of transmitting a 1000 byte packet every millisecond (8 MHz bit rate).

Note IONet supports control operation at up to 100 times per second.

In a multiple module or multiple cabinet system, powering down one module of a channel does not disrupt IONet communication between other modules within that channel. If one IONet stops communicating then the I/O boards, in that channel, time out and the outputs go to a safe state. This state does not affect TMR system operation. If two IONets stop then the I/O boards in both channels go to a safe state which would result in a turbine trip, if the turbine was generating.

I/O Boards

Most I/O boards, are single width VME boards, of similar design and front cabinet, using the same digital signal processor (TMS320C32).

The central processing unit (CPU) is a high-speed processor designed for digital filtering and for working with data in IEEE 32-bit floating point format. The task scheduler operates at a 1 ms and 5 ms rate to support high-speed analog and discrete inputs. The I/O boards synchronize their input scan to complete a cycle before being read by the VCMC board. Contact inputs in the VCCC and VCRC are time stamped to 1 ms to provide a sequence of events (SOE) monitor.

Each I/O board contains the required sensor characteristic library, for example thermocouple and RTD linearizations. Bad sensor data and alarm signal levels, both high and low, are detected and alarmed. The I/O configuration in the toolbox can be downloaded over the network to change the program online. This means that I/O boards can accept tune-up commands and data while running.

Certain I/O boards, such as the servo and turbine board, contain special control functions in firmware. This allows loops, such as the valve position control, to run locally instead of in the controller. Using the I/O boards in this way provides fast response for a number of time critical functions. Servo loops, can be performed in the servo board at 200 times per second.

Each I/O board sends an identification message (ID packet) to the VCMC when requested. The packet contains the hardware catalog number of the I/O board, the hardware revision, the board barcode serial number, the firmware catalog number, and the firmware version. Also each I/O board identifies the connected terminal boards via the ID wire in the 37-pin cable. This allows each connector on each terminal board to have a separate identity.

I/O Processor Board	Terminal Board	I/O Signal Types	No. per I/O Processor Board	Type of Terminal Board	Comments
VAIC	TBAI (2)	Analog inputs, 0–1mA, 4–20 mA, voltage Analog outputs, 4–20 mA, 0–200 mA	20 4	TMR, simplex	
VAOC	TBAO	Analog outputs, 4–20 mA	16	TMR, simplex	
VCCC and VCRC	TBCI (2)	Contact inputs	48	TMR, simplex	(VCCC is two slots)
	TRLY (2)	Relay Outputs (note 1)*	24	TMR, simplex	
VCCC	TICI (2)	Point Isolated Contact inputs	48	TMR, simplex	VCCC-only in place of TBCI. (optional)
VGEN	TGEN	Analog inputs, 4–20 mA Potential transformers Current transformers	4 2 3	TMR, simplex	
	TRLY	Relay outputs (optional)	12		for FAS (PLU)
VPRO (3)	TPRO	Pulse rate Potential transformers Thermocouples Analog inputs, 4–20 mA	3 2 3 3	TMR	Emergency Protect

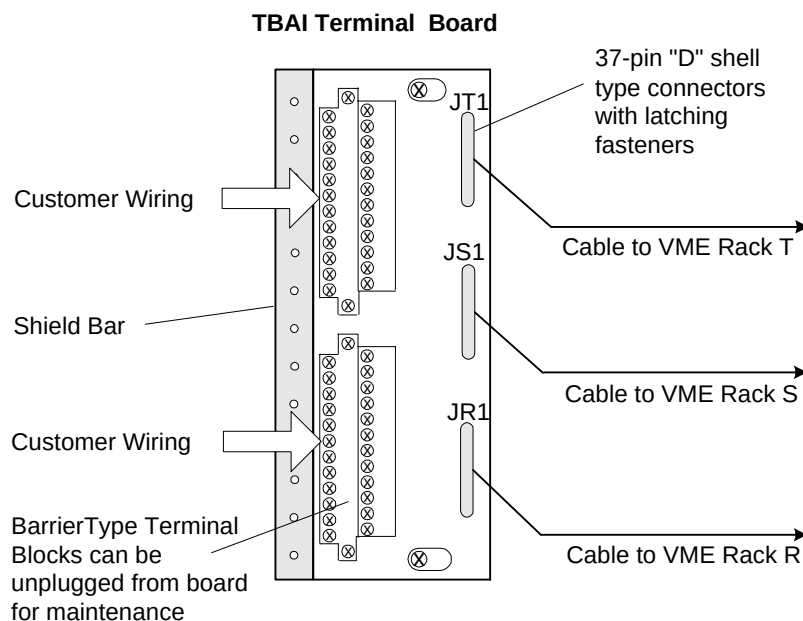
VPYR	TREG (2)	Solenoid drivers	6	TMR	Gas turbine
		Trip contact inputs	7		
		Emergency stop	2		
	TREL	Solenoid drivers	3	TMR	Large steam
		Trip contact inputs	7		
	TRES	Solenoid drivers	3	TMR, simplex	Small/medium steam
		Trip contact inputs	7		
	TPYR	Pyrometers (4 analog inputs each)	2	TMR, simplex	
		KeyPhasor shaft position sensors	2		
	VRTD	TRTD, Resistance Temperature Devices (RTD)	16	TMR, simplex	3 wire
VSVO	TSVO (2)	Servo outputs to valve hydraulic servo	4	TMR, simplex	Trip, Clamp, Input
		LVDT inputs from valve	12		
		LVDT excitation	8		
		Pulse rate inputs for flow monitoring	2		
		Pulse rate excitation	2		
VTCC	TBTC	Thermocouples	24	TMR, simplex	
VTUR	TTUR	Pulse rate magnetic pickups	4	TMR, simplex	
		Potential transformers, gen. and bus	2		
		Shaft current and voltage monitor	2		
		Breaker interface	1		
	TRPG	Flame detectors (Geiger Mueller)	8	TMR, simplex	Gas turbine
		Solenoid drivers (note 2)*	3		
	TRPL	Solenoid drivers	3	TMR	Large steam
		Emergency stop	2		
	TRPS	Solenoid drivers	3	TMR, simplex	Small/med. steam
		Emergency stop	2		
VVIB	TVIB (2)	Shaft vibration probes (Bently Nevada)	16	TMR, simplex	Buffered using BNC
		Shaft proximity probes (Displacement)	8		
		Shaft proximity reference (KeyPhasor)	2		

*Note 1: Refer to the table in the section *Relay Terminal Boards*

*Note 2: VTURH2 occupies two slots and supports two TRPG boards, flame detector support on only the first TRPG.

Terminal Boards

The terminal board provides the customer wiring connection point, and fans out the signals to three separate 37-pin D connectors for cables to the R, S, and T I/O boards. Each type of I/O board has its own special terminal board, some with a different combination of connectors. For example, one version of the thermocouple board does not fan out and has only two connectors for cabling to one I/O board. The other version does fan out and has six connectors for R, S, and T. Since the fan out circuit is a potential single point failure, the terminal board contains a minimum of active circuitry limited primarily to filters and protective devices. Power for the outputs usually comes from the I/O board, but for some relay and solenoid outputs, separate power plugs are mounted on the terminal board.



Typical Terminal Board with Cabling to I/O Boards in VME Rack

DIN-rail Mounted Terminal Boards

Smaller DIN-rail mounted terminal boards are available for simplex applications. These low cost, small size simplex control systems are designed for small gas and steam turbines. IONet is not used since the D-type terminal boards cable directly into the control chassis to interface with the I/O boards. The types of DIN-rail boards are shown in the following table.

DIN–Rail Mounted Terminal Boards

DIN Euro Size Terminal Board	Number of Points	Description of I/O	Associated I/O Processor Board
DTTC	12	Thermocouple temperature inputs with one cold junction reference	VTCC
DRTD	8	RTD temperature inputs	VRTD
DTAI	10	Analog current or voltage inputs with on-board 24 V dc power supply	VAIC
	2	Analog current outputs, with choice of 20 mA or 200 mA	
DTAO	8	Analog current outputs, 0-20 mA	VAOC
DTCI	24	Contact Inputs with external 24 V dc excitation	VCRC (or VCCC)
DRLY	12	Form-C relay outputs, dry contacts, customer powered	VCRC (or VCCC)
DTRT	-----	Transition board between VTUR and DRLY for solenoid trip functions	VTUR
DTUR	4	Magnetic (passive) pulse rate pickups for speed and fuel flow measurement	VTUR
DSVO	2	Servo-valve outputs with choice of coil currents from 10 mA to 120 mA	VSVO
	6	LVDT valve position sensors with on-board excitation	
	2	Active pulse rate probes for flow measurement, with 24 V dc excitation provided	
DVIB	8	Vibration, Position, or Seismic, or Accelerometer, or Velometer	VVIB
	4	Position prox probes	
	1	KeyPhasor (reference)	
DSCB	6	Serial communication ports supporting RS-232C, RS-422 & RS-485.	VSCA

Relay Terminal Boards

The following table provides a comparison of the features offered by the different relay terminal boards.

Relay Terminal Boards

Board	Relays	Power Distribution	Feedback	Relay type	Redundancy	Suppression	Terminals
DRLYH1A	12 form C relays 24dc@10A 125dc@0.5A 120ac@10A 240ac@3A	none	none	soldered sealed mechanical relays	none, simplex only	No	72 Euro-box
DRLYH1B	12 form C relays 24dc@2A 125dc@0.5A 120ac@1A 240ac@0.5A	none	none	soldered sealed mechanical relays	none, simplex only	No	72 Euro-box
TRLYH1B	12 form C relays 24dc@3A 125dc@0.6A 120/240ac@3A	6 fused branches, 1 special unfused	voted coil drive	socketed sealed mechanical relays	Coil drive = voted TMR input or simplex input	MOV	48 Barrier
TRLYH1C	12 form C relays 125dc@0.6A 120/240ac@3A	6 fused branches, 1 special unfused	isolated contact voltage feedback	socketed sealed mechanical relays	Coil drive = voted TMR input or simplex input	MOV & R-C	48 Barrier
TRLYH2C	12 form C relays 24dc@3A	6 fused branches, 1 special unfused	isolated contact voltage feedback	socketed sealed mechanical relays	Coil drive = voted TMR input or simplex input	MOV & R-C	48 Barrier
TRLYH1D	6 form A relays 24dc@3A 125dc@0.6A	6 fused branches	ohm meter (dc solenoid integrity monitor)	socketed sealed mechanical relays	Coil drive = voted TMR input or simplex input	MOV	24 Barrier
TRLYH1E	12 form A relays 120/240ac@6A	none	isolated contact voltage feedback	soldered solid-state relays	Coil drive = voted TMR input or simplex input	No	24 Barrier
TRLYH2E	12 form A relays 24dc@7A	none	isolated contact voltage feedback	soldered solid-state relays	Coil drive = voted TMR input or simplex input	No	24 Barrier
TRLYH3E	12 form A relays 125dc@3A	none	isolated contact voltage feedback	soldered solid-state relays	Coil drive = voted TMR input or simplex input	No	24 Barrier
TRLYH1F	12 form A relays	none without WPDF	non- voted coil drive	soldered sealed mechanical relays	Relay contact voting, TMR only	No	48 Barrier (24 used)
TRLYH1F	12 form A relays	With WPDF, 12 fused outputs	non- voted coil drive	soldered sealed mechanical relays	Relay contact voting, TMR only	No	48 Barrier

TRLYH2F	12 form B relays	none without WPDF	non-voted coil drive	soldered sealed mechanical relays	Relay contact voting, TMR only	No	48 Barrier (24 used)
TRLYH2F	12 form B relays	With WPDF, 12 fused outputs	non-voted coil drive	soldered sealed mechanical relays	Relay contact voting, TMR only	No	48 Barrier

Trip Terminal Boards

The following table provides a comparison of the features offered by the different trip terminal boards.

Board	TMR	Simplex	Output Contacts, 125 V dc, 1 A	Output Contacts, 24 V dc, 3 A	ESTOP	Input Contacts Dry 125 V dc	Input Contacts Dry 125 V dc	Economy Resistor
TRPGH1A*	Yes	No	Yes	No	No	No	No	No
TRPGH1B	Yes	No	Yes	Yes	No	No	No	No
TRPGH2A*	No	Yes	Yes	No	No	No	No	No
TRPGH2B	No	Yes	Yes	Yes	No	No	No	No
TREGH1A*	Yes	No	Yes	No	Yes	Yes	No	Yes
TREGH1B	Yes	No	Yes	Yes	Yes	Yes	No	Yes
TREGH2B	Yes	No	Yes	Yes	Yes	No	Yes	Yes
TRPLH1A	Yes	No	Yes	Yes	Yes	No	No	No
TRELH1A	Yes	No	Yes	Yes	No	Yes	No	No
TRELH2A	Yes	No	Yes	Yes	No	No	Yes	No
TRPSH1A	Yes	Yes	Yes	Yes	Yes	No	No	No
TRESH1A	Yes	Yes	Yes	Yes	No	Yes	No	No
TRESH2A	Yes	Yes	Yes	Yes	No	No	Yes	No

* These boards will become obsolete

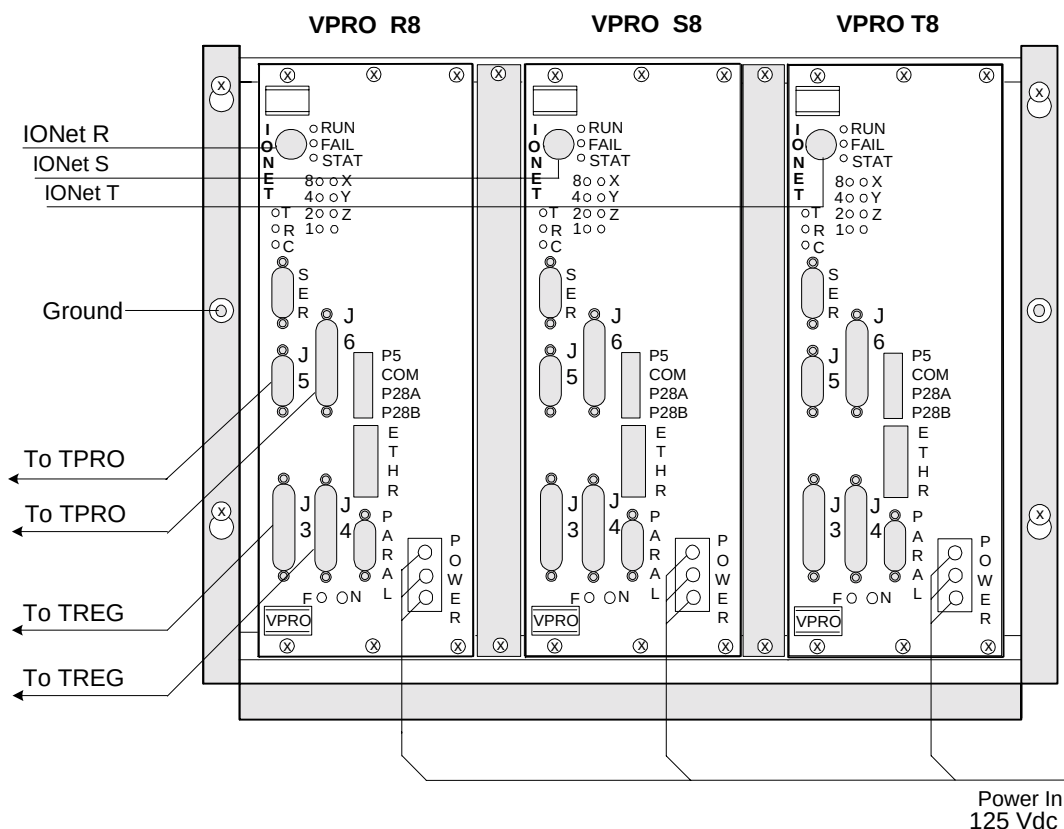
Power Sources

A reliable source of power is provided to the rack power supplies from either a battery, or from multiple power converters, or from a combination of both. The multiple power sources are connected as high select in the Power Distribution Module (PDM) to provide the required redundancy.

A balancing resistor network creates a floating dc bus using a single ground connection. From the 125 V dc, the resistor bridge produces +62.5 V dc (referred to as P125) and -62.5 V dc (referred to as N125) to supply the system racks and terminal boards. The PDM has ground fault detection and can tolerate a single ground fault without losing any performance and without blowing fuses. This fault is alarmed so it can be repaired.

Turbine Protection Module

The Turbine Protection Module (VPRO) and associated terminal boards (TPRO and TREG) provide an independent emergency overspeed protection for turbines that do not have a mechanical overspeed bolt. The protection module is separate from the turbine control and consists of triple redundant VPRO boards, each with their own on-board power supply, as shown in the following figure. VPRO controls the trip solenoids through relay voting circuits on the TREG, TREL, and TRES boards.



Turbine Protection Module with Cabling Connections

The TPRO terminal board provides independent speed pickups to each VPRO, which processes them at high speed. This high speed reduces the maximum time delay to calculate a trip and signal the ETR relay driver to 20 ms. In addition to calculating speed, VPRO calculates acceleration which is another input to the overspeed logic.

TPRO fans out generator and line voltage inputs to each VPRO where an independent generator synchronization check is made. Until VPRO closes the K25A permissive relay on TTUR, generator synchronization cannot occur. For gas turbine applications, inputs from temperature sensors are brought into the module for exhaust over temperature protection.

The VPRO boards do not communicate over the VME backplane. Failures on TREG are detected by VPRO and fed back to the control system over the IONet. Each VPRO has an IONet communication port equivalent to that of the VCMI.

Operating Systems

All operator stations, communication servers, and engineering workstations use the Windows operating system. The HMIs and servers run CIMPLICITY software, and the engineer's workstation runs toolbox software for system configuration.

The I/O system, because of its TMR requirements, uses a proprietary executive system designed for this special application. This executive is the basis for the operating system in the VCMIs and all of the I/O boards.

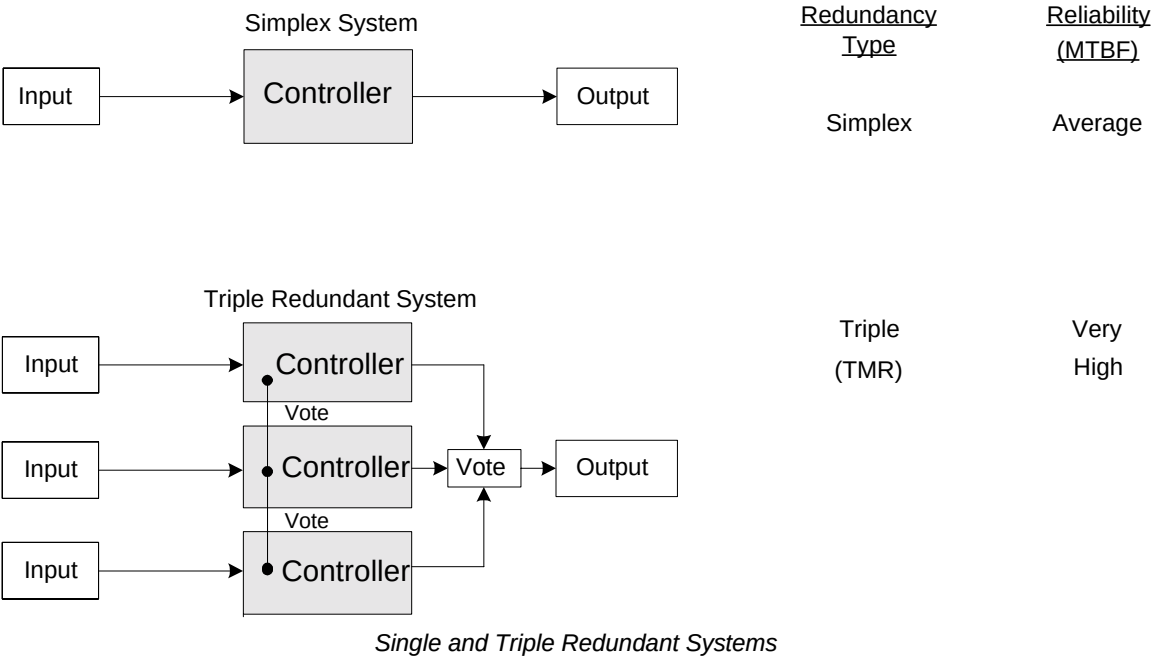
The controller uses the QNX operating system from QNX Software Systems Ltd. This is a real time POSIX-compliant operating system ideally suited to high speed automation applications such as turbine control and protection

Levels of Redundancy

The need for higher system reliability has led vendors to develop different systems of increasing redundancy.

Simplex systems are the simplest systems having only one chain, and are therefore the least expensive. Reliability is average.

TMR systems have a very high reliability, and since the voting software is simple, the amount of software required is reasonable. Input sensors can be triplicated if required.



Single and Triple Redundant Systems

Simplex systems in a typical power plant are used for applications requiring normal reliability, such as control of auxiliaries and balance of plant (BOP). A single PLC with local and remote I/O might be used in this application. In a typical Mark VI, many of the I/O are non-critical and are installed and configured as simplex. These simplex I/O boards can be mixed with TMR boards in the same interface module.

Triple Modular Redundant (TMR) control systems, such as Mark VI, are used for the demanding turbine control and protection application. Here the highest reliability ensures the minimum plant downtime due to control problems, since the turbine can continue running even with a failed controller or I/O channel. In a TMR system, failures are detected and annunciated, and can be repaired online. This means the turbine protection system can be relied on to be fully operational, if a turbine problem occurs.

Control and Protection Features

This section describes the fault tolerant features of the TMR part of the control system. The control system can operate in two different configurations:

- Simplex configuration is for non-redundant applications where system operation after a single failure is not a requirement.
- TMR configuration is for applications where the probability of a single failure causing a process shutdown has to be taken to an extremely low value.

Triple Modular Redundancy

A TMR system is a special case of N-modular redundancy where $N=3$. It is based on redundant modules with input and output voting.

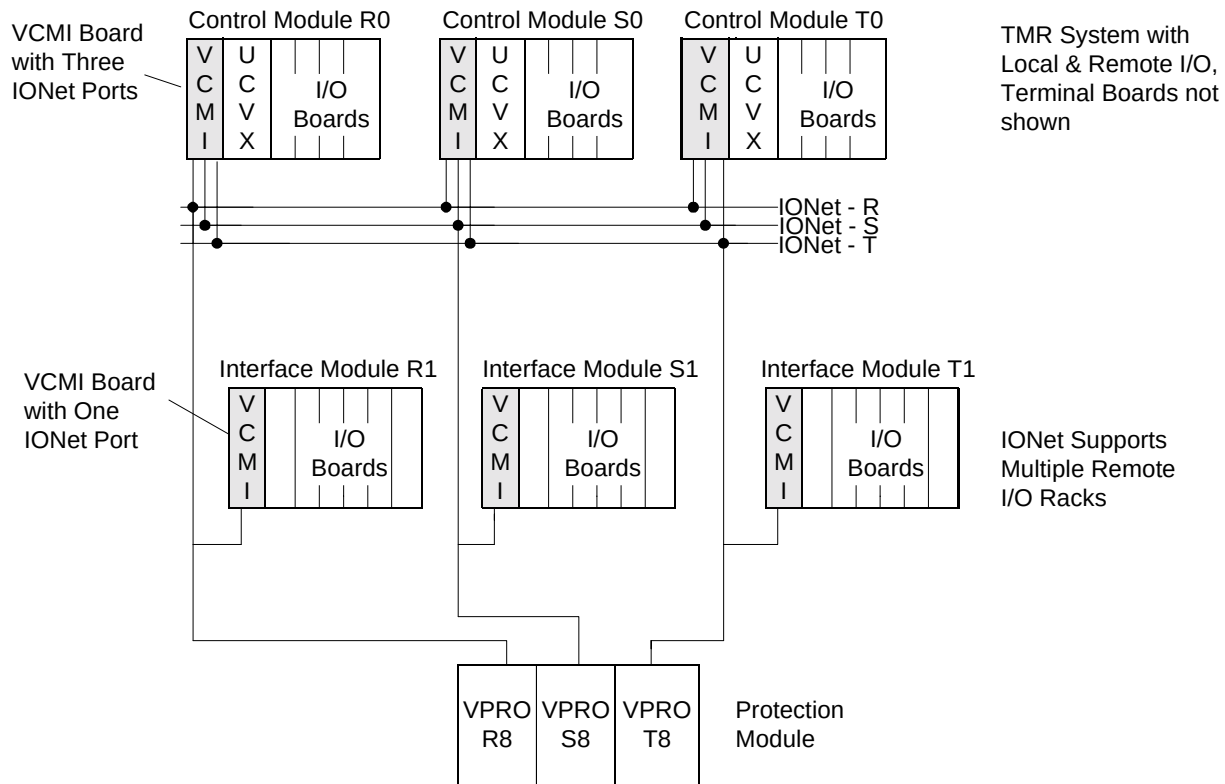
Input signal voting is performed by software using an approach known as Software Implemented Fault Tolerance (SIFT). Output voting is performed by hardware circuits that are an integral part of the output terminal boards.

The voting of inputs and outputs provides a high degree of fault masking. When three signals are voted, the failure of any one signal is masked by the other two good signals. This is because the voting process selects the median of the three analog inputs. In the case of discrete inputs, the voting selects the two that agree. In fact, the fault masking in a TMR system hides the fault so well that special fault detection functions are included as part of the voting software. Before voting, all input values are compared to detect any large differences. This value comparison generates a system diagnostic alarm.

In addition to fault masking, there are many other features designed to prevent fault propagation or to provide fault isolation. A distributed architecture with dc isolation provides a high degree of hardware isolation. Restrictions on memory access using dual-port memories prevent accidental data destruction by adjacent processors. Isolated power sources prevent a domino effect if a faulty module overloads its power supply.

TMR Architecture

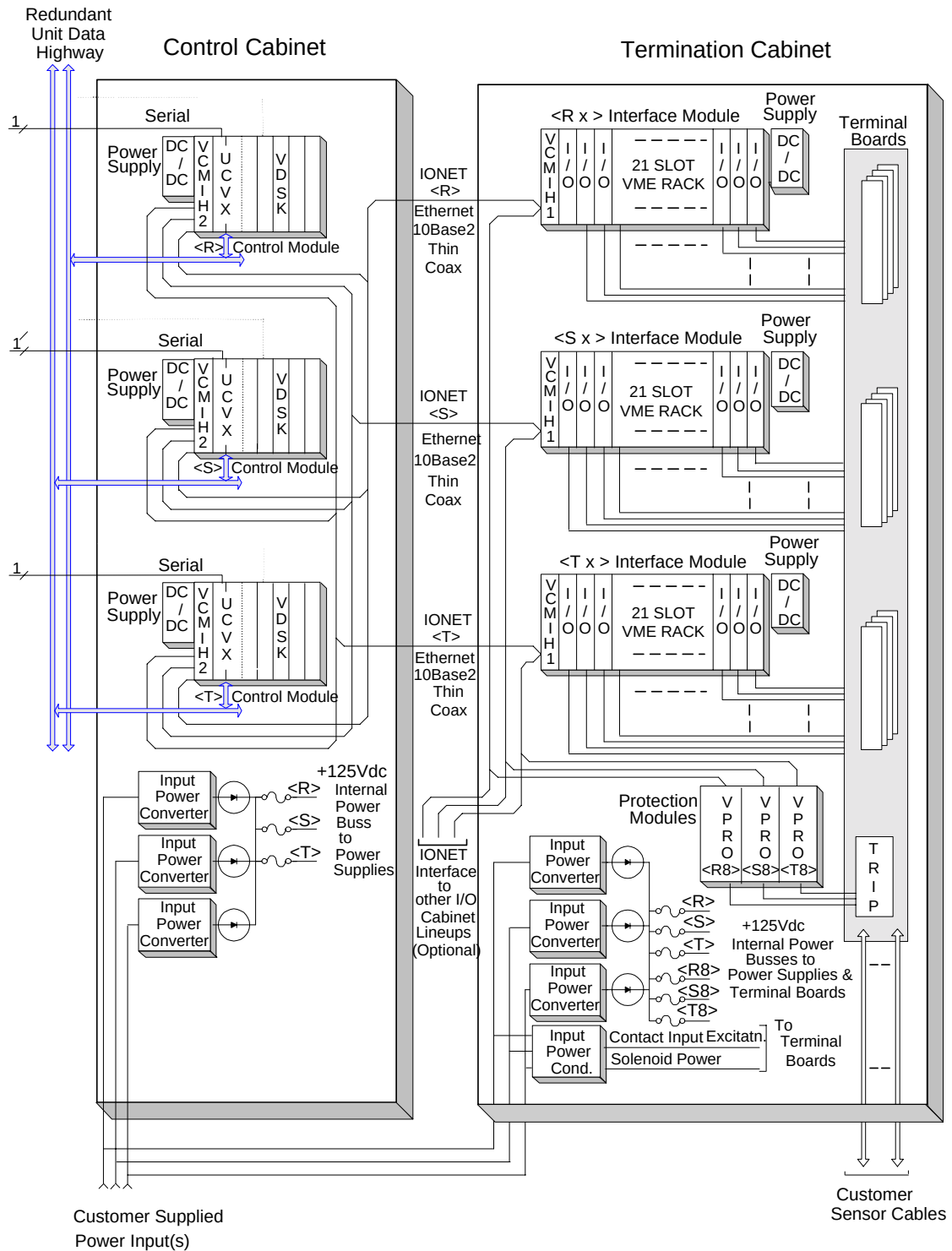
The TMR control architecture has three duplicate hardware controller modules labeled R, S, and T. A high-speed network connects each control module with its associated set of I/O modules, resulting in three independent I/O networks. Each network is also extended to connect to separate ports on each of the other controllers. Each of the three controllers has a VCM I communication board with three independent I/O communication ports to allow each controller to receive data from all of the I/O modules on all three I/O networks. The three protection modules are also on the I/O networks.



TMR Architecture with Local & Remote I/O, and Protection Module

Each of the three controllers is loaded with the same software image, so that there are three copies of the control program running in parallel. External computers, such as the HMI operator stations, acquire data from only the designated controller. The designated controller is determined by a simple algorithm.

A separate protection module provides for very reliable trip operation. The VPRO is an independent TMR subsystem complete with its own controllers and integral power supplies. Separate independent sensor inputs and voted trip relay outputs are used



Typical Cabinet Layout of Mark VI TMR System

TMR Operation

Voting systems require that the input data be voted, and the voted result be available for use on the next calculation pass. The sequential operations for each pass are input, vote, calculate, and output. The time interval that is allotted to these operations is referred to as the *frame*. The frame is set to a fixed value for a given application so that the control program operates at a uniform rate.

For SIFT systems, a significant portion of the fault tolerance is implemented in software. The advantage to this approach is software does not degrade over time. The SIFT design requires little more than three identical controllers with some provision of transferring data between them. All of the data exchange, voting, and output selection may be performed by software. The exception to the *all software* approach is the modification to the hardware output circuitry for hardware voting.

With each controller using the same software, the mode control software in each controller is synchronizing with, and responding to, an identical copy of itself that is operating in each of the other controllers. The three programs acting together are referred to as the *distributed executive* and coordinate all operations of the controllers including the sequential operations mentioned above.

There are several different synchronization requirements. Frame synchronization enables all controllers and associated I/O modules to process the data at the same time for a given frame. The frame synchronization error is determined at the start of frame (SOF) and the controllers are required to adjust their internal timing so that all three controllers reach SOF of the same frame at the same time.

The acceptable error in time of SOF is typically several microseconds in the 10 to 25 Hz control systems that are encountered. Large errors in SOF timing will affect overall response time of the control since the voter will cause a delay until at least two controllers have computed the new values. The constraining requirement for synchronization comes from the need to measure contact SOE times with an accuracy of 1 ms.

Designated Controller

Although three controllers R, S, and T contain identical hardware and software, some of the functions performed are individually unique. A single designated controller is automatically chosen to perform the following functions:

- Supply initialization data to the other two controllers at boot-up
- Keep the Master time clock
- Calculate the control state data for the cabinet if one of the other controllers fails.

The VCMIs determine the designated controller through a process of nomination and voting based upon local visibility of the IONet and whether a designated controller currently exists. If all controllers are equal, a priority scheme is used favoring first R, then S, and then T. If a controller, which was designated, is powered down and repowered, the designated controller will move and not come back if all controllers are equal. This ensures that a toggling designated controller is not automatically reselected.

UDH Communicator

Controller communications takes place across the Unit Data Highway (UDH). A UDH communicator is a controller selected to provide the cabinet data to that network. This data includes both control signals (EGD) and alarms. Each controller has an independent, physical connection to the UDH. In the event that the UDH fractures and a controller becomes isolated from its companion controllers, it assumes the role of UDH communicator for that network fragment. While for one cabinet there can be only one designated controller, there may be multiple UDH communicators. The designated controller is always a UDH communicator.

Fault Tolerant EGD

When a controller does not receive expected external EGD data from its UDH connection, (for example, due to a severed network) it will request that the data be forwarded across the IONet from another UDH communicator. One or more communicators may supply the data and the requesting controller uses the last data set received. Only the EGD data used in sequencing by the controllers is forwarded in this manner.

Output Processing

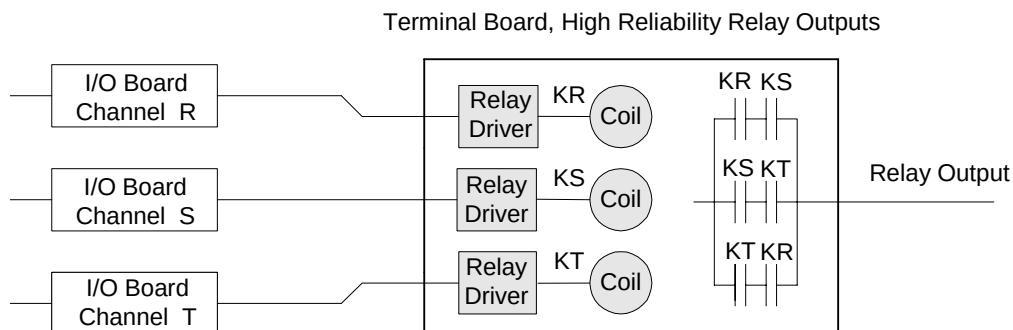
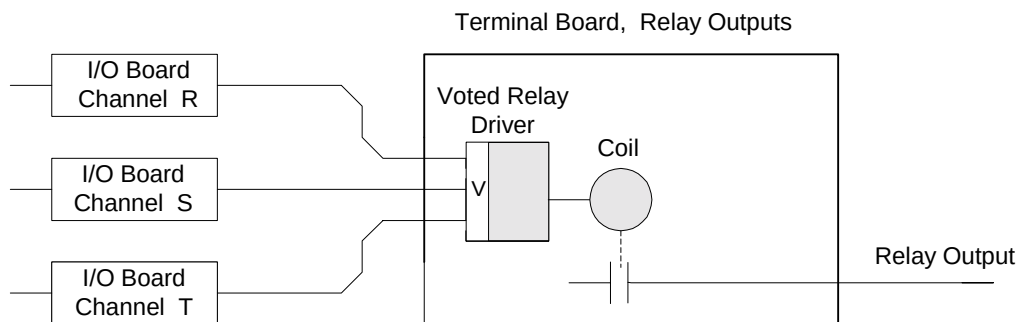
The system outputs are the portions of the calculated data that have to be transferred to the external hardware interfaces and then to the various actuators controlling the process. Most of the outputs from the TMR system are voted in the output hardware, but the system can also output individual signals in a simplex manner. Output voting is performed as close to the final control element as possible.

Normally, outputs from the TMR system are calculated independently by the three voting controllers and each controller sends the output to its associated I/O hardware (for example, R controller sends to R I/O). The three independent outputs are then combined into a single output by a voting mechanism. Different signal types require different methods of establishing the voted value.

The signal outputs from the three controllers fall into three groups:

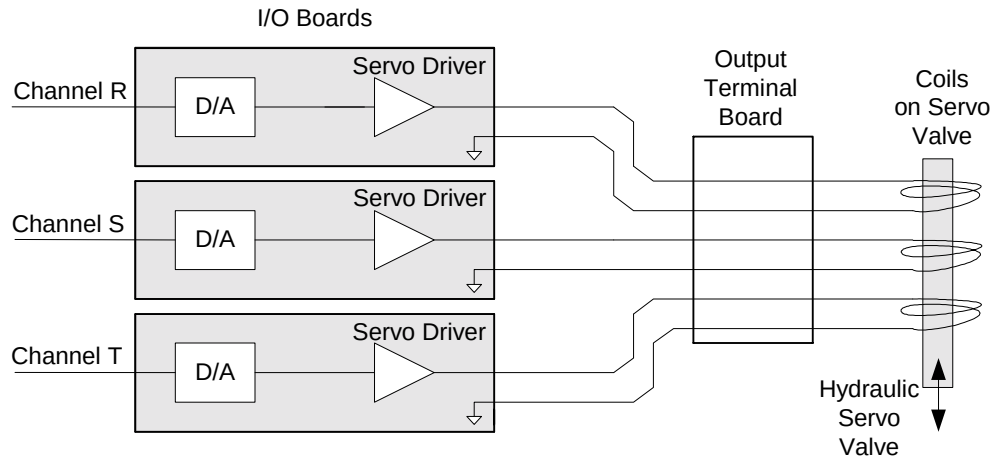
- Signals exist in only one I/O channel and are driven as single ended non-redundant outputs
- Signals exist in all three controllers and are sent as output separately to an external voting mechanism
- Signals exist in all three controllers but are merged into a signal by the output hardware

For normal relay outputs, the three signals feed a voting relay driver, which operates a single relay per signal. For more critical protective signals, the three signals drive three independent relays with the relay contacts connected in the typical six-contact voting configuration. The following figure shows two types of output boards.



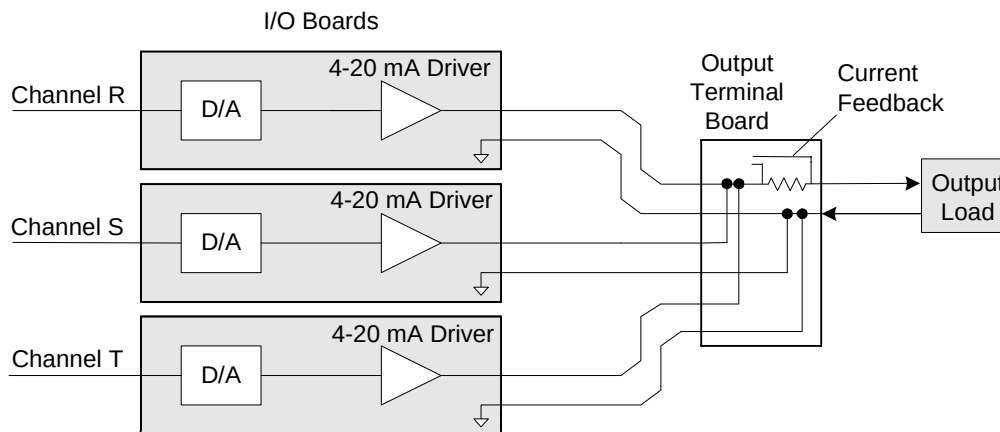
Relay Output Circuits for Protection

For servo outputs as shown in the following figure, the three independent current signals drive a three-coil servo actuator, which adds them by magnetic flux summation. Failure of a servo driver is sensed and a deactivating relay contact is opened.



TMR Circuit to Combine Three Analog Currents into a Single Output

The following figure shows 4-20 mA signals combined through a 2/3 current sharing circuit that allows the three signals to be voted to one. This unique circuit ensures that the total output current is the voted value of the three currents. Failure of a 4-20 mA output is sensed and a deactivating relay contact is opened.

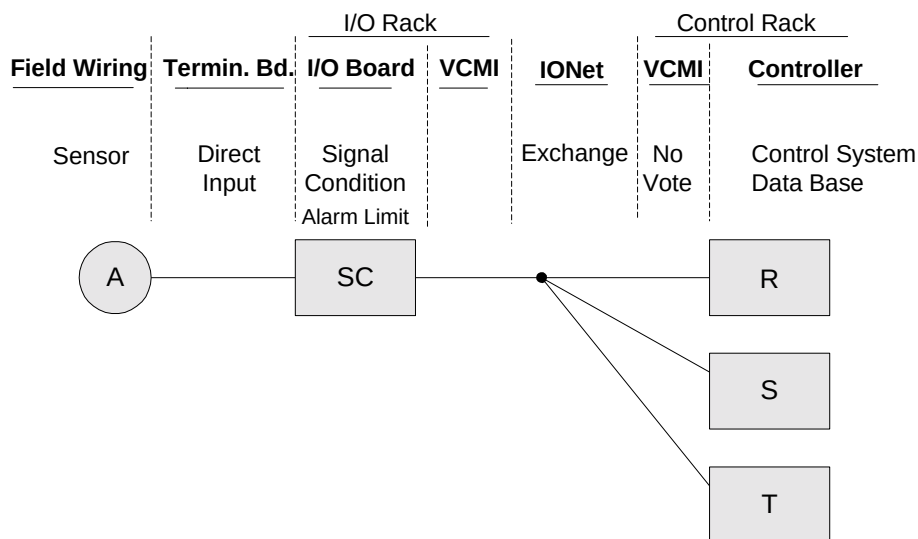


TMR Circuits for Voted 4-20 mA Outputs

Input Processing

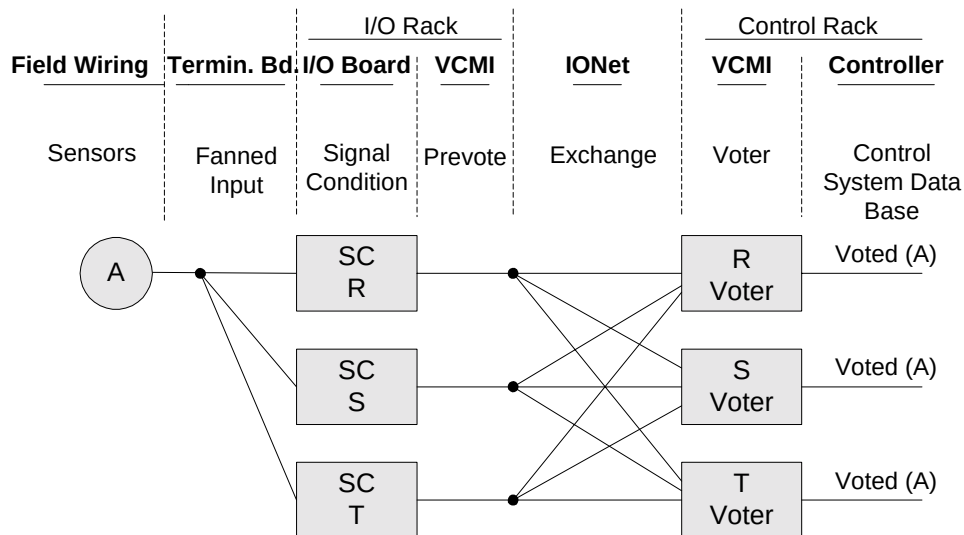
All inputs are available to all three controllers but there are several ways that the input data is handled. For those input signals that exist in only one I/O module, the value is used by all three controllers as common input without SIFT-voting as shown in the following figure. Signals that appear in all three I/O channels may be application-voted to create a single input value. The triple inputs either may come from three independent sensors or may be created from a single sensor by hardware fanning at the terminal board.

A single input can be brought to the three controllers without any voting as shown in the following figure. This arrangement is used for non-critical, generic I/O, such as monitoring 4-20 mA inputs, contacts, thermocouples, and RTDs.



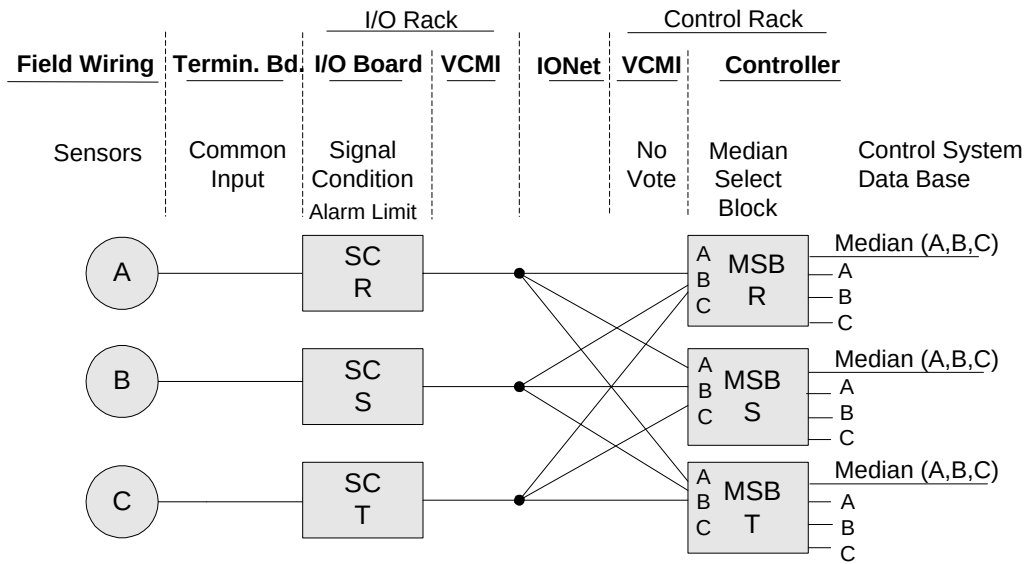
Single Input to Three Controllers, Not Voted

One sensor can be fanned to three I/O boards for medium-integrity applications as shown in the following figure. This configuration is used for sensors with medium-to-high reliability. Three such circuits are needed for three sensors. Typical inputs are 4-20 mA inputs, contacts, thermocouples, and RTDs.



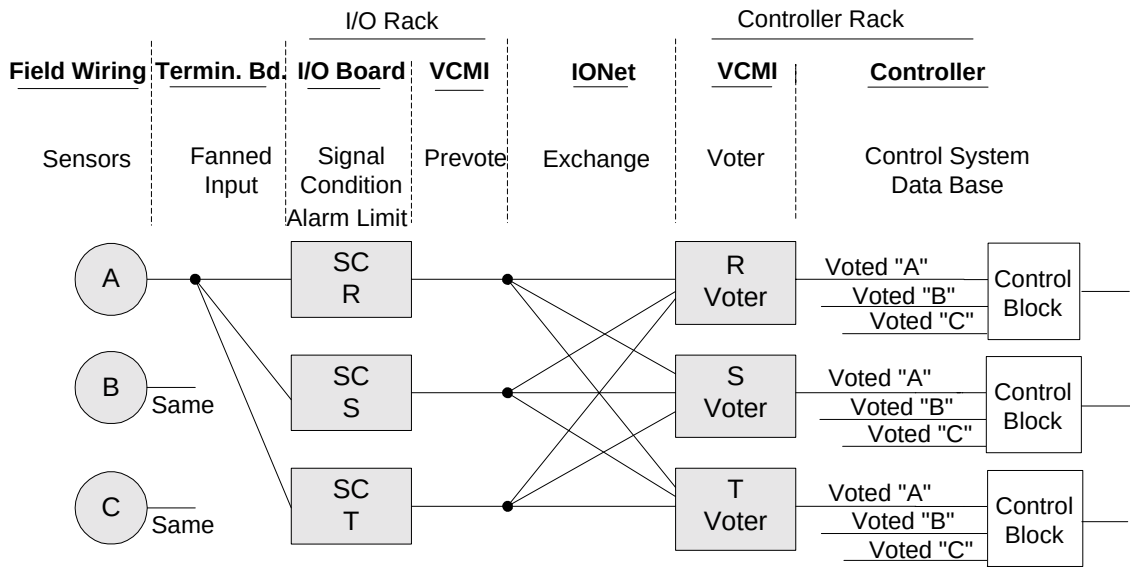
One Sensor with Fanned Input & Software Voting

Three independent sensors can be brought into the controllers without voting to provide the individual sensor values to the application. Median values can be selected in the controller if required. This configuration, shown in the following figure, is used for special applications only.



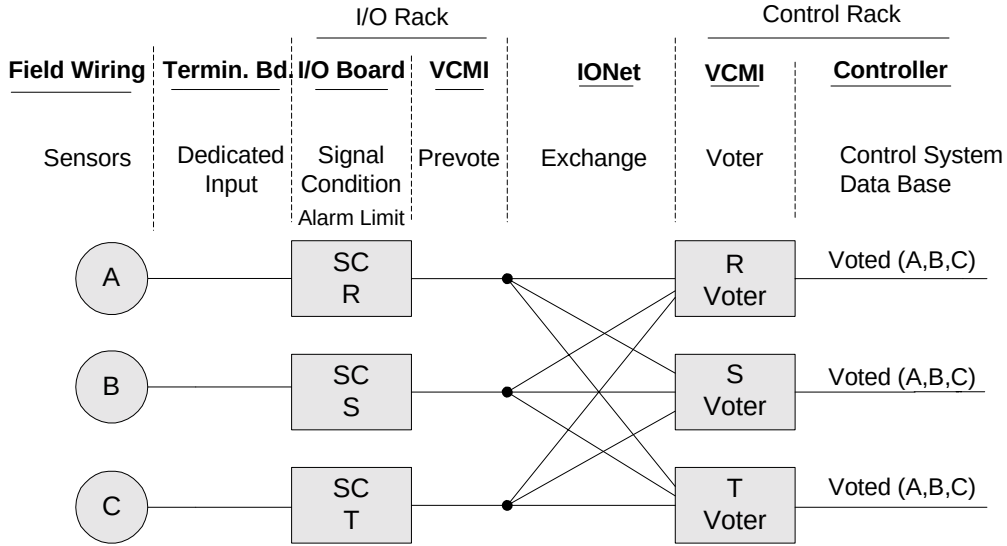
Three Independent Sensors with Common Input, Not Voted

The following figure shows three sensors, each one fanned and then SIFT-voted. This arrangement provides a high reliability system for current and contact inputs, and temperature sensors.



Three Sensors, Each One Fanned and Voted, for Medium to High Reliability Applications

Speed inputs to high reliability applications are brought in as dedicated inputs and then SIFT-voted. The following figure shows the configuration. Inputs such as speed control and overspeed are not fanned so there is a complete separation of inputs with no hardware cross-coupling which could propagate a failure. RTDs, thermocouples, contact inputs, and 4-20 mA signals can also be configured this way.



Three Sensors with Dedicated Inputs, Software Voted for High Reliability Applications

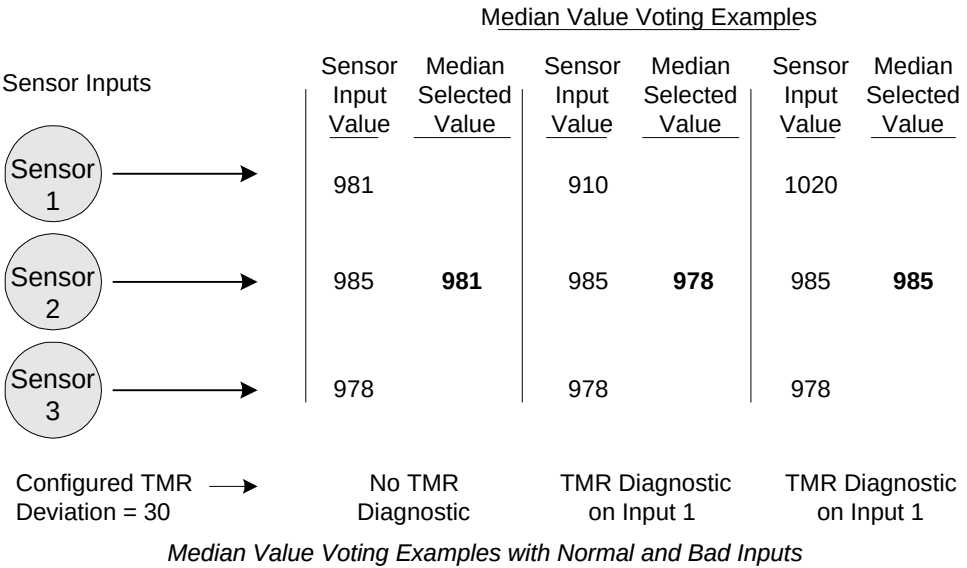
State Exchange

Voting all of the calculated values in the TMR system is unnecessary and not practical. The actual requirement is to vote the state of the controller database between calculation frames. Calculated values such as timers, counters, and integrators are dependent on the value from the previous calculation frame. Logic signals such as bistable relays, momentary logic with seal-in, cross-linked relay circuits, and feedbacks have a memory retention characteristic. A small section of the database values is voted each frame.

Median Value Analog Voting

The analog signals are converted to floating point format by the I/O interface boards. The voting operation occurs in each of the three controller modules (R, S, and T). Each module receives a copy of the data from the other two channels. For each voted data point, the module has three values including its own. The median value voter selects the *middle* value of the three as the voter output. This is the most likely of the three values to be closest to the true value. In the following figure shows some examples.

The disagreement detector (see the section, *Disagreement Detector*) checks the signal deviations and sets a diagnostic if they exceed a preconfigured limit, thereby identifying failed input sensors or channels.



Two Out of Three Logic Voter

Each of the controllers has three copies of the data as described above for the analog voter. The logical values are stored in the controller database in a format that requires a byte per logical value. Voting is a simple logic process, which inputs the three values and finds the two values that agree.

The logical data has an auxiliary function called forcing which allows the operator to force the logical state to be either true or false and have it remain in that state until unforced. The logical data is packed in the input tables and the state exchange tables to reduce the bandwidth requirements. The input cycle involves receive, vote, unpack, and transfer to the controller database. The transfer to the database must leave the forced values as they are.

Disagreement Detector

A disagreement detector is provided to continuously scan the prevote input data sets and produce an alarm bit if a disagreement is detected between the three values in a voted data set. The comparisons are made between the voted value and each of the three prevote values. The delta for each value is compared with a user programmable limit value. The limit can be set as required to avoid nuisance alarms but give indication that one of the prevote values has moved out of normal range. Each controller is required to compare only its prevote value with the voted value, for example, R compares only the R prevote value with the voted value.

Failure of one of the three voted input circuits has no effect on the controlled process since the fault is masked by SIFT. Without a disagreement detector, a failure could go unnoticed until occurrence of a second failure.

Peer I/O

In addition to the data from the I/O modules, there is a class of data that comes from other controllers in other cabinets that are connected through a common data network. For the Mark VI controller the common network is the UDH. For integrated systems, this common network provides a data path between multiple turbine controllers and possibly the controls for the generator, the exciter, or the HRSG/boiler.

Selected signals from the controller database may be mapped into a page of peer outputs that are broadcast periodically on the UDH to provide external panels a status update. For the TMR system this action is performed by the UDH communicator using the data from its internal voted database.

Reception of peer data is handled independently by each controller.

Command Action

Commands sent to the TMR control require special processing to ensure that the three voting controllers perform the requested action at the same time. Typically, the commanding device is a PC connected to the UDH and sending messages over a single network so there is no opportunity to vote the commands in each controller. Moreover, commands may be sent from one of several redundant computers at the operator position(s).

When any TMR controller receives a command message, it synchronizes the corresponding response of all three controllers by retransmitting the command to its companions across the IONet and queuing it for action at the start of the next frame.

By default the HMIs are predisposed to send all commands to the UDH communicator.

Rate of Response

The control system can run selected control programs at the rate of 100 times per second, (10 ms frame rate) for simplex systems and 50 times per second (20 ms frame rate) for TMR systems.

Failure Handling

The general operating principle on failures is that corrective or default action takes place in both directions away from the fault. This means that, in the control hierarchy extending from the terminal mounts through I/O boards, backplanes, networks and main CPUs, when a fault occurs, there is a reaction at the I/O processor and also at the main controller if still operating. When faults are detected, health bits are reset in a hierarchical fashion. If a signal goes bad, the health bit is set false at the control module level. If a board goes bad, all signals associated with that board, whether input or output, have the health bits set false. A similar situation exists for the I/O rack. In addition, there are preconfigured default failure values defined for all input and output signals so that normal application code may cope with failures without excessive healthy bit referencing. Healthy bits in TMR systems are voted if the corresponding signal is TMR.

Loss of Control Module in Simplex System - If a control module fails in a simplex system, the output boards go to the configured default output state after a timeout. The loss of the controller board propagates down through the IONet so that the output board knows what to do. This is accomplished by shutting down the IONet.

Loss of Control Module in TMR System - If a control module fails in a TMR system, the TMR outputs and simplex outputs on that channel timeout to the configured default output state. TMR control continues using the other two control modules.

Loss of I/O VCMi in TMR System - If the VCMi in an interface module in a TMR system fails, the outputs timeout to the configured default output state. The inputs are set to the configured default state so that resultant outputs, such as UDH, may be set correctly. Inputs and output healthy bits are reset. A failure of the VCMi in Rack 0 is viewed as equivalent to a failure of the control module itself.

Loss of I/O VCMi in Simplex System - If the VCMi in an interface module in a simplex system fails, the outputs and inputs are handled the same as a TMR system.

Loss of I/O Board in Simplex System - If an I/O board in a simplex system fails, hardware on the outputs from the I/O boards set the outputs to a low power default value given typical applications. Input boards have the input values set to the preconfigured default value in the Master VCMi board.

Loss of Simplex I/O Board in TMR System - If the failed simplex I/O board is in a TMR system, the inputs and outputs are handled as described herein if they were in a simplex system.

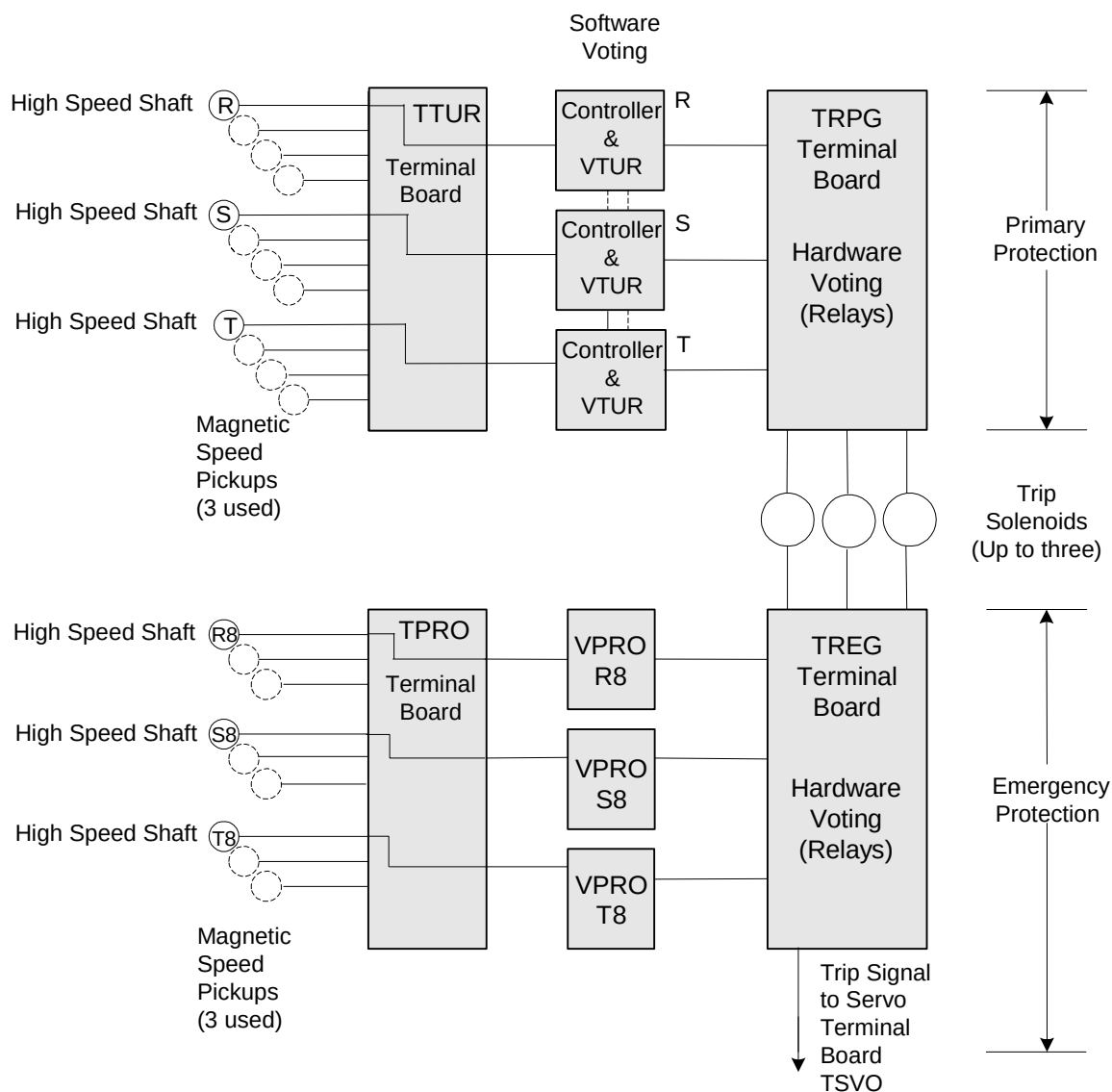
Loss of TMR I/O Board in TMR System - If a TMR I/O board fails in a TMR system, inputs and outputs are handled. TMR SIFT and hardware output voting keep the process running.

Loss of IONet in Simplex System - If the IONet fails in a simplex system, the output boards in the I/O racks timeout and set the preconfigured default output values. The Master VCMi board defaults the inputs so that UDH outputs can be correctly set.

Loss of IONet in TMR System - If the IONet fails in a simplex system, outputs follow the same sequence as for a Loss of Control Module in simplex. Inputs follow the same sequence as for Loss of I/O VCMi in TMR.

Turbine Protection

Turbine overspeed protection is available in three levels, control, primary, and emergency. Control protection comes through closed loop speed control using the fuel/steam valves. Primary overspeed protection is provided by the controller. The TTUR terminal board and VTUR I/O board bring in a shaft speed signal to each controller where they are median selected. If the controller determines a trip condition, the controller sends the trip signal to the TRPG terminal board through the VTUR I/O board. The three VTUR outputs are 2/3 voted in three-relay voting circuits (one for each trip solenoid) and power is removed from the solenoids. The following figure shows the primary and emergency levels of protection.



Primary and Emergency Overspeed Protection

Emergency overspeed protection is provided by the independent triple redundant VPRO protection system. This uses three shaft speed signals from magnetic pickups, one for each protection module. These are brought into TPRO, a terminal board dedicated to the protection system. Either the controllers or the protection system can independently trip the turbine. Each VPRO independently determines when to trip, and the signals are passed to the TREG terminal board. TREG operates in a similar way to TRPG, voting the three trip signals in relay circuits and removing power from the trip solenoids. This system contains no software voting, making the three VPRO modules completely independent. The only link between VPRO and the other parts of the control system is the IONet cable, which transmits status information.

Additional protection for simplex systems is provided by the protection module through the Servo Terminal Board, TSVO. Plug J1 on TREG is wired to plug JD1 on TSVO, and if this is energized, relay K1 disconnects the servo output current and applies a bias to force the control valve closed.

Reliability and Availability

System reliability and availability can be calculated using the component failure rates. These numbers are important for deciding when to use simplex circuits versus TMR circuits. TMR systems have the advantage of online repair discussed in the section, *Online Repair for TMR Systems*.

Online Repair for TMR Systems

The high availability of the TMR system is a result of being able to do repair online. It is possible to shut down single modules for repair and leave the voting trio in full voting mode operation, which effectively masks the absence of the signals from the powered down module. However, there are some restrictions and special cases that require extra attention.

Many signals are reduced to a single customer wire at the terminal boards so removal of the terminal board requires that the wires be disconnected momentarily. Each type of terminal board must be evaluated for the application and the signal type involved. Voltages in excess of 50 V are present in some customer wiring. Terminal boards that have only signals from one controller channel may be replaced at any time if the faulty signals are being masked by the voter. For other terminal boards such as the relay outputs, the individual relays may be replaced without disconnecting the terminal board.

For those singular signals that are driven from only one I/O board, there is no redundancy or masking. These are typically used for non-critical functions such as pump drives, where loss of the control output simply causes the pump to run continuously. Application designers must avoid using such singular signals in critical circuits. The TMR system is designed such that any of the three controllers may send outputs to the singular signals, keeping the function operational even if the normal sending controller fails.

Note Before performing an online repair, power down only the module (rack) that has the fault. Failure to observe this rule may cause an unexpected shutdown of the process (each module has its own power disconnect or switch). The modules are labeled such that the diagnostic messages identify the faulty module.

Repair the faulty modules as soon as possible. Although the TMR system will survive certain multiple faults without a forced outage, a lurking fault problem may exist after the first unrepaired failure occurs. Multiple faults within the same module cause no concern for online repair since all faults will be masked by the other voters. However, once a second unrelated fault occurs in the same module set, then either of the faulty modules of the set that is powered down will introduce a dual fault in the same three signal set which may cause a process shutdown.

Reliability

Reliability is represented by the Mean Time Between Forced Outage (MTBFO) of the control system. The MTBFO is a function of which boards are being used to control and protect the turbine. The complete system MTBFO depends on the size of the system, number of simplex boards, and the amount of sensor triplication.

In a simplex system, failure of the controller or I/O communication may cause a forced outage. Failure of a critical I/O module will cause a forced outage, but there are non-critical I/O modules, which can fail and be changed out without a shutdown. The MTBFO is calculated using published failure rates for components.

Availability is the percentage of time the system is operating, taking into account the time to repair a failure. Availability is calculated as follows:

$$\frac{\text{MTBFO} \times 100\%}{\text{MTBFO} + \text{MTTR}}$$

where:

MTTR is the Mean Time To Repair the system failure causing the forced outage.

With a TMR system there can be failures without a forced outage because the system can be repaired while it continues to run. The MTBFO calculation is complex since essentially it is calculating the probability of a second (critical) failure in another channel during the time the first failure is being repaired. The time to repair is an important input to the calculation.

The availability of a well-designed TMR system with timely online repair is effectively 100%. Possible forced outages may still occur if a second failure of a critical circuit comes before the repair can be completed. Other possible forced outages may occur if the repairman erroneously powers down the wrong module.

Note To avoid possible forced outages from powering down the wrong module, check the diagnostics for identification of the modules which contain the failure.

System reliability has been determined by calculating the Failures In Time (FIT) (failures per 10⁹ hours) based on the Bellcore TR-332 Reliability Prediction Procedure for Electronic Equipment. The Mean Time Between Failures (MTBF) can be calculated from the FIT.

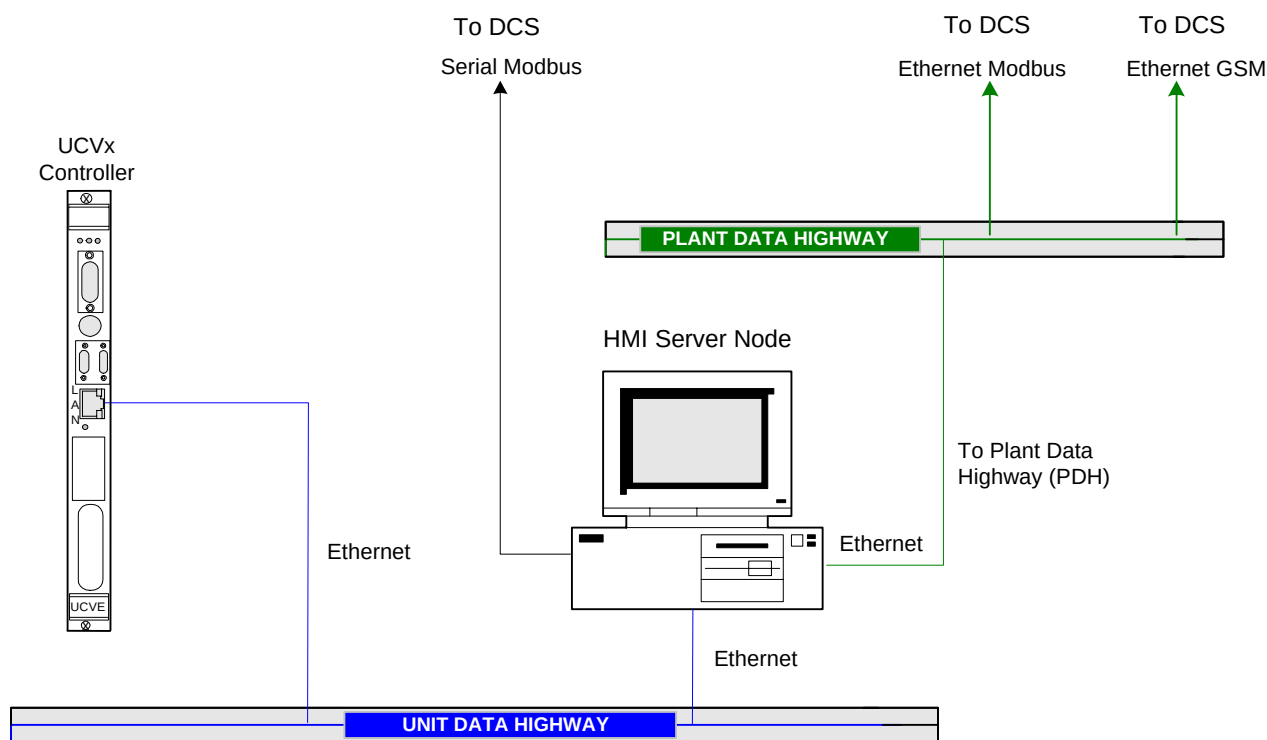
Third Party Connectivity

The Mark VI can be linked to the plant Distributed Control System (DCS) in three different ways as follows.

- Modbus link from the HMI Server RS-232C port to the DCS
- A high speed 10 Mbaud Ethernet link using the Modbus over TCP/IP protocol
- A high speed 10 Mbaud Ethernet link using the TCP/IP protocol with an application layer called GEDS Standard Messages (GSM)

The Mark VI can be operated from the plant control room.

GSM supports turbine control commands, Mark VI data and alarms, the alarm silence function, logical events, and contact input sequence of events records with 1 ms resolution. The following figure shows the three options. Modbus is widely used to link to DCSs, but Ethernet GSM has the advantage of speed, distance, and functionality.



Optional Communication Links to Third-Party Distributed Control System

Chapter 3 Networks

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Introduction

This chapter defines the various communication networks in the control system. These networks provide communication with the operator interfaces, servers, controllers, and I/O. It also provides information on fiber-optic cables, including components and guidelines.

Network Overview

The Mark VI system is based on a hierarchy of networks used to interconnect the individual nodes. These networks separate the different communication traffic into layers according to their individual functions. This hierarchy extends from the I/O and controllers, which provide real-time control of the turbine and its associated equipment, through the operator interface systems, and up to facility wide monitoring or distributed control systems (DCS). Each layer uses standard components and protocols to simplify integration between different platforms and improve overall reliability and maintenance. The layers are designated as the Enterprise, Supervisory, Control, and I/O.

Note Ethernet is used for all Mark VI data highways and the I/O network.

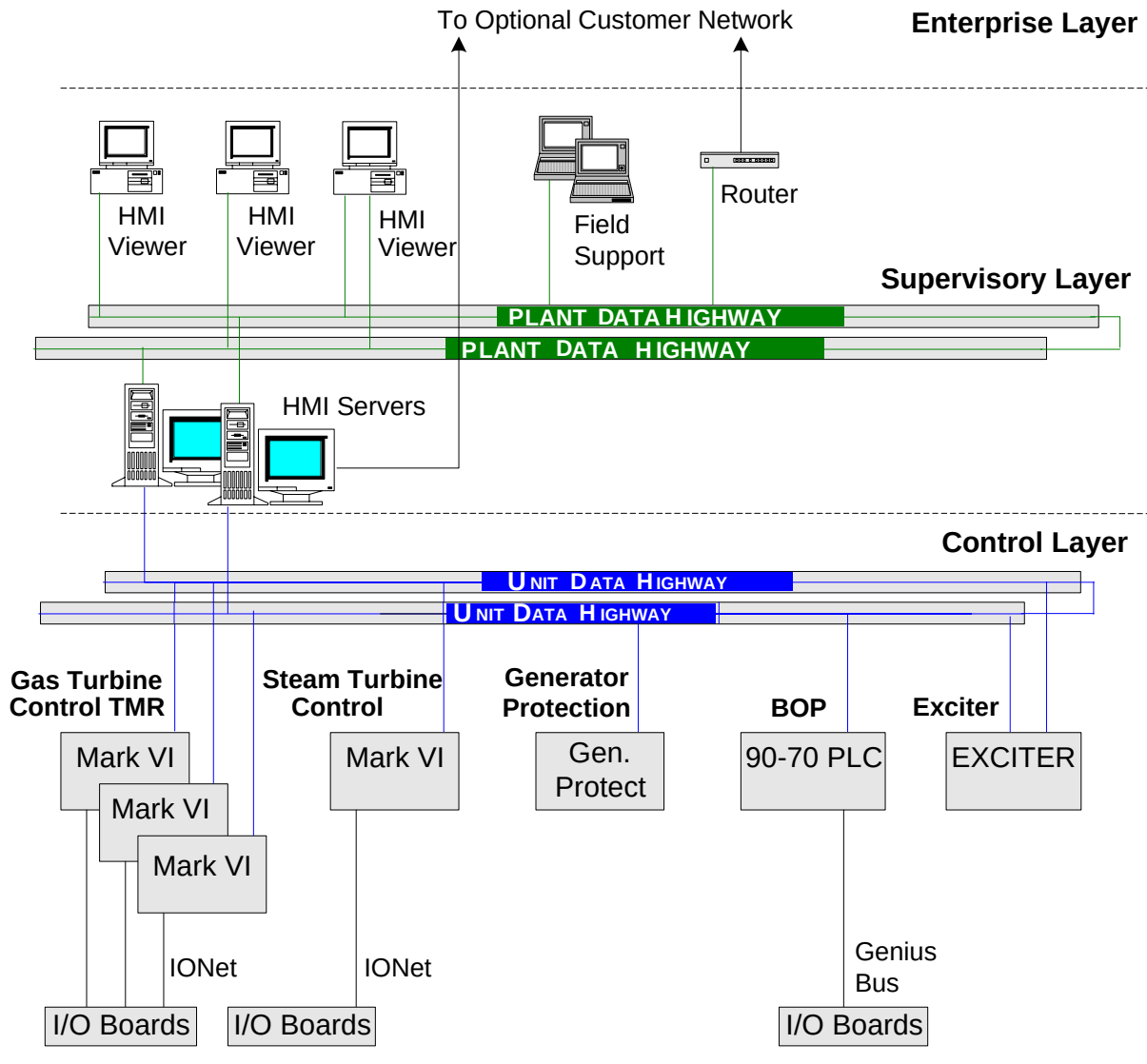
Enterprise Layer

The Enterprise layer serves as an interface from specific process control into a facility wide or group control layer. These higher layers are provided by the customer. The network technology used in this layer is generally determined by the customer and may include either Local Area Network (LAN) or Wide Area Network (WAN) technologies, depending on the size of the facility. The Enterprise layer is generally separated from other control layers through a router, which isolates the traffic on both sides of the interface. Where unit control equipment is required to communicate with a facility wide or DCS system, GE uses either a Modbus interface or a TCP/IP protocol known as GE Standard Messaging (GSM).

Supervisory Layer

The Supervisory layer provides operator interface capabilities such as to coordinate HMI viewer and server nodes, and other functions like data collection (Historian), remote monitoring, and vibration analysis.

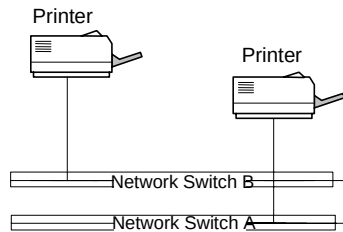
This layer may be used as a single or dual network configuration. A dual network provides redundant Ethernet switches and cables to prevent complete network failure if a single component fails. The network is known as the Plant Data Highway (PDH).



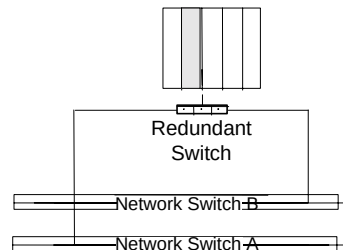
Mark VI Control as Part of Integrated Control System

Control Layer

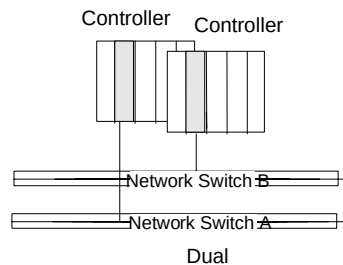
The control layer provides continuous operation of the process equipment. The controllers on this layer are highly coordinated to support continuous operation without interruption. The controllers operate at a fundamental rate called the frame rate, which can be between 6-100 Hz. These controllers use Ethernet Global Data (EGD) to exchange data between nodes. Various levels of redundancy for the connected equipment are supported by the supervisory and control layers.



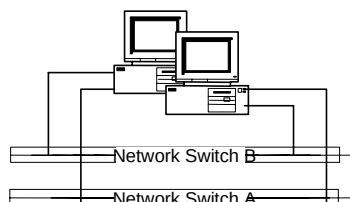
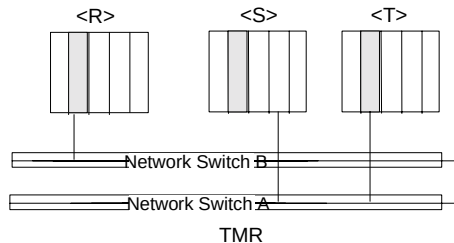
Type 1 Redundancy Non-critical nodes such as printers can be connected without using additional communication devices.



Type 2 Redundancy Nodes that are only available in Simplex configuration can be connected with a redundant switch. The switch automatically senses a failed network component and fails-over to a secondary link.



Type 3 Redundancy Nodes such as dual or TMR controllers are tightly coupled so that each node can send the same information. By connecting each controller to alternate networks, data is still available if a controller or network fails.



Type 4 Redundancy This type provides redundant controllers and redundant network links for reliability. This is useful if the active controller network interface cannot sense a failed network condition.

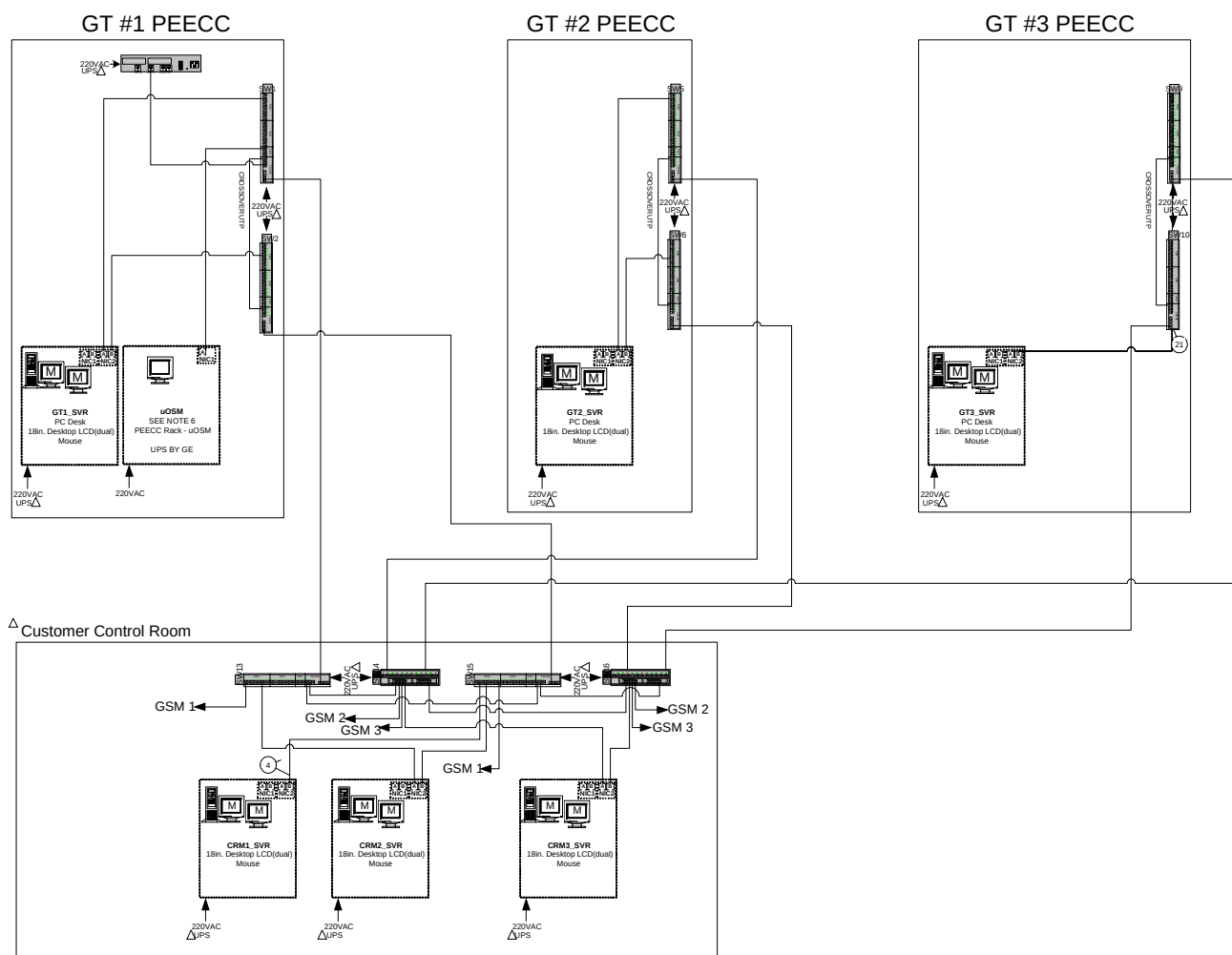
Redundant Networks for Different Applications

Data Highways

Plant Data Highway (PDH)

The PDH is the plant level supervisory network. The PDH connects the HMI Server with remote viewers, printers, historians, and external interfaces. There is no direct connection to the Mark VI controllers, which communicate over the UDH. Use of Ethernet with the TCP/IP protocol over the PDH provides an open system for third-party interfaces. The following figure shows the equipment connections to the PDH.

Fiber-optic cable provides the best signal quality, completely free of electromagnetic interference (EMI) and radio frequency interference (RFI). Large point-to-point distances are possible, and since the cable does not carry electrical charges, ground potential problems are eliminated.

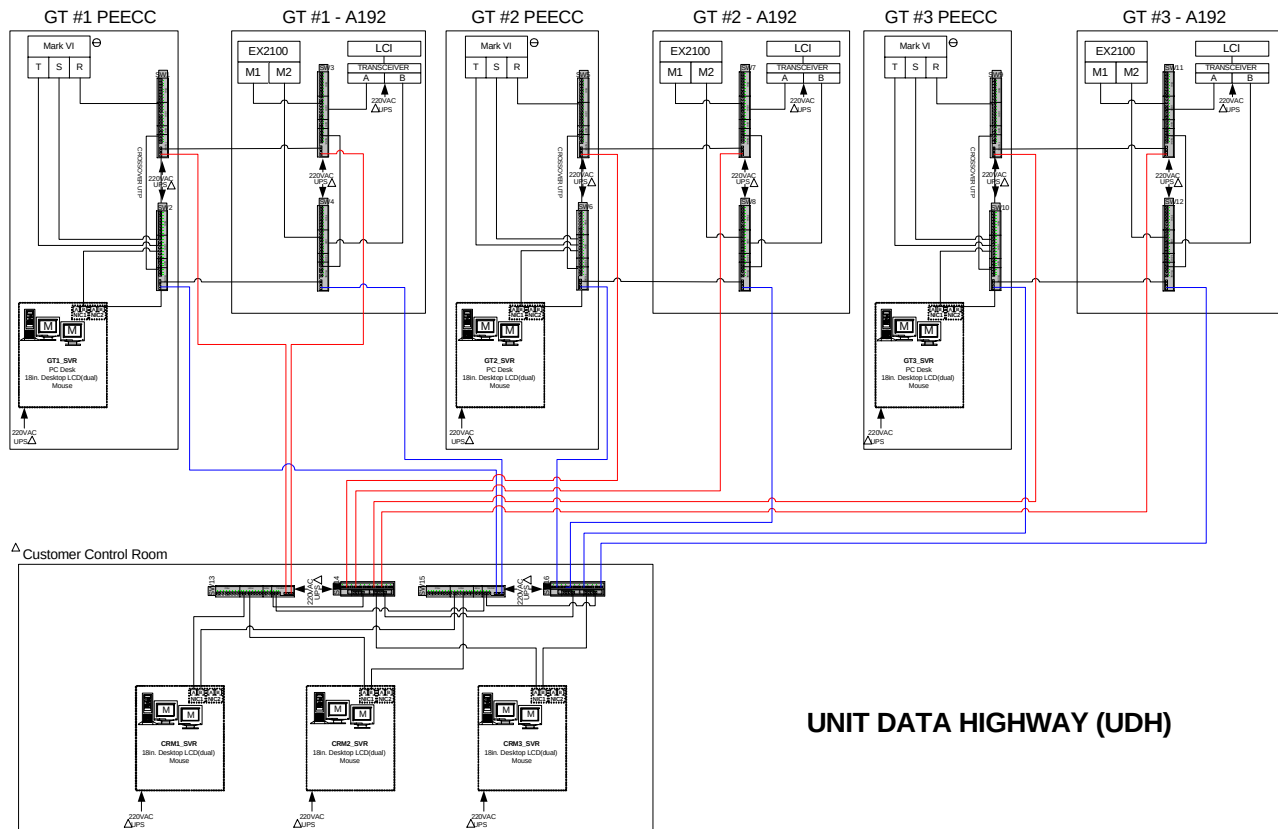


Typical Plant Data Highway Layout Drawing

Feature	Description
Type of Network	Ethernet CSMA/CD in a single or redundant star configuration
Speed	100 Mb/s, Full Duplex
Media and Distance	Ethernet 100BaseTX for switch to controller/device connections. The cable is 22 to 26 AWG with unshielded twisted-pair, category 5e EIA/TIA 568 A/B. Distance is up to 100 meters. Ethernet 100BaseFX with fiber-optic cable for distances up to 2 km (1.24 miles).
Number of Nodes	Up to 1024 nodes supported
Protocols	Ethernet compatible protocol, typically TCP/IP based. Use GE Standard Messaging (GSM) or Modbus over Ethernet for external communications.
Message Integrity	32-bit Cyclic Redundancy Code (CRC) appended to each Ethernet packet plus additional checks in protocol used.
External Interfaces	Various third-party interfaces are available, GSM and Modbus are the most common.

Unit Data Highway (UDH)

The UDH is an Ethernet-based network that provides direct or broadcast peer-to-peer communications between controllers and an operator/maintenance interface. It uses Ethernet Global Data (EGD) which is a message-based protocol for sharing information with multiple nodes based on UDP/IP. UDH network hardware is similar to the PDH hardware. The following figure shows redundant UDH networks with connections to the controllers and HMI servers.



Typical Unit Data Highway Layout Drawing

UDH Network Features

Feature	Description
Type of Network	Ethernet , full duplex, in a single or redundant star configuration
Media and Distance	Ethernet 100BaseTX for switch to controller/device connections. The cable is 22 to 26 AWG unshielded twisted pair; category 5e EIA/TIA 568 A/B. Distance is up to 100 meters. Ethernet 100BaseFX with fiber-optic cable optional for distances up to 2 km (1.24 miles).
Number of Nodes	At least 25 nodes, given a 25 Hz data rate. For other configurations contact the factory.
Type of Nodes Supported	Controllers, PLCs, operator interfaces, and engineering workstations
Protocol	EGD protocol based on the UDP/IP
Message Integrity	32-bit CRC appended to each Ethernet packet plus integrity checks built into UDP and EGD
Time Sync. Methods	Network Time Protocol (NTP), accuracy ± 1 ms.

Data Highway Ethernet Switches

The UDH and PDH networks use Fast Ethernet switches. The system modules are cabled into the switches to create a star type network architecture. Redundancy is obtained by using two switches with an interconnecting cable.

Redundant switches provide redundant, duplex communication links to controllers and HMIs. Primary and secondary designate the two redundant Ethernet links. If the primary link fails, the converter automatically switches the traffic on main over to the secondary link without interruption to network operation. At 10 Mb/s, using the minimum data packet size, the maximum data loss during fail-over transition is 2-3 packets.

Note Switches are configured by GE for the control system, pre configured switches should be purchased from GE. Each switch is configured to accept UDH and PDH.

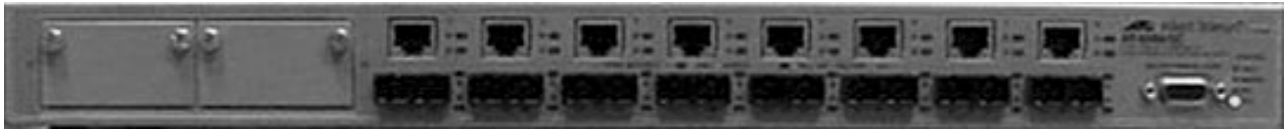
GE Part # 323A4747NZP31(A,B or C)



Configuration	A	B	C
PDH	1-8	Single VLAN May be used for UDH or PDH	1-18,23-26
UDH	9-16		None
ADH	17-19		19-21
Uplinks	20-26		22 to Router

Configuration 323A4747NZP31A is the standard configuration with 323A4747NZP31B being used for legacy systems with separate UDH and PDH networks. Part 323A4747NZP31C is obsolete and was used in special instances to provide connectivity between the PDH and the OSM system.

GE Part # 323A4747NZP37(A or B)



Configuration	A	B
PDH	1-3	Single VLAN May me used for UDH or PDH
UDH	5-7	
ADH	None	
Uplinks	4,8,9-16	

Virtual LAN (VLAN) technology is used in the UDH and PDH infrastructure to provide separate and redundant network infrastructure using the same hardware. The multi-VLAN configuration (Configuration A) provides connectivity to both PDH and UDH networks. Supplying multiple switches at each location provides redundancy. The switch fabric provides separation of the data. Each uplink between switches carries each VLANs data encapsulated per IEEE 802.1q. The UDH VLAN data is given priority over the other VLANs by increasing its 802.1p priority.

Selecting IP Addresses for UDH and PDH

Use the following table to select IP addresses on the UDH and PDH. The standard IP address is 192.168.ABC.XYZ.

Ethernet IP Address Rules

Network	A	BC	X	Y	Z
Type	Type	Network Number	Controller/Device Number	Unit Number	Type of Device
UDH	1	01-99	1 = gas turbine controllers 2 = steam turbine controllers	1 = Unit 1 2 = Unit 2 • 9 = Unit 9 0 = All other devices on the UDH	1 = R0 2 = S0 3 = T0 4 = HRSG A 5 = HRSG B 6 = EX2000 or EX2100 A 7 = EX2000 or EX2100 B 8 = EX2000 or EX2100 C 9 = Not assigned 0 = Static Starter 02 - 15 = Servers 16 - 25 = Workstations 26 - 37 = Other stations (Viewers) 38 = Turbine Historian 39 = OSM 40 - 99 = Aux Controllers, such as ISCs
PDH	2	01 – 54	2 to 199 are reserved for customer supplied items 200 to 254 are reserved for GE supplied items such as viewers and printers		

The following are examples of IP addresses:

192.168.104.133 would be UDH number 4, gas turbine unit number 3, T0 core.

192.168.102.215 would be UDH number 2, steam turbine unit number 1, HRSG B.

192.168.201.201 could be a CIMPLICITY Viewer supplied by GE, residing on PDH#1.

192.168.205.10 could be a customer-supplied printer residing on PDH#5.

Note Each item on the network such as a controller, server, or viewer must have an IP address. The above addresses are recommended, but if this is a custom configuration, the requisition takes precedence.

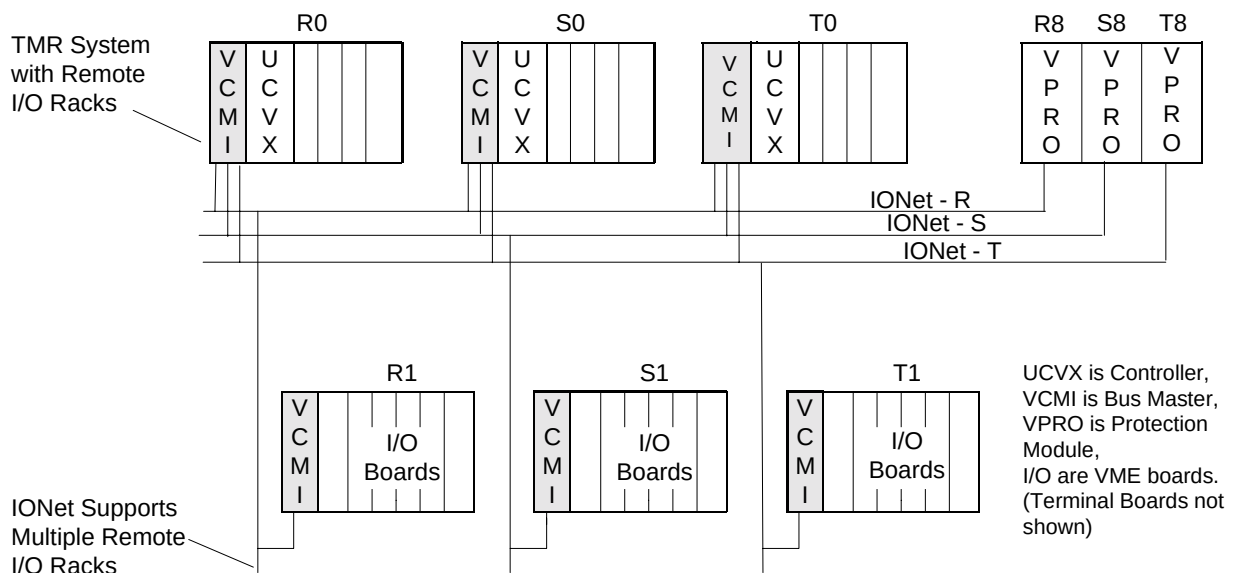
IONet

IONet is an Ethernet 10Base2 network used to communicate data between the VCMI communication board in the control module, the I/O boards, and the three independent sections of the Protection Module <P>. In large systems, it is used to communicate with an expansion VME board rack containing additional I/O boards. These racks are called interface modules since they contain exclusively I/O boards and a VCMI. IONet also communicates data between controllers in TMR systems.

Note Remote I/O can be located up to 185 m (607 ft) from the controller.

Another application is to use the interface module as a remote I/O interface located at the turbine or generator.

The following figure shows a TMR configuration using remote I/O and a protection module.



IONet Communications with Controllers, I/O, and Protection Modules

IONet Features

IONet Feature	Description
Type of Network	Ethernet using extension of ADL protocol
Speed	10 Mb/s data rate
Media and Distance	Ethernet 10Base2, RG-58 coax cable is standard Distance to 185 m (607 ft) Ethernet 10BaseFL with fiber-optic cable and converters Distance is 2 km (1.24 miles)
Number of Nodes	16 nodes
Protocol	Extension of ADL protocol designed to avoid message collisions; Collision Sense (CSMA) functionality is still maintained
Message Size	Maximum packet size 1500 bytes
Message Integrity	32-bit CRC appended to each Ethernet packet

IONet - Communications Interface

Communication between the control module (control rack) and interface module (I/O rack) is handled by the VCMI in each rack. In the control module, the VCMI operates as the IONet Master, while in the interface module it operates as an IONet slave. The VCMI establishes the network ID, and displays the network ID, channel ID, and status on its front cabinet LEDs.

The VCMI serves as the Master frame counter for all nodes on the IONet. Frames are sequentially numbered and all nodes on IONet run in the same frame. This ensures that selected data is being transmitted and operated on correctly.

I/O Data Collection

I/O Data Collection, Simplex Systems - When used in an interface module, the VCMi acts as the VME bus Master. It collects input data from the I/O boards and transmits it to the control module through IONet. When it receives output data from the control module it distributes it to the I/O boards.

The VCMi in slot 1 of the control module operates as the IONet Master. As packets of input data are received from various racks on the IONet, the VCMi collects them and transfers the data through the VME bus to the I/O table in the controller. After application code completion, the VCMi transfers output values from the controller I/O table to the VCMi where the data is then broadcast to all the I/O racks.

I/O Data Collection and Voting, TMR Systems - For a small TMR system, all the I/O may be in one module (triplicated). In this case the VCMi transfers the input values from each of the I/O boards through the VME bus to an internal buffer. After the individual board transfers are complete, the entire block of data is transferred to the pre-vote table, and also sent as an input packet on the IONet. As the packet is being sent, corresponding packets from the other two control modules are being received through the other IONet ports. Each of these packets is then transferred to the pre-vote table.

After all packets are in the pre-vote table, the voting takes place. Analog data (floating point) goes through a median selector, while logical data (bit values) goes through a two-out-of-three majority voter. The results are placed in the voted table.

A selected portion of the controller variables (the states such as counter/timer values and sequence steps) must be transferred by the Master VCMi boards to the other Master VCMi boards to be included in the vote process. At completion of the voting the voted table is transferred through the VME bus to the state table memory in the controller.

For a larger TMR system with remote I/O racks, the procedure is very similar except that packets of input values come into the Master VCMi over IONet. After all the input data is accumulated in the internal buffer, it is placed in the pre-vote table and also sent to the other control modules over IONet. After all the packets and states are in the pre-vote table, they are voted, and the results are transferred to the controller.

Output Data Packet - All the output data from a control module VCMi is placed in packets. These packets are then broadcast on the IONet and received by all connected interface and control modules. Each interface module VCMi extracts the required information and distributes to its associated I/O boards.

Ethernet Global Data (EGD)

EGD allows you to share information between controller components in a networked environment. Controller data configured for transmission over EGD are separated into groups called exchanges. Multiple exchanges make up pages. Pages can be configured to either a specific address (unicast) if supported or to multiple consumers at the same time (broadcast or multicast, if supported).

Each page is identified by the combination of a Producer ID and an Exchange ID so the consumer recognizes the data and knows where to store it. EGD allows one controller component, referred to as the producer of the data, to simultaneously send information at a fixed periodic rate to any number of peer controller components, known as the consumers. This network supports a large number of controller components capable of both producing and consuming information.

The exchange contains a configuration signature, which shows the revision number of the exchange configuration. If the consumer receives data with an unknown configuration signature then it makes the data unhealthy.

In the case of a transmission interruption, the receiver waits three periods for the EGD message, after which it times out and the data is considered unhealthy. Data integrity is preserved by:

- 32-bit cyclic redundancy code (CRC) in the Ethernet packet
- Standard checksums in the UDP and IP headers
- Configuration signature
- Data size field

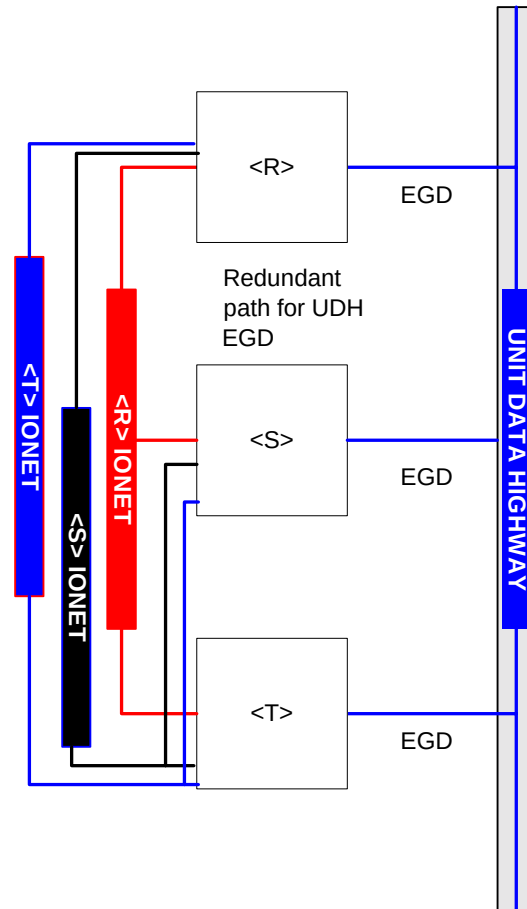
EGD Communications Features

Feature	Description
Type of Communication	Supervisory data is transmitted either 480 or 960 ms. Control data is transmitted at frame rate.
Message Type	Broadcast - a message to all stations on a subnet Unicast - a directed message to one station
Redundancy	Pages may be broadcast onto multiple Ethernet subnets or may be received from multiple Ethernet subnets, if the specified controller hardware supports multiple Ethernet ports.
Fault Tolerance	In TMR configurations, a controller can forward EGD data across the IONet to another controller that has been isolated from the Ethernet.
Sizes	AN exchange can be a maximum of 1400 bytes. Pages can contain multiple exchanges. The number of exchanges within a page and the number of pages within an EGD node are limited by each EGD device type. The Mark VI does not limit the number or exchanges or pages.
Message Integrity	Ethernet supports a 32-bit CRC appended to each Ethernet packet. Reception timeout (determined by EGD device type. The exchange times out after an exchange update had not occurred within four times the exchange period.), Using Sequence ID. Missing/out of order packet detection UDP and IP header checksums Configuration signature (data layout revision control) Exchange size validation
Function Codes	EGD allows each controller to send a block of information to, or receive a block from, other controllers in the system. Integer, Floating Point, and Boolean data types are supported.

In a TMR configuration, each controller receives UDH EGD data independently from a direct Ethernet connection. If the connection is broken a controller may request the missing data from the second or third controller through the IONet.

One controller in a TMR configuration is automatically selected to transmit the EGD data onto the UDH. If the UDH fractures causing the controllers to be isolated from each other onto different physical network segments, multiple controllers are enabled for transmission, providing data to each of the segments.

These features add a level of Ethernet fault tolerance to the basic protocol.



Unit Data Highway EGD TMR Configuration

In a DUAL configuration, each controller receives UDH EGD data independently from a direct Ethernet connection. If the connection is broken a controller may request the missing data from the second through the IONet.

One controller in a DUAL configuration is automatically selected to transmit the EGD data onto the UDH. If the UDH fractures causing the controllers to be isolated from each other onto different physical network segments, each controller is enabled for transmission, providing data to both segments.

Modbus Communications

The Mark VI control platform can be a Modbus Slave on either the COM2 RS-232C serial connection or over Ethernet. In the TMR configuration, commands are replicated to multiple controllers so only one physical Modbus link is required. All the same functions are supported over Ethernet that are supported over the serial ports. All Ethernet Modbus messages are received on Ethernet port 502.

Note The Modbus support is available in either the simplex or TMR configurations.

Messages are transmitted and received using the Modbus RTU transmission mode where data is transmitted in 8-bit bytes. The other Modbus transmission mode where characters are transmitted in ASCII is not supported. The supported Modbus point data types are bits, shorts, longs and floats. These points can be scaled and placed into compatible Mark VI signal types.

There are four Modbus register page types used:

- Input coils
- Output coils
- Input registers
- Holding registers

Since the Mark VI has high priority control code operating at a fixed frame rate, it is necessary to limit the amount of CPU resources that can be taken by the Modbus interface. To limit the operation time, a limit on the number of commands per second received by the Mark VI is enforced. The Mark VI control code also can disable all Modbus commands by setting an internal logical signal.

There are two diagnostic utilities that can be used to diagnose problems with the Modbus communications on a Mark VI. The first utility prints out the accumulated Modbus errors from a network and the second prints out a log of the most recent Modbus messages. This data can be viewed using the toolbox.

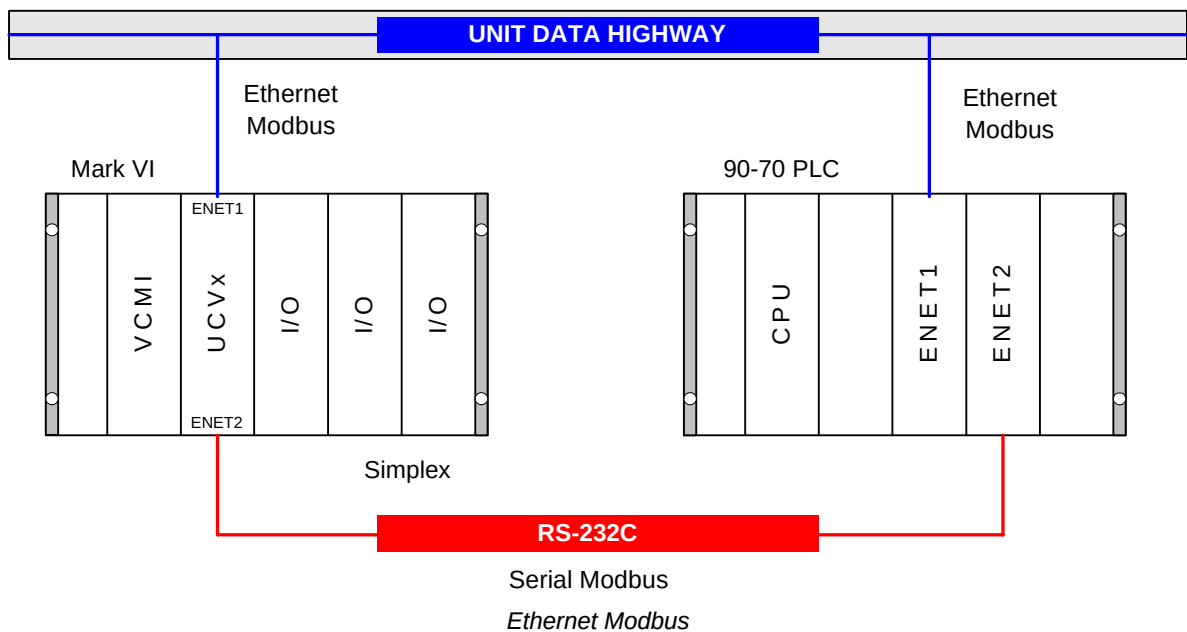
Note For additional information on Mark VI Modbus communications, refer to the sections *Ethernet Modbus Slave* and *Serial Modbus Slave* and to document, *GEI-100535, Modbus Communications*.

Ethernet Modbus Slave

Modbus is widely used in control systems to establish communication between distributed control systems, PLCs, and HMIs. The Mark VI controller supports Ethernet Modbus as a standard slave interface. Ethernet establishes high-speed communication between the various portions of the control system, and the Ethernet Modbus protocol is layered on top of the TCP/IP stream sockets. The primary purpose of this interface is to allow third party Modbus Master computers to read and write signals that exist in the controller, using a subset of the Modbus function codes.

The Mark VI controller will respond to Ethernet Modbus commands received from any of the Ethernet ports supported by its hardware configuration.

Ethernet Modbus may be configured as an independent interface or may share a register map with a serial Modbus interface.



Ethernet Modbus Features

Feature	Description
Communication Type	Multidrop Ethernet CSMA/CD, employing TCP/IP with Modbus Application Protocol (MBAP) layered on top. Slave protocol only
Speed	10 Mb/s data rate
Media and Distance	Using 10Base2 RG-58 coax, the maximum distance is 185 m (607 ft). Using 10BaseT shielded twisted-pair, with media access converter, the maximum distance is 100 m (328 ft) Using 10BaseFL fiber-optics, with media access converter, a distance of several kilometers is possible Only the coax cable can be multidropped; the other cable types use a hub forming a Star network.
Message Integrity	Ethernet supports a 32-bit CRC appended to each Ethernet packet.
Redundancy	Responds to Modbus commands from any Ethernet interface supported by the controller hardware Supports register map sharing with serial Modbus
Function Codes	
01 Read Coil	Read the current status of a group of 1 to 2000 Boolean signals
02 Read Input	Read the current status of a group of 1 to 2000 Boolean signals
03 Read Registers	Read the current binary value in 1 to 125 holding registers
04 Read Input Registers	Read the current binary values in 1 to 125 analog signal registers
05 Force Coil	Force a single Boolean signal to a state of ON or OFF
06 Preset Register	Set a specific binary value into holding registers
07 Read Exception Status	Read the first 8 logic coils (coils 1-8) - short message length permits rapid reading
15 Force Coils	Force a series of 1 to 800 consecutive Boolean signals to a specific state
16 Preset Registers	Set binary values into a series of 1 to 100 consecutive holding registers

Serial Modbus Slave

Serial Modbus is used to communicate between the Mark VI and the plant Distributed Control System (DCS). This is shown as the Enterprise layer in the introduction to this chapter. The serial Modbus communication link allows an operator at a remote location to make an operator command by sending a logical command or an analog setpoint to the Mark VI. Logical commands are used to initiate automatic sequences in the controller. Analog setpoints are used to set a target such as turbine load, and initiate a ramp to the target value at a predetermined ramp rate.

Note The Mark VI controller also supports serial Modbus slave as a standard interface.

The HMI Server supports serial Modbus as a standard interface. The DCS sends a request for status information to the HMI, or the message can be a command to the turbine control. The HMI is always a slave responding to requests from the serial Modbus Master, and there can only be one Master.

Serial Modbus Features

Serial Modbus Feature	Description
Type of Communication	Master/slave arrangement with the slave controller following the Master; full duplex, asynchronous communication
Speed	19,200 baud is standard; 9,600 baud is optional
Media and Distance	Using an RS-232C cable without a modem, the distance is 15.24 m (50 ft); using an RS-485 converter it is 1.93 km (1.2 miles).
Mode	ASCII Mode - Each 8-bit byte in the message is sent as two ASCII characters, the hexadecimal representation of the byte. (Not available from the HMI server.) Remote Terminal Unit (RTU) Mode - Each 8-bit byte in the message is sent with no translation, which packs the data more efficiently than the ASCII mode, providing about twice the throughput at the same baud rate.
Redundancy	Supports register map sharing with Ethernet Modbus.
Message Security	An optional parity check is done on each byte and a CRC16 check sum is appended to the message in the RTU mode; in the ASCII mode an LRC is appended to the message instead of the CRC.

Note This section discusses serial Modbus communication in general terms. Refer to *GEH-6410, Innovation Series Controller System Manual* and HMI manuals for additional information. Refer to *GEH-6126, HMI Application Guide and GFK-1180, CIMPLICITY HMI for Windows NT and Windows 95 User's Manual*. For details on how to configure the graphic screens refer to *GFK-1396, CIMPLICITY HMI for Windows NT and Windows 95 CimEdit Operation Manual*.

Modbus Configuration

Systems are configured as single point-to-point RS-232C communication devices. A GE device on Serial Modbus is a slave supporting binary RTU (Remote Terminal Unit) full duplex messages with CRC. Both dedicated and broadcast messages are supported.

A dedicated message is a message addressed to a specific slave device with a corresponding response from that slave. A broadcast message is addressed to all slaves without a corresponding return response.

The binary RTU message mode uses an 8-bit binary character data for messages. RTU mode defines how information is packed into the message fields by the sender and decoded by the receiver. Each RTU message is transmitted in a continuous stream with a 2-byte CRC checksum and contains a slave address. A slave station's address is a fixed unique value in the range of 1 to 255.

The Serial Modbus communications system supports 9600 and 19,200 baud, none, even, or odd parity, and 7 or 8 data bits. Both the Master and slave devices must be configured with the same baud rate, parity, and data bit count.

Modbus Function Codes

Function Codes	Title	Message Description
01	01 Read Holding Coils	Read the current status of a group of 1 to 2000 Boolean signals
02	02 Read Input Coils	Read the current status of a group of 1 to 2000 Boolean signals
03	03 Read Holding Registers	Read the current binary values in 1 to 125 analog signal registers
04	04 Read Input Registers	Read the current binary values in 1 to 125 analog signal registers
05	05 Force Single Holding Coil	Force (or write) a single Boolean signal to a state of ON or OFF
06	06 Preset Single Holding Register	Preset (or write) a specific binary value into a holding register
07	07 Read Exception Status	Read the first 8 logic coils (coils 1-8) - short message length permits rapid reading of these values
08	08 Loopback Test	Loopback diagnostic to test communication system
15	15 Force Multiple Coils	Force a series of 1 to 800 consecutive Boolean signals to a specific state
16	16 Preset Multiple Holding Registers	Set binary values into a series of 1 to 100 consecutive analog signals

Hardware Configuration

A Data Terminal Equipment Device (DTD) transmits serial data on pin 3 (TD) of a 9-pin RS-232C cable. A Data Communication Device (DCE) is identified as a device that transmits serial data on pin 2 (RD) of a 9-pin RS-232C cable. Refer to the following table.

Using this definition, the GE slave Serial Modbus device is DTD because it transmits serial data on pin 3 (TD) of the 9-pin RS-232C cable. If the master serial Modbus device is also a DTD, connecting the master and slave devices together requires an RS-232C null modem cable.

The RS-232C standard specifies 25 signal lines: 20 lines for routine operation, two lines for modem testing, and three remaining lines unassigned. Nine of the signal pins are used in a nominal RS-232C communication system. Cable references in this document will refer to the 9-pin cable definition found in the following table.

Terms describing the various signals used in sending or receiving data are expressed from the point of view of the DTE. For example the signal, transmit data (TD), represents the transmission of data coming from the DTD going to the DCE.

Each RS-232C signal uses a single wire. The standard specifies the conventions used to send sequential data as a sequence of voltage changes signifying the state of each signal. Depending on the signal group, a negative voltage (less than -3 V) represents either a binary 1 data bit, a signal mark, or a control off condition, while a positive voltage (greater than +3 V) represents either a binary zero data bit, a signal space, or a control on condition. Because of voltage limitations, an RS-232C cable may not be longer than 15.2 m (50 ft).

Nine of the twenty-five RS-232C pins are used in a common asynchronous application. All nine pins are necessary in a system configured for hardware handshaking. The Modbus system does not use hardware handshaking; therefore it requires just three wires, receive data (RD), transmit data (TD), and signal ground (GND) to transmit and receive data.

The nine RS-232C signals used in the asynchronous communication system can be broken down into four groups of signals: data, control, timing, ground.

RS-232C Connector Pinout Definition

DB 9	DB 25	Description	DTE Output	DTE Input	Signal Type	Function
1	8	Data Carrier Detect (DCD)		X	Control	Signal comes from the other RS-232C device telling the DTE device that a circuit has been established
2	3	Receive Data (RD)		X	Data	Receiving serial data
3	2	Transmit Data (TD)	X		Data	Transmitting serial data
4	20	Data Terminal Ready (DTR)	X		Control	DTE places positive voltage on this pin when powered up
5	7	Signal Ground (GND)			Ground	Must be connected
6	6	Data Set Ready (DSR)		X	Control	Signal from other RS-232C device telling the DTE that the other RS-232C device is powered up
7	4	Request To Send (RTS)	X		Control	DTE has data to send and places this pin high to request permission to transmit
8	5	Clear To Send (CTS)		X	Control	DTE looks for positive voltage on this pin for permission to transmit data
9	22	Ring Indicator (RI)		X	Control	A modem signal indicating a ringing signal on the telephone line

Data Signal wires are used to send and receive serial data. Pin 2 (RD) and pin 3 (TD) are used for transmitting data signals. A positive voltage ($> +3$ V) on either of these two pins signifies a logic 0 data bit or space data signal. A negative voltage (< -3 V) on either of these two pins signifies a logic 1 data bit or mark signal.

Control Signals coordinate and control the flow of data over the RS-232C cable. Pins 1 (DCD), 4 (DTR), 6 (DSR), 7 (RTS), and 8 (CTS) are used for control signals. A positive voltage ($> +3$ V) indicates a control on signal, while a negative voltage (< -3 V) signifies a control off signal. When a device is configured for hardware handshaking, these signals are used to control the communications.

Timing Signals are not used in an asynchronous 9-wire cable. These signals, commonly called clock signals, are used in synchronous communication systems to synchronize the data rate between transmitting and receiving devices. The logic signal definitions used for timing are identical to those used for control signals.

Signal Ground on both ends of an RS-232C cable must be connected. Frame ground is sometimes used in 25-pin RS-232C cables as a protective ground.

Serial Port Parameters

An RS-232C serial port is driven by a computer chip called a universal asynchronous receiver/transmitter (UART). The UART sends an 8-bit byte of data out of a serial port preceded with a start bit, the 8 data bits, an optional parity bit, and one or two stop bits. The device on the other end of the serial cable must be configured the same as the sender to understand the received data. The software configurable setup parameters for a serial port are baud rate, parity, stop, and data bit counts. Transmission baud rate signifies the bit transmission speed measured in bits per second. Parity adds an extra bit that provides a mechanism to detect corrupted serial data characters. Stop bits are used to pad a serial data character to a specific number of bits. If the receiver expects 11 bits for each character, the sum of the start bit, data bits, parity bit, and the specified stop bits should equal 11. The stop bits are used to adjust the total to the desired bit count.

UARTs support three serial data transmission modes: simplex (one way only), full duplex (bi-directional simultaneously), and half duplex (non-simultaneous bi-directional). GE's Modbus slave device supports only full duplex data transmission.

Device number is the physical RS-232C communication port.

Baud rate is the serial data transmission rate of the Modbus device measured in bits per second. The GE Modbus slave device supports 9,600 and 19,200 baud (default).

Stop bits are used to pad the number of bits that are transmitted for each byte of serial data. The GE Modbus slave device supports 1 or 2 stop bits. The default is 1 stop bit.

Parity provides a mechanism to error check individual serial 8-bit data bytes. The GE Modbus slave device supports none, even, and odd parity. The default is none.

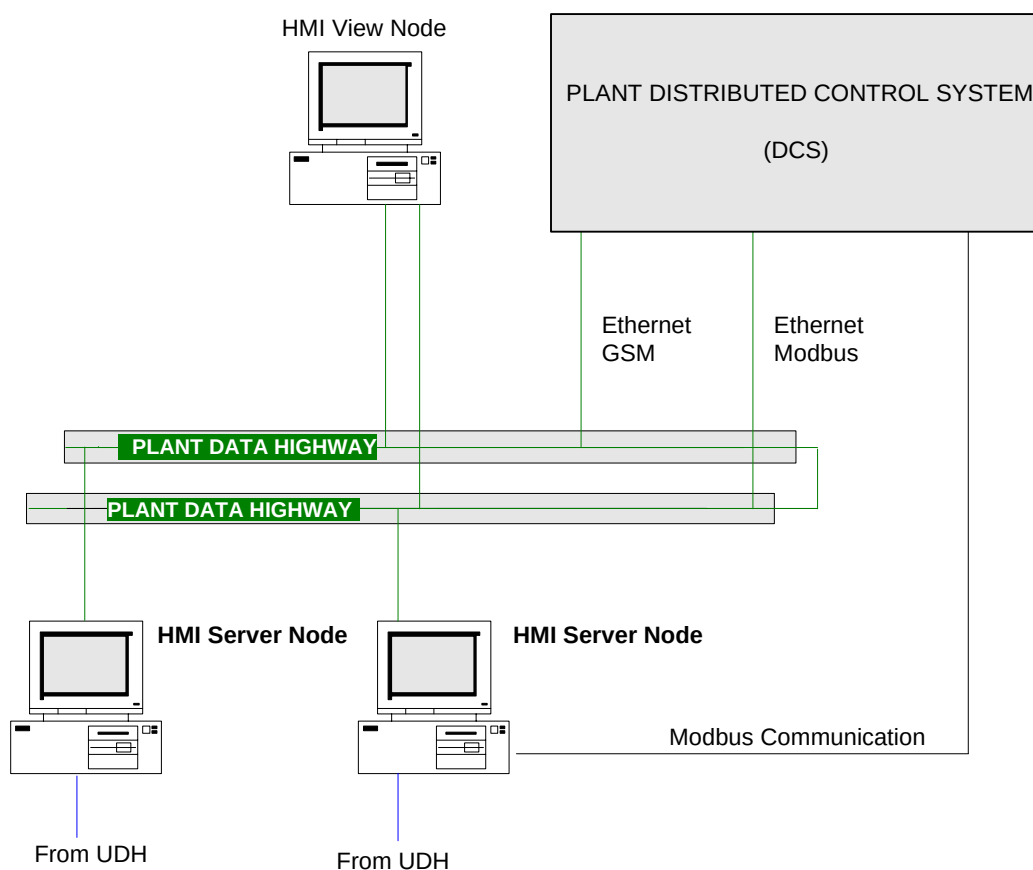
Code (byte size) is the number of data bits in each serial character. The GE Modbus slave device supports 7 and 8-bit data bytes. The default byte size is 8 bits.

Ethernet GSM

Some applications require transmitting alarm and event information to the DCS. This information includes high-resolution local time tags in the controller for alarms (25 Hz), system events (25 Hz), and sequence of events (SOEs) for contact inputs (1 ms). Traditional SOEs have required multiple contacts for each trip contact with one contact wired to the turbine control to initiate a trip and the other contact to a separate SOE instrumentation rack for monitoring. The Mark VI uses dedicated processors in each contact input board to time stamp all contact inputs with a 1 ms time stamp, thus eliminating the initial cost and long term maintenance of a separate SOE system.

Note The HMI server has the turbine data to support GSM messages.

An Ethernet link is available using TCP/IP to transmit data with the local time tags to the plant level control. The link supports all the alarms, events, and SOEs in the Mark VI cabinet. GE supplies an application layer protocol called GSM (GEDS Standard Messages), which supports four classes of application level messages. The HMI Server is the source of the Ethernet GSM communication.



Communication to DCS from HMI using Modbus or Ethernet Options

Administration Messages are sent from the HMI to the DCS with a Support Unit message, which describes the systems available for communication on that specific link and general communication link availability.

Event Driven Messages are sent from the HMI to the DCS spontaneously when a system alarm occurs or clears, a system event occurs or clears, or a contact input (SOE) closes or opens. Each logic point is transmitted with an individual time tag.

Periodic Data Messages are groups of data points, defined by the DCS and transmitted with a group time tag. All of the 5,000 data points in the Mark VI are available for transmission to the DCS at periodic rates down to 1 second. One or multiple data lists can be defined by the DCS using controller names and point names.

Common Request Messages are sent from the DCS to the HMI including turbine control commands and alarm queue commands. Turbine control commands include momentary logical commands such as raise/lower, start/stop, and analog setpoint target commands. Alarm queue commands consist of silence (plant alarm horn) and reset commands as well as alarm dump requests which cause the entire alarm queue to be transmitted from the Mark VI to the DCS.

PROFIBUS Communications

PROFIBUS is used in wide variety of industrial applications. It is defined in PROFIBUS Standard EN 50170 and in other ancillary guideline specifications. PROFIBUS devices are distinguished as Masters or slaves. Masters control the bus and initiate data communication. They decide bus access by a token passing protocol. Slaves, not having bus access rights, only respond to messages received from Masters. Slaves are peripherals such as I/O devices, transducers, valves, and such devices. PROFIBUS is an open fieldbus communication standard.

Note PROFIBUS functionality is only available in simplex, non-TMR Mark VI's only.

At the physical layer, PROFIBUS supports three transmission mediums: RS-485 for universal applications; IEC 1158-2 for process automation; and optical fibers for special noise immunity and distance requirements. The Mark VI PROFIBUS controller provides opto-isolated RS-485 interfaces routed to 9-pin D-sub connectors. Termination resistors are not included in the interface and must therefore be provided by external connectors. Various bus speeds ranging from 9.6 kbit/s to 12 Mbit/s are supported, although maximum bus lengths decrease as bus speeds increase.

To meet an extensive range of industrial requirements, PROFIBUS consists of three variations: PROFIBUS-DP, PROFIBUS-FMS, and PROFIBUS-PA. Optimized for speed and efficiency, PROFIBUS-DP is utilized in approximately 90% of PROFIBUS slave applications. The Mark VI PROFIBUS implementation provides PROFIBUS-DP Master functionality. PROFIBUS-DP Masters are divided into Class 1 and Class 2 types. Class 1 Masters cyclically exchange information with slaves in defined message cycles, and Class 2 Masters provide configuration, monitoring, and maintenance functionality.

Note The Mark VI operates as a PROFIBUS-DP Class 1 Master exchanging information (generally I/O data) with slave devices each frame.

Mark VI UCVE controller versions are available providing one to three PROFIBUS-DP Masters. Each may operate as the single bus Master or may have several Masters on the same bus. Without repeaters, up to 32 stations (Masters and slaves) may be configured per bus segment. With repeaters, up to 126 stations may exist on a bus.

Note More information on PROFIBUS can be obtained at www.profibus.com.

PROFIBUS Features

PROFIBUS Feature	Description
Type of Communication	PROFIBUS-DP Class 1 Master/slave arrangement with slaves responding to Masters once per frame; a standardized application based on the ISO/OSI model layers 1 and 2
Network Topology	Linear bus, terminated at both ends with stubs possible
Speed	9.6 kbit/s, 19.2 kbit/s, 93.75 kbit/s, 187.5 kbit/s, 500 kbit/s, 1.5 Mbit/s, 12 Mbit/s
Media	Shielded twisted pair cable
Number of Stations	Up to 32 stations per line segment; extendable to 126 stations with up to 4 repeaters
Connector	9-pin D-sub connector
Number of Masters	From 1-3 Masters per UCVE

PROFIBUS Bus Length

kb/s	Maximum Bus Length in Meters
9.6	1200
19.2	1200
93.75	1200
187.5	1000
500	400
1500	200
12000	100

Configuration

The properties of all PROFIBUS Master and slave devices are defined in electronic device data sheets called GSD files (for example, SOFTB203.GSD). PROFIBUS can be configured with configuration tools such as Softing AG's PROFI-KON-DP. These tools enable the configuration of PROFIBUS networks comprised of devices from different suppliers based on information imported from corresponding GSD files.

Note GSD files define the properties of all PROFIBUS devices.

The third party tool is used rather than the toolbox to identify the devices making up PROFIBUS networks as well as specifying bus parameters and device options (also called parameters). The toolbox downloads the PROFIBUS configurations to Mark VI permanent storage along with the normal application code files.

Note Although the Softing AG's PROFI-KON-DP tool is provided as the PROFIBUS configurator, any such tool will suffice as long as the binary configuration file produced is in the Softing format.

For additional information on Mark VI PROFIBUS communications, refer to document, *GEI-100536, PROFIBUS Communications*.

I/O and Diagnostics

PROFIBUS I/O transfer with slave devices is driven at the Mark VI application level by a set of standard block library blocks. Pairs of blocks read and write analog, Boolean, and byte-oriented data types. The analog blocks read 2, 4, 8 bytes, depending on associated signal data types, and handle the proper byte swapping. The Boolean blocks automatically pack and unpack bit-packed I/O data. The byte-oriented blocks access PROFIBUS I/O as single bytes without byte swapping or bit packing. To facilitate reading and writing unsigned short integer-oriented PROFIBUS I/O (needed since unsigned short signals are not available), a pair of analog-to-word/word-to-analog blocks work in tandem with the PROFIBUS analog I/O blocks as needed.

Data transfers initiated by multiple blocks operating during a frame are fully coherent since data exchange with slave devices takes place at the end of each frame.

PROFIBUS defines three types of diagnostic messages generated by slave devices:

- Station-related diagnostics provide general station status.
- Module-related diagnostics indicate certain modules having diagnostics pending.
- Channel-related diagnostics specify fault causes at the channel (point) level.

Note PROFIBUS diagnostics can be monitored by the toolbox and the Mark VI application.

Presence of any of these diagnostics can be monitored by the toolbox as well as in Mark VI applications by a PROFIBUS diagnostic block included in the standard block library.

Fiber-Optic Cables

Fiber-optic cable is an effective substitute for copper cable, especially when longer distances are required, or electrical disturbances are a serious problem.

The main advantages of fiber-optic transmission in the power plant environment are:

- Fiber segments can be longer than copper because the signal attenuation per foot is less.
- In high lightning areas, copper cable can pick up currents, which can damage the communications electronics. Since the glass fiber does not conduct electricity, the use of fiber-optic segments avoids pickup and reduces lightning-caused outages.
- Grounding problems are avoided with optical cable. The ground potential can rise when there is a ground fault on transmission lines, caused by currents coming back to the generator neutral point, or lightning.
- Optical cable can be routed through a switchyard or other electrically noisy area and not pick up any interference. This can shorten the required runs and simplify the installation.
- Fiber optic-cable with proper jacket materials can be run direct buried in trays or in conduit.
- High quality optical fiber cable is light, tough, and easily pulled. With careful installation, it can last the life of the plant.

Disadvantages of fiber optics include:

- The cost, especially for short runs, may be more for a fiber-optic link.
- Inexpensive fiber-optic cable can be broken during installation, and is more prone to mechanical and performance degradation over time. The highest quality cable avoids these problems.

Components

Basics

Each fiber link consists of two fibers, one outgoing, and the other incoming to form a duplex channel. A LED drives the outgoing fiber, and the incoming fiber illuminates a phototransistor, which generates the incoming electrical signal.

Multimode fiber, with a graded index of refraction core and outer cladding, is recommended for the optical links. The fiber is protected with buffering which is the equivalent of insulation on metallic wires. Mechanical stress is bad for fibers so a strong sheath is used, sometimes with pre-tensioned Kevlar fibers to carry the stress of pulling and vertical runs.

Connectors for a power plant need to be fastened to a reasonably robust cable with its own buffering. The square connector (SC) type connector is recommended. This connector is widely used for LANs, and is readily available.

Fiber-Optic Cable

Multimode fibers are rated for use at 850 nm and 1300 nm wavelength. Cable attenuation is between 3.0 and 3.3 db/km at 850 nm. The core of the fiber is normally 62.5 microns in diameter, with a gradation of index of refraction. The higher index of refraction is at the center, gradually shifting to a medium index at the circumference. The higher index slows the light, therefore a light ray entering the fiber at an angle curves back toward the center, out toward the other side, back toward the center, etc. This ray travels further but goes faster because it spends most of its time closer to the circumference where the index is less. The index is graded to keep the delays nearly equal, thus preserving the shape of the light pulse as it passes through the fiber.

The inner core is protected with a low index of refraction cladding, which for the recommended cable is 125 microns in diameter. 62.5/125 optical cable is the most common type of cable and should be used.



Never look directly into a fiber. Although most fiber links use LEDs that cannot damage the eyes, some longer links use lasers, which can cause permanent damage to the eyes.

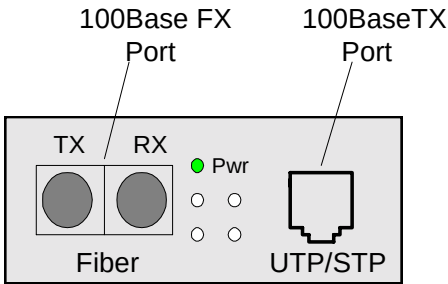
Warning

Guidelines on cables usage:

- Gel filled (or loose tube) cables should not be used because of difficulties making installations, and terminations, and the potential for leakage in vertical runs.
- Use a high quality break out cable, which makes each fiber a sturdy cable, and helps prevent too sharp bends.
- Sub-cables are combined with more strength and filler members to build up the cable to resist mechanical stress and the outside environment
- Two types of cable are recommended, one with armor and one without. Rodent damage is a major cause of optical cable failure. If this is a problem in the plant, the armored cable should be used. If not, the armor is not recommended because it is heavier, has a larger bend radius, is more expensive, attracts lightning currents, and has lower impact and crush resistance.
- Optical characteristics of the cable can be measured with an optical time domain reflectometer. Some manufacturers will supply the OTDR printouts as proof of cable quality. A simpler instrument is used by installer to measure attenuation, and they should supply this data to demonstrate the installation has a good power margin.
- Cables described here have four fibers, enough for two fiber-optic links. This can be used to bring redundant communications to a central control room, or the extra fibers can be retained as spares for future plant enhancements. Cables with two fibers are available for indoor use.

Fiber-Optic Converter

Fiber-Optic connections are normally terminated at the 100BaseFX Fiber port of the Ethernet switch. Occasionally, the Mark VI communication system may require an Ethernet media converter to convert selected UDH and PDH electrical signals to fiber-optic signals. The typical media converter makes a two-way conversion of one or more Ethernet 100BaseTX signals to Ethernet 100Base FX signals.

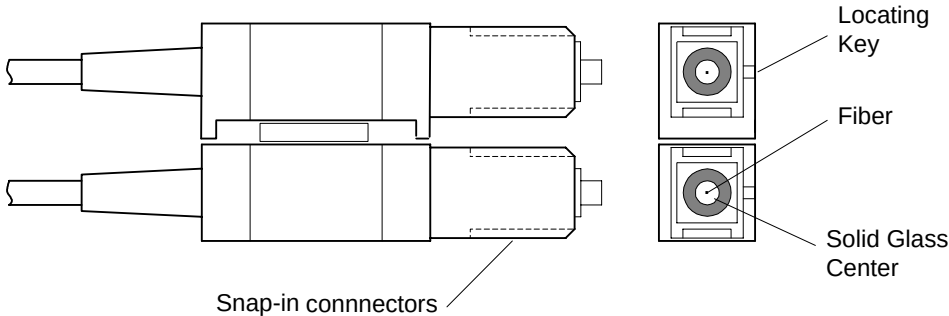


<u>Dimensions:</u>	<u>Power:</u>	<u>Data</u>
Width: 3.0 (76 mm)	120 V ac,	100 Mbps,
Height: 1.0 (25 mm)	60 Hz	fiber optic
Depth: 4.75 (119 mm)		

Media Converter, Ethernet Electric to Ethernet Fiber-Optic

Connectors

The 100Base FX fiber-optic cables for indoor use in Mark VI have SC type connectors. The connector, shown in the following figure, is a keyed, snap-in connector that automatically aligns the center strand of the fiber with the transmission or reception points of the network device. An integral spring helps to keep the SC connectors from being crushed together, to avoid damaging the fiber. The two plugs can be held together as shown, or they can be separate.



SC Connector for Fiber-Optic Cables

The process of attaching the fiber connectors involves stripping the buffering from the fiber, inserting the end through the connector, and casting it with an epoxy or other plastic. This requires a special kit designed for that particular connector. After the epoxy has hardened, the end of the fiber is cut off, ground, and polished. The complete process takes an experienced person about 5 minutes.

System Considerations

When designing a fiber optic network, note the following considerations.

Redundancy should be considered for continuing central control room (CCR) access to the turbine controls. Redundant HMIs, fiber-optic links, Ethernet switches, and power supplies are recommended.

Installation of the fiber can decrease its performance compared to factory new cable. Installers may not make the connectors as well as experts can, resulting in more loss than planned. The LED light source can get dimmer over time, the connections can get dirty, the cable loss increases with aging, and the receiver can become less sensitive. For all these reasons there must be a margin between the available power budget and the link loss budget, of a minimum of 3 dB. Having a 6 dB margin is more comfortable, helping assure a fiber link that will last the life of the plant.

Installation

Planning is important for a successful installation. This includes the layout for the required level of redundancy, cable routing distances, proper application of the distance rules, and procurement of excellent quality switches, UPS systems, and connectors.

- Install the fiber-optic cable in accordance with all local safety codes. Polyurethane and PVC are two possible options for cable materials that might NOT meet the local safety codes.
- Select a cable strong enough for indoor and outdoor applications, including direct burial.
- Adhere to the manufacturer's recommendations on the minimum bend radius and maximum pulling force.
- Test the installed fiber to measure the losses. A substantial measured power margin is the best proof of a high quality installation.
- Use trained people for the installation. If necessary hire outside people with fiber LAN installation experience.
- The fiber switches and converters need reliable power, and should be placed in a location that minimizes the amount of movement they must endure, yet keep them accessible for maintenance.

Component Sources

The following are typical sources for fiber-optic cable, connectors, converters, and switches.

Fiber-Optic Cable:

Optical Cable Corporation
5290 Concourse Drive
Roanoke, VA 24019
Phone: (540)265-0690

Siecor Corporation
PO Box 489
Hickory, NC 28603-0489
Phone: (800)743-2673

Fiber-Optic Connectors:

3M - Connectors and Installation kit
Thomas & Betts - Connectors and Assembly polishing kit
Amphenol – Connectors and Termination kit

Time Synchronization

The time synchronization option synchronizes all turbine controls, generator controls, and operator interfaces (HMIs) on the Unit Data Highway to a Global Time Source (GTS). Typical GTSs are Global Positioning Satellite (GPS) receivers such as the StarTime GPS Clock or similar time processing hardware. The preferred time sources are Coordinated Universal Time (UTC) or GPS.

A time/frequency processor board, either the BC620AT or BC627AT, is placed in the HMI computer. This board acquires time from the GTS with a high degree of accuracy. When the HMI receives the time signal, it makes the time information available to the turbine and generator controls on the network through Network Time Protocol (NTP). The HMI Server provides time to time slaves either by broadcasting time, or by responding to NTP time queries, or by both methods. Refer to RFC 1305 Network Time Protocol (Version 3) dated March 1992 for details.

Redundant time synchronization is provided by supplying a time/frequency processor board in another HMI Server as a backup. Normally, the primary HMI Server on the UDH is the time Master for the UDH, and other computers without the time/frequency board are time slaves. The time slave computes the difference between the returned time and the recorded time of request and adjusts its internal time. Each time slave can be configured to respond to a time Master through unicast mode or broadcast mode.

Local time is used for display of real-time data by adding a local time correction to UTC. A node's internal time clock is normally global rather than local. This is done because global time steadily increases at a constant rate while corrections are allowed to local time. Historical data is stored with global time to minimize discontinuities.

Redundant Time Sources

If either the GTS or time Master becomes inoperative, the backup is to switch the BC620AT or BC627AT to flywheel mode with a drift of ± 2 ms/hour. In most cases, this allows sufficient time to repair the GTS without severe disruption of the plant's system time. If the time Master becomes inoperative, then each of the time slaves picks the backup time Master. This means that all nodes on the UDH lock onto the identical reference for their own time even if the primary and secondary time Masters have different time bases for their reference. If multiple time Masters exist, each time slave selects the current time Master based on whether or not the time Master is tracking the GTS, which time Master has the best quality signal, and which Master is listed first in the configuration file.

Selection of Time Sources

The BC620AT and BC627AT boards support the use of several different time sources; however, the time synchronization software does not support all sources supported by the BC620AT board. A list of time sources supported by both the BC620AT and the time synchronization software includes:

- Modulated IRIG-A, IRIG-B, 2137, or NASA-36 timecode signals
 - Modulation ratio 3:1 to 6:1
 - Amplitude 0.5 to 5 V peak to peak
- Dc Level Shifted Modulated IRIG-A, IRIG-B, 2137, or NASA-36 timecode signals
 - TTL/CMOS compatible voltage levels
- 1 PPS (one pulse per second) using the External 1 PPS input signal of the BC620AT board
 - TTL/CMOS compatible voltage levels, positive edge on time
- Flywheel mode using no signal, using the low drift clock on the BC620AT or BC627AT board
 - Flywheel mode as the sole time source for the plant

Notes

Chapter 4 Codes, Standards, and Environment

Introduction	4-1
Safety Standards	4-1
Electrical.....	4-2
Environment	4-5

Introduction

This chapter describes the codes, standards, and environmental guidelines used for the design of all printed circuits, modules, cores, panels, and cabinet line-ups in the control system. Requirements for harsh environments, such as marine applications, are not covered here.

Safety Standards

EN 61010-1	Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use, Part 1: General Requirements
CAN/CSA 22.2 No. 1010.1-92	Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use, Part 1: General Requirements
ANSI/ISA 82.02.01 1999	Safety Standard for Electrical and Electronic Test, Measuring, Controlling, and Related Equipment – General Requirements
IEC 60529	Intrusion Protection Codes/NEMA 1/IP 20

Electrical

Printed Circuit Board Assemblies

UL 796	Printed Circuit Boards
ANSI IPC guidelines	
ANSI IPC/EIA guidelines	

Electromagnetic Compatibility (EMC)

EN 50081-2	General Emission Standard
EN 55011	Radiated and Conducted RF Emissions
EN 50082-2	Generic Immunity Industrial Environment
EN/IEC 61000-4-2	Electrostatic Discharge Susceptibility
EN/IEC 61000-4-3	Radiated RF Immunity
EN/IEC 61000-4-4	Electrical Fast Transient Susceptibility
EN/IEC 61000-4-5	Surge Immunity
EN/IEC 61000-4-6	Conducted RF Immunity
EN/IEC 61000-4-11	Voltage Variation, Dips and Interruptions
ANSI/IEEE C37.90.1	Surge

Low Voltage Directive

EN 61010-1 Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use, Part 1: General Requirements

Supply Voltage

Line Variations

Ac Supplies – Operating line variations of $\pm 10\%$

IEEE Std 141-1993 defines the Equipment Terminal Voltage – Utilization voltage.

The above meets IEC 60204-1 1999, and exceeds IEEE Std 141-1993, and ANSI C84.1-1989.

Dc Supplies – Operating line variations of -30% , $+20\%$ or 145 V dc. This meets IEC 60204-1 1999.

Voltage Unbalance

Less than 2% of positive sequence component for negative sequence component

Less than 2% of positive sequence component for zero sequence component

This meets IEC 60204-1 1999 and IEEE Std 141-1993.

Harmonic Distortion

Voltage: Less than 10% of total rms voltage between live conductors for 2nd through 5th harmonic

Additional 2% of total rms voltage between live conductors for sum of 6th – 30th harmonic

This meets IEC 60204-1 1999.

Current: The system specification is not per individual equipment

Less than 15% of maximum demand load current for harmonics less than 11

Less than 7% of maximum demand load current for harmonics between 11 and 17

Less than 6% of maximum demand load current for harmonics between 17 and 23

Less than 2.5% of maximum demand load current for harmonics between 23 and 35

The above meets IEEE Std 519 1992.

Frequency Variations

Frequency variation of $\pm 5\%$ when operating from ac supplies (20 Hz/sec slew rate)

This exceeds IEC 60204-1 1999.

Surge

Withstand 2 kV common mode, 1 kV differential mode

This meets IEC 61000-4-5 (ENV50142), and ANSI C62.41 (combination wave).

Clearances

NEMA Tables 7-1 and 7-2 from NEMA ICS1-2000

This meets IEC 61010-1:1993/A2: 1995, CSA C22.2 #14, and UL 508C.

Power Loss

100 % Loss of supply - minimum 10 ms for normal operation of power products

100 % Loss of supply - minimum 500 ms before control products require reset (only applicable to ac powered systems with DACAs; not applicable to dc-only powered Mark VIs).

This exceeds IEC 61000-4-11.

Environment

Storage

If the system is not installed immediately upon receipt, it must be stored properly to prevent corrosion and deterioration. Since packing cases do not protect the equipment for outdoor storage, the customer must provide a clean, dry place, free of temperature variations, high humidity, and dust.

Use the following guidelines when storing the equipment:

- Place the equipment under adequate cover with the following requirements:
 - Keep the equipment clean and dry, protected from precipitation and flooding.
 - Use only breathable (canvas type) covering material – do not use plastic.
 - Unpack the equipment as described, and label it.
 - Maintain the following environment in the storage enclosure:
 - Recommended ambient storage temperature limits from -40 to 80°C (-40 to 176 °F).
 - Surrounding air free of dust and corrosive elements, such as salt spray or chemical and electrically conductive contaminants
 - Ambient relative humidity from 5 to 95% with provisions to prevent condensation
 - No rodents
 - No temperature variations that cause moisture condensation
-



Moisture on certain internal parts can cause electrical failure.

Caution

Condensation occurs with temperature drops of 15°C (27 °F) at 50% humidity over a 4 hour period, and with smaller temperature variations at higher humidity.

If the storage room temperature varies in such a way, install a reliable heating system that keeps the equipment temperature slightly above that of the ambient air. This can include space heaters or cabinet space heaters (when supplied) inside each enclosure. A 100 W lamp can sometimes serve as a substitute source of heat.



To prevent fire hazard, remove all cartons and other such flammable materials packed inside units before energizing any heaters.

Caution

Operating

The Mark VI control components are suited to most industrial environments. To ensure proper performance and normal operational life, the environment should be maintained as follows:

Temperature at bottom of module (acceptable):

Control Module with running fans	0 to 60°C (32 to 140 °F)
I/O Module	0 to 60°C (32 to 140 °F)

Enclosures should be designed to maintain this temperature range.

Relative humidity: 5 to 95%, non-condensing.

Note Higher ambient temperature decreases the life expectancy of any electronic component.

Environments that include excessive amounts of any of the following elements reduce panel performance and life:

- Dust, dirt, or foreign matter
- Vibration or shock
- Moisture or vapors
- Rapid temperature changes
- Caustic fumes
- Power line fluctuations
- Electromagnetic interference or noise introduced by:
 - Radio frequency signals, typically from nearby portable transmitters
 - Stray high voltage or high frequency signals, typically produced by arc welders, unsuppressed relays, contactors, or brake coils operating near control circuits

The preferred location for the Mark VI control system cabinet would be in an environmentally controlled room or in the control room itself. The cabinet should be mounted where the floor surface allows for attachment in one plane (a flat, level, and continuous surface). The customer provides the mounting hardware. Lifting lugs are provided and if used, the lifting cables must not exceed 45° from the vertical plane. Finally, the cabinet is equipped with a door handle, which can be locked for security.

Interconnecting cables can be brought into the cabinet from the top or the bottom through removable access plates. Convection cooling of the cabinet requires that conduits be sealed to the access plates. Also, air passing through the conduit must be within the acceptable temperature range as listed previously. This applies to both top and bottom access plates.

Elevation

Equipment elevation is related to the equivalent ambient air pressure.

- Normal Operation - 0 to 1000 m (3300 ft) (101.3 KPa - 89.8 KPa)
- Extended Operation - 1000 to 3050 m (3300 to 10,000 ft) (89.8 KPa - 69.7 KPa)
- Shipping - 4600 m (15000 ft) maximum (57.2 KPa)

Note A guideline for system behavior as a function of altitude is that for altitudes above 1000 m (3300 ft), the maximum ambient rating of the equipment decreases linearly to a derating of 5°C (41°F) at 3050 m (10000 ft).

The extended operation and shipping specifications exceed EN50178.

Contaminants

Gas

The control equipment withstands the following concentrations of corrosive gases at 50% relative humidity and 40°C (104 °F):

Sulfur dioxide (SO ₂)	30 ppb
Hydrogen sulfide (H ₂ S)	10 ppb
Nitrous fumes (NO _x)	30 ppb
Chlorine (Cl ₂)	10 ppb
Hydrogen fluoride (HF)	10 ppb
Ammonia (NH ₃)	500 ppb
Ozone (O ₃)	5 ppb

The above meets EN50178 Section A.6.1.4 Table A.2 (m).

Vibration

Seismic

Universal Building Code (UBC) - Seismic Code section 2312 Zone 4

Operating / Installed at Site

Vibration of 1.0 G Horizontal, 0.5 G Vertical at 15 to 120 Hz

See Seismic UBC for frequencies lower than 15 Hz.

Packaging

The standard Mark VI cabinets meet NEMA 1 requirements (similar to the IP-20 cabinet). Optional cabinets for special applications meet NEMA 12 (IP-54), NEMA 4 (IP-65), and NEMA 4X (IP-68) requirements. Redundant heat exchangers or air conditioners, when required, can be supplied for the above optional cabinets.

UL Class 1 Division 2 Listed Boards

Certain boards used in the Mark VI are UL listed (E207685) for Class 1 Division 2, Groups A, B, C, and D, Hazardous Locations, Temperature Class T4 using UL-1604.

Division 2 is described by NFPA 70 NEC 1999 Article 500 (NFPA - National Fire Protection Association, NEC - National Electrical Code).

The Mark VI boards/board combinations that are listed may be found under file number E207685 at the UL website and currently include:

- IS200VCMIH1B, H2B
- IS200DTCCH1A, IS200VTCCH1C
- IS200DRTDH1A, IS200VRTDH1C
- IS200DTAIH1A, IS200VAICH1C
- IS200DTAOH1A, IS200VAOCH1B
- IS200DTCIH1A, IS200VCRCH1B
- IS200DRLYH1B
- IS200DTURH1A, IS200VTURH1B
- IS200DTRTH1A
- IS200DSVOH2B, IS200VSVOH1B
- IS200DVIBH1B, IS200VVIBH1C
- IS200DSCBH1A, IS200VSCAH2A
- IS215UCVEH2A, M01A, M03A, M04A, M05A
- IS215UCVDH2A
- IS2020LVPSG1A

Chapter 5 Installation and Configuration

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Startup and Configuration	5-45

Introduction

This chapter defines installation requirements for the Mark VI control system. Specific topics include GE installation support, wiring practices, grounding, typical equipment weights and dimensions, power dissipation and heat loss, and environmental requirements.

Installation Support

GE's system warranty provisions require both quality installation and that a qualified service engineer be present at the initial equipment startup. To assist the customer, GE offers both standard and optional installation support. Standard support consists of documents that define and detail installation requirements. Optional support is typically the advisory services that the customer may purchase.

Early Planning

To help ensure a fast and accurate exchange of data, a planning meeting with the customer is recommended early in the project. This meeting should include the customer's project management and construction engineering representatives. It should accomplish the following:

- Familiarize the customer and construction engineers with the equipment
- Set up a direct communication path between GE and the party making the customer's installation drawings
- Determine a drawing distribution schedule that meets construction and installation needs
- Establish working procedures and lines of communication for drawing distribution

GE Installation Documents

Installation documents consist of both general and requisition-specific information. The cycle time and the project size determine the quantity and level of documentation provided to the customer.

General information, such as this document, provides product-specific guidelines for the equipment. They are intended as supplements to the requisition-specific information.

Requisition documents, such as outline drawings and elementary diagrams provide data specific to a custom application. Therefore, they reflect the customer's specific installation needs and should be used as the primary data source.

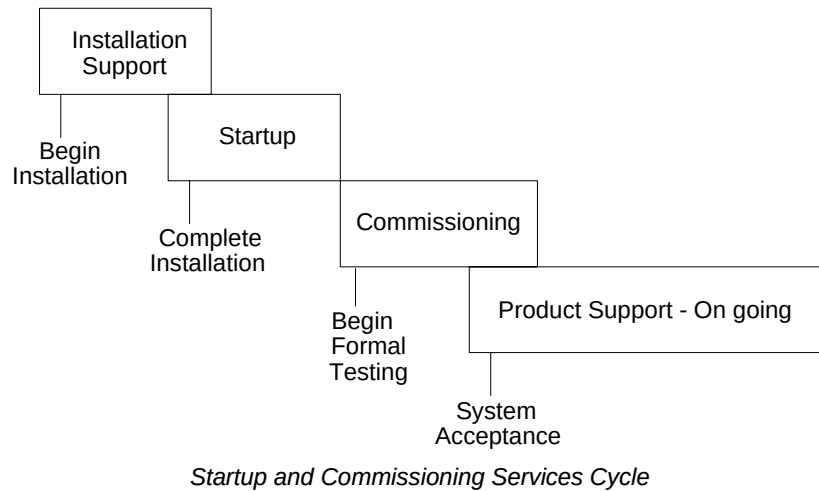
As-Shipped drawings consist primarily of elementary diagrams revised to incorporate any revisions or changes made during manufacture and test. These are issued when the equipment is ready to ship. Revisions made after the equipment ships, but before start of installation, are sent as *Field Change*, with the changes circled and dated.

Technical Advisory Options

To assist the customer, GE Energy offers the optional technical advisory services of field engineers for:

- Review of customer's installation plan
- Installation support

These services are not normally included as installation support or in basic startup and commissioning services shown below. GE presents installation support options to the customer during the contract negotiation phase.



Installation Plan and Support

It is recommended that a GE field representative review all installation/construction drawings and the cable and conduit schedule when completed. This optional review service ensures that the drawings meet installation requirements and are complete.

Optional installation support is offered: planning, practices, equipment placement, and onsite interpretation of construction and equipment drawings. Engineering services are also offered to develop transition and implementation plans to install and commission new equipment in both new and existing (revamp) facilities.

Customer's Conduit and Cable Schedule

The customer's finished conduit and cable schedule should include:

- Interconnection wire list (optional)
- Level definitions
- Shield terminations

The cable and conduit schedule should define signal levels and classes of wiring (see the section, *Cable Separation and Routing*). This information should be listed in a separate column to help prevent installation errors.

The cable and conduit schedule should include the signal level definitions in the instructions. This provides all level restriction and practice information needed before installing cables.

The conduit and cable schedule should indicate shield terminal practice for each shielded cable (refer to section, *Connecting the System*).

Equipment Receiving and Handling

Note For information on storing equipment, refer to Chapter 4

GE inspects and packs all equipment before shipping it from the factory. A packing list, itemizing the contents of each package, is attached to the side of each case.

Upon receipt, carefully examine the contents of each shipment and check them with the packing list. Immediately report any shortage, damage, or visual indication of rough handling to the carrier. Then notify both the transportation company and GE Energy. Be sure to include the serial number, part (model) number, GE requisition number, and case number when identifying the missing or damaged part.



Immediately upon receiving the system, place it under adequate cover to protect it from adverse conditions. Packing cases are not suitable for outdoor or unprotected storage. Shock caused by rough handling can damage electrical equipment. To prevent such damage when moving the equipment, observe normal precautions along with all handling instructions printed on the case.

If assistance is needed contact:

GE Energy
Post Sales Service
1501 Roanoke Blvd.
Salem, VA 24153-6492

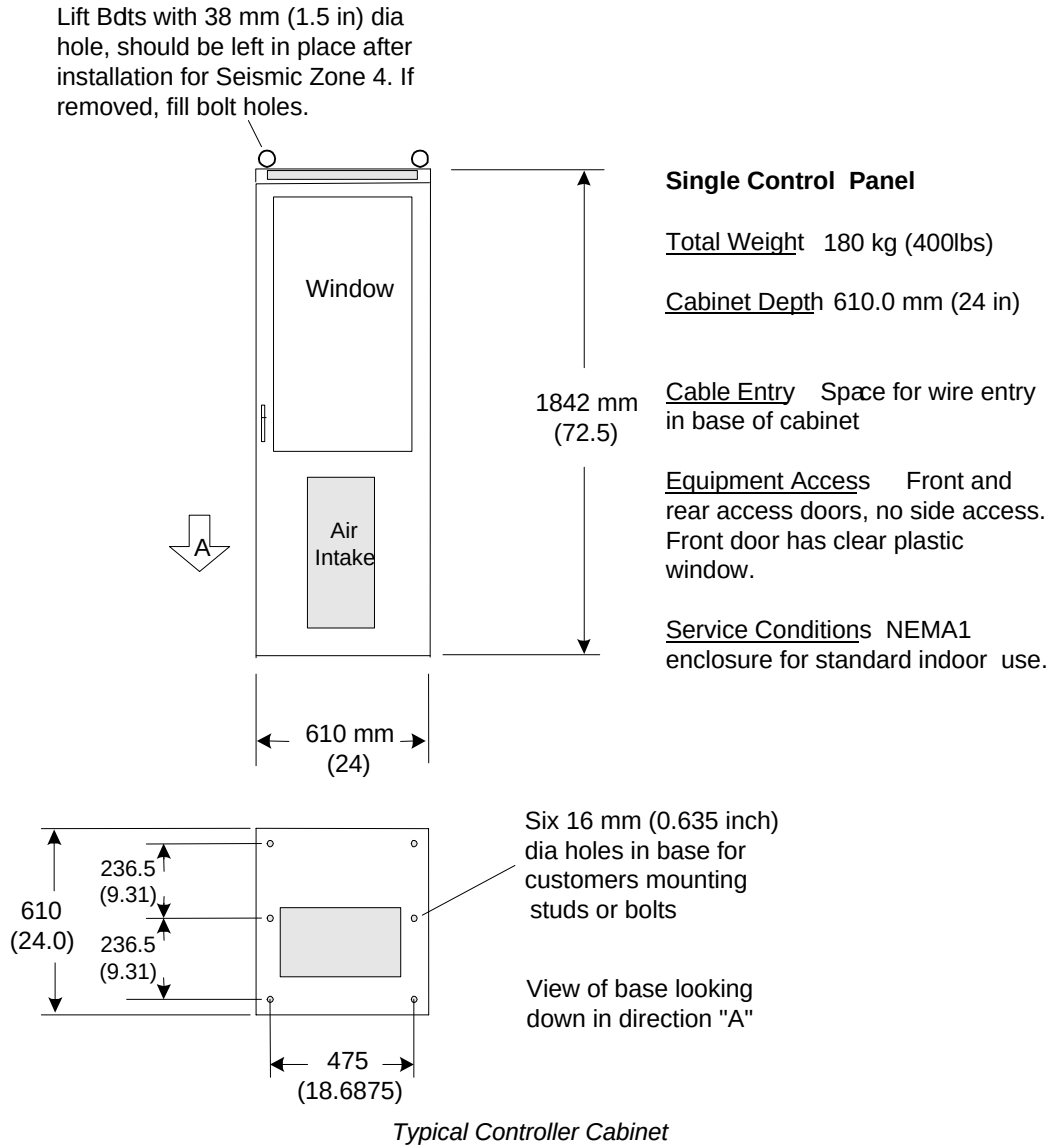
Phone: 1 888 GE4 SERV (888 434 7378, United States)
+ 1 540 378 3280 (International)
Fax: + 1 540 387 8606 (All)

Note "+" indicates the international access code required when calling from outside of the USA.

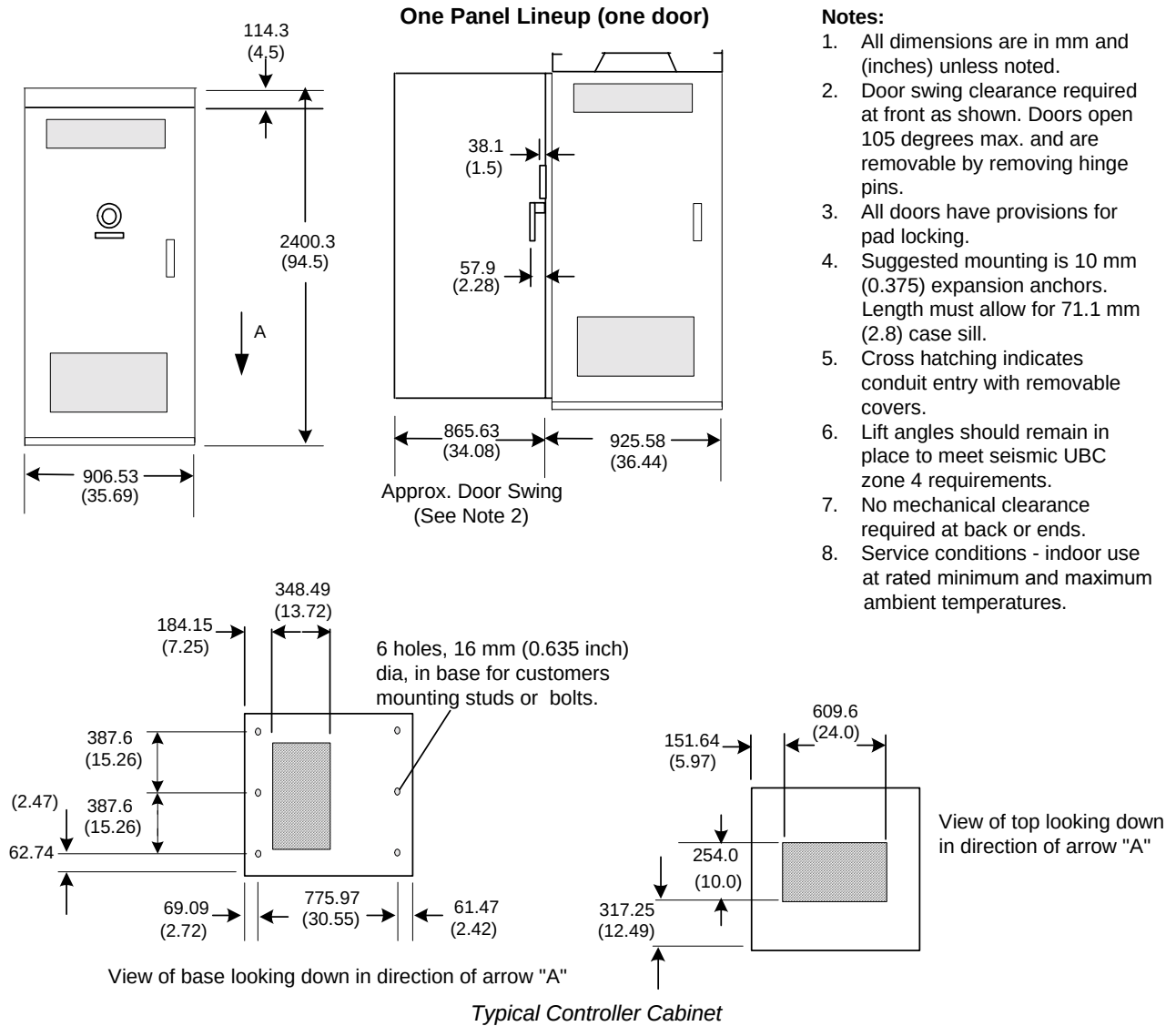
Weights and Dimensions

Cabinets

A single Mark VI cabinet is shown below. This can house three controllers used in a system with all remote I/O. Dimensions, clearance, bolt holes, lifting lugs, and temperature information is included.

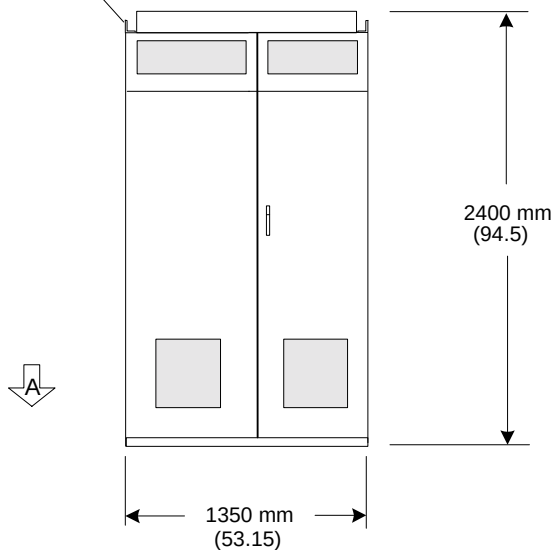


The controller cabinet is for small gas turbine systems (simplex only). It contains control, I/O, and power supplies, and weighs 620 kg (1,367 lbs) complete.



The two-door cabinet shown in the following figure is for small gas turbine systems. It contains control, I/O, and power supplies, and weighs approximately 720 kg (1,590 lbs) complete. A 1600 mm wide version of this cabinet is available, and weighs approximately 912 kg (2,010 lbs) complete.

Lift Angles with two 30.2 (1.18) holes, should be left in place for Seismic Zone 4, if removed, fill bolt holes.



Two Panel Lineup (Two Doors)

Total Weight 912 kg (2010lbs)

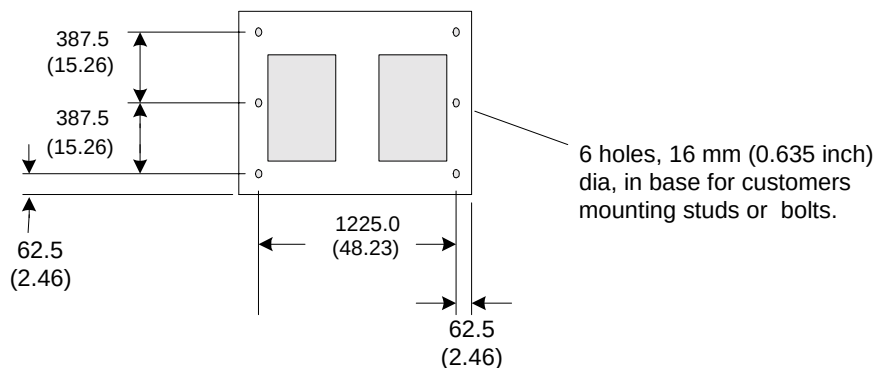
Cabinet Depth 903.9 mm (35.59 in)

Cable Entry Removable covers top and bottom.

Equipment Access Front doors only, no rear or side access. Door swing clearance 977.9 mm (38.5).

Mounting Holes in Base
Six 16 mm (0.635 in) dia holes in base of the cabinet for customers mounting studs or bolts, for details see GE dwgs.

Service Conditions
Standard NEMA1 enclosure for indoor use.



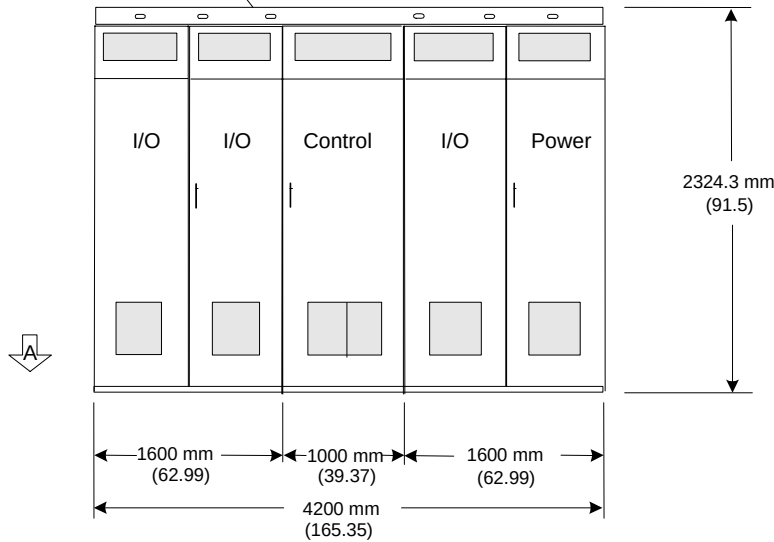
View of base looking down in direction of arrow "A"

Typical Controller Cabinet

A typical lineup for a complete Mark VI system is shown in the following figure. These cabinets contain controllers, I/O, and terminal boards, or they can contain just the remote I/O and terminal boards.

Lift Angles front and back, should be left in place for Seismic Zone 4, if removed, fill bolt holes.

Three Cabinet Lineup (Five Doors)



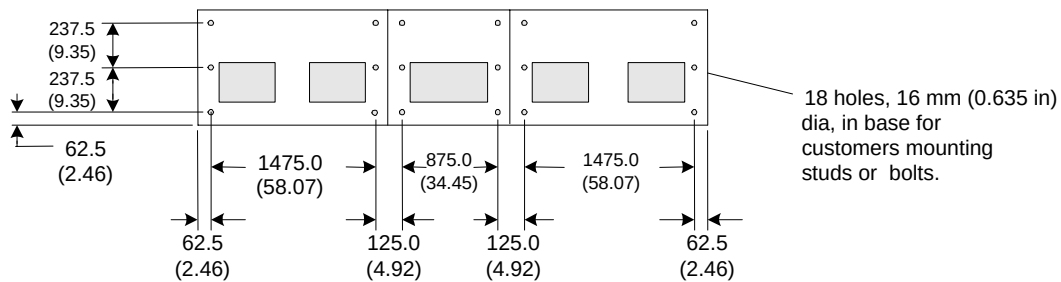
Total Weight 1770 kg (3,900 lbs)
Cabinet Depth 602 mm (23.7 in)

Cable Entry Removable covers top and bottom.

Equipment Access Front doors only, no rear or side access. Door swing clearance 977.9 mm (38.5 in).

Mounting Holes in Base
 Six 16 mm (0.635 in) dia holes in base of each of the three cabinets for customers mounting studs or bolts, for details see GE dwgs.

Service Conditions
 Standard NEMA1 enclosure for indoor use.

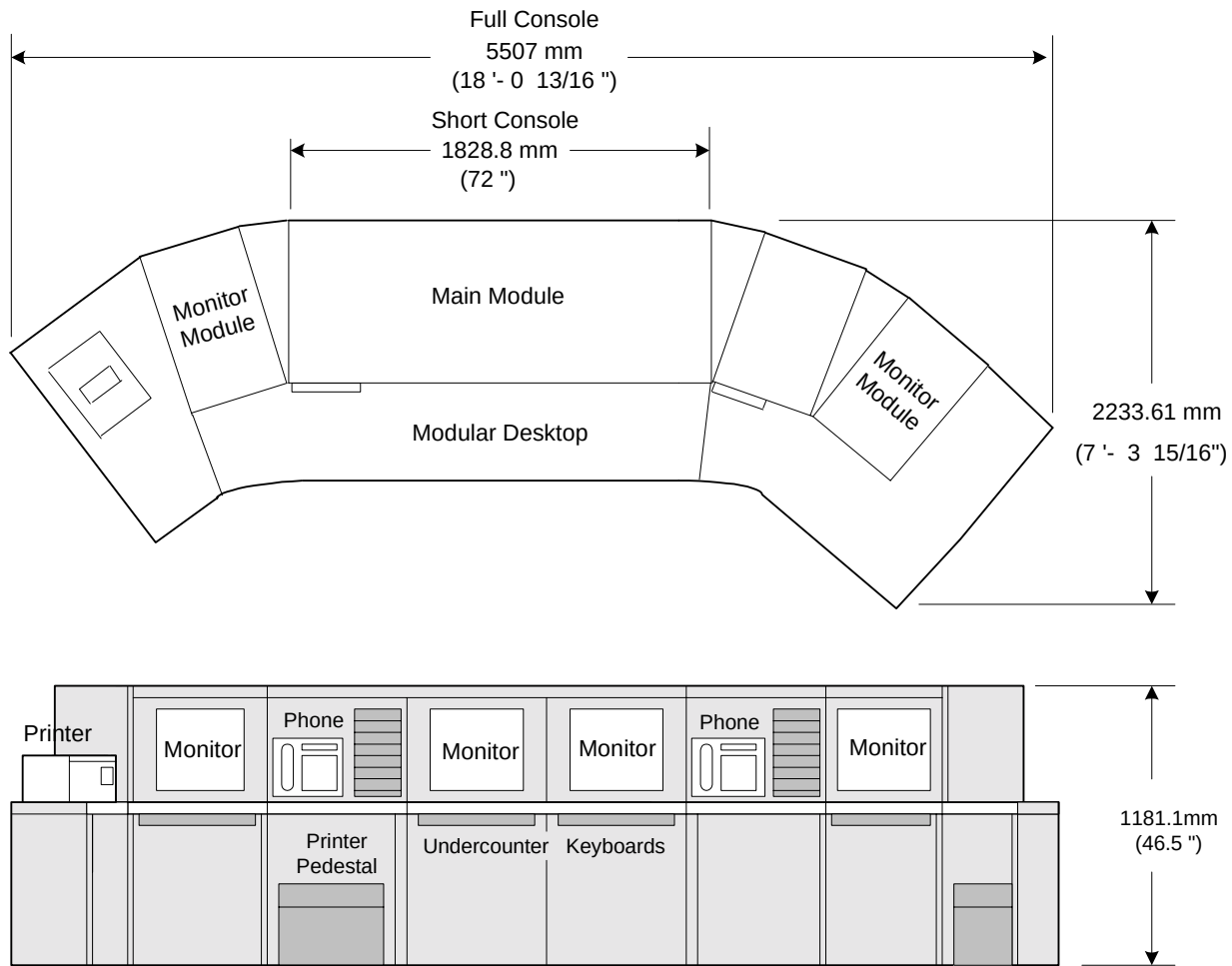


View of base looking down in direction of arrow "A"

Typical Mark VI Cabinet Lineup

Control Console (Example)

The turbine control HMI computers can be table-mounted, or installed in the optional control console shown in the following figure. The console is modular and expandable from an 1828.8 mm version with two computers. A 5507 mm version with four computers is shown. The console rests on feet and is not usually bolted to the floor.



Turbine Control Console with Dimensions

Power Requirements

The Mark VI control cabinet can accept power from multiple power sources. Each power input source (such as the dc and two ac sources) should feed through its own external 30 A two-pole thermal magnetic circuit breaker before entering the Mark VI enclosure. The breaker should be supplied in accordance with required site codes.

Power sources can be any combination of 24 V dc, 125 V dc and 120/240 V ac sources. The Mark VI power distribution hardware is configured for the required sources, and not all inputs may be available in a configuration. Input power is converted to 28 V dc for operation of the control electronics. Other power is distributed as needed for use with I/O signals.

Power requirements for a typical three-bay (five-door) 4200 mm cabinet containing controllers, I/O, and terminal boards are shown in the following table. The power shown is the heat generated in the cabinet, which must be dissipated. For the total current draw, add the current supplied to external solenoids as shown in the notes below the table. These external solenoids generate heat inside the cabinet. Heat Loss in a typical 4200 mm (165 in) TMR cabinet is 1500 W fully loaded.

For a single control cabinet containing three controllers only (no I/O), the following table shows the nominal power requirements. This power generates heat inside the control cabinet. Heat Loss in a typical TMR controller cabinet is 300 W.

The current draw number in the following table is assuming a single voltage source, if two or three sources are used, they share the load. The actual current draw from each source cannot be predicted because of differences in the ac/dc converters. For further details on the cabinet power distribution system, refer to Volume II of this System Guide.

Power Requirements for Cabinets

Cabinet	Voltage		Frequency		Current Draw
4200 mm Cabinet	125 V dc	100 to 144 V dc (see Note 5)	N/A	N/A	10.0 A dc (see Note 1)
	120 V ac	108 to 132 V ac (see Note 6)	50/60 Hz	± 3 Hz	17.3 A rms (see Notes 2 and 4)
	240 V ac	200 to 264 V ac	50/60 Hz	± 3 Hz	8.8 A rms (see Notes 3 and 4)
Controller Cabinet	125 V dc	100 to 144 V dc (see Note 5)	N/A	N/A	1.7 A dc
	120 V ac	108 to 132 V ac (see Note 6)	50/60 Hz	± 3 Hz	3.8 A rms
	240 V ac	200 to 264 V ac	50/60 Hz	± 3 Hz	1.9 A rms

* Notes on table (these are external and do not create cabinet heat load).

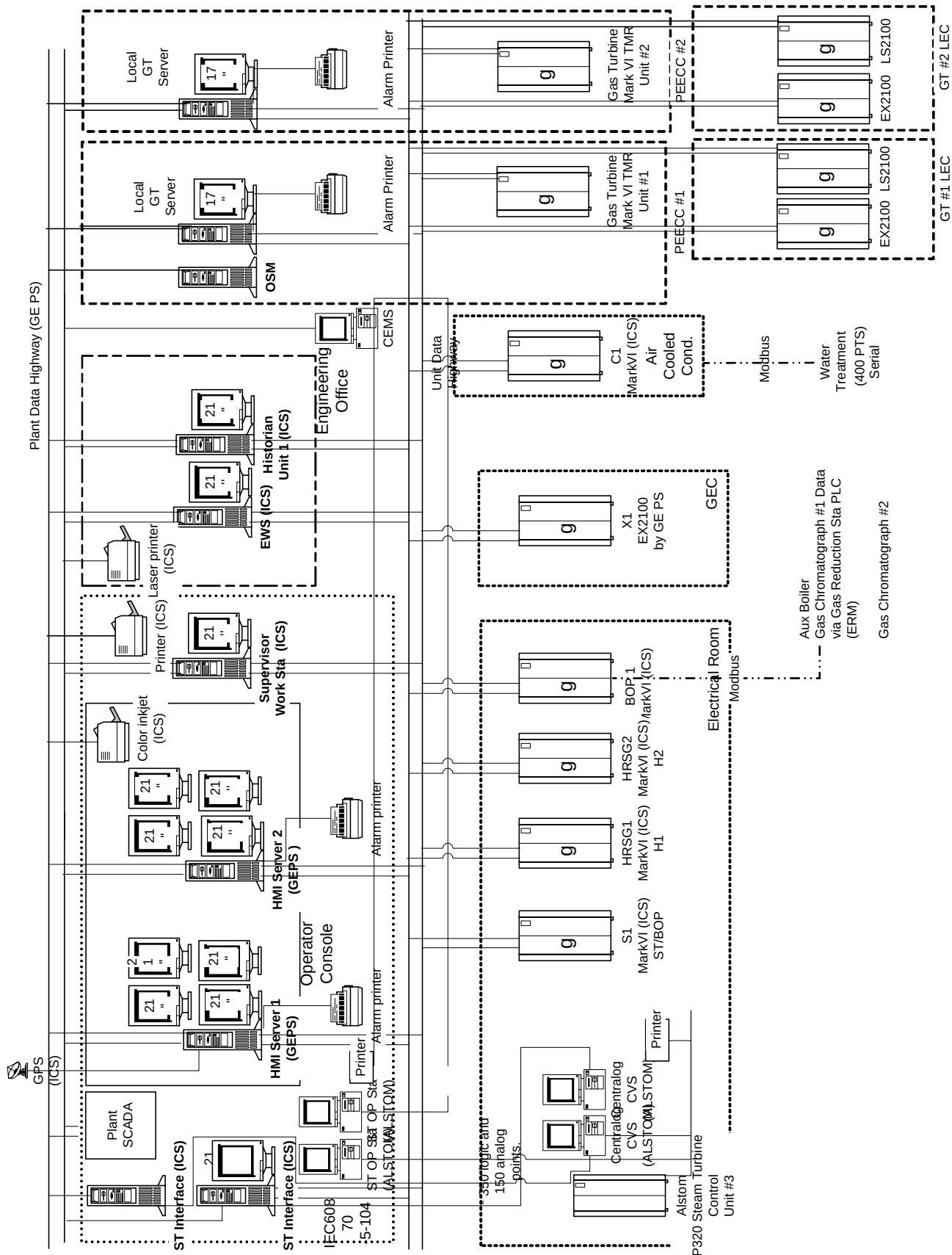
- 1 Add 0.5 A dc continuous for each 125 V dc external solenoid powered.
- 2 Add 6.0 A rms for a continuously powered ignition transformer (2 maximum).
- 3 Add 3.5 A rms for a continuously powered ignition transformer (2 maximum).
- 4 Add 2.0 A rms continuous for each 120 V ac external solenoid powered (in rush 10 A).
- 5 Supply voltage ripple is not to exceed 10 V peak-to-peak.
- 6 Supply voltage total harmonic distortion is not to exceed 5.0%.

Installation Support Drawings

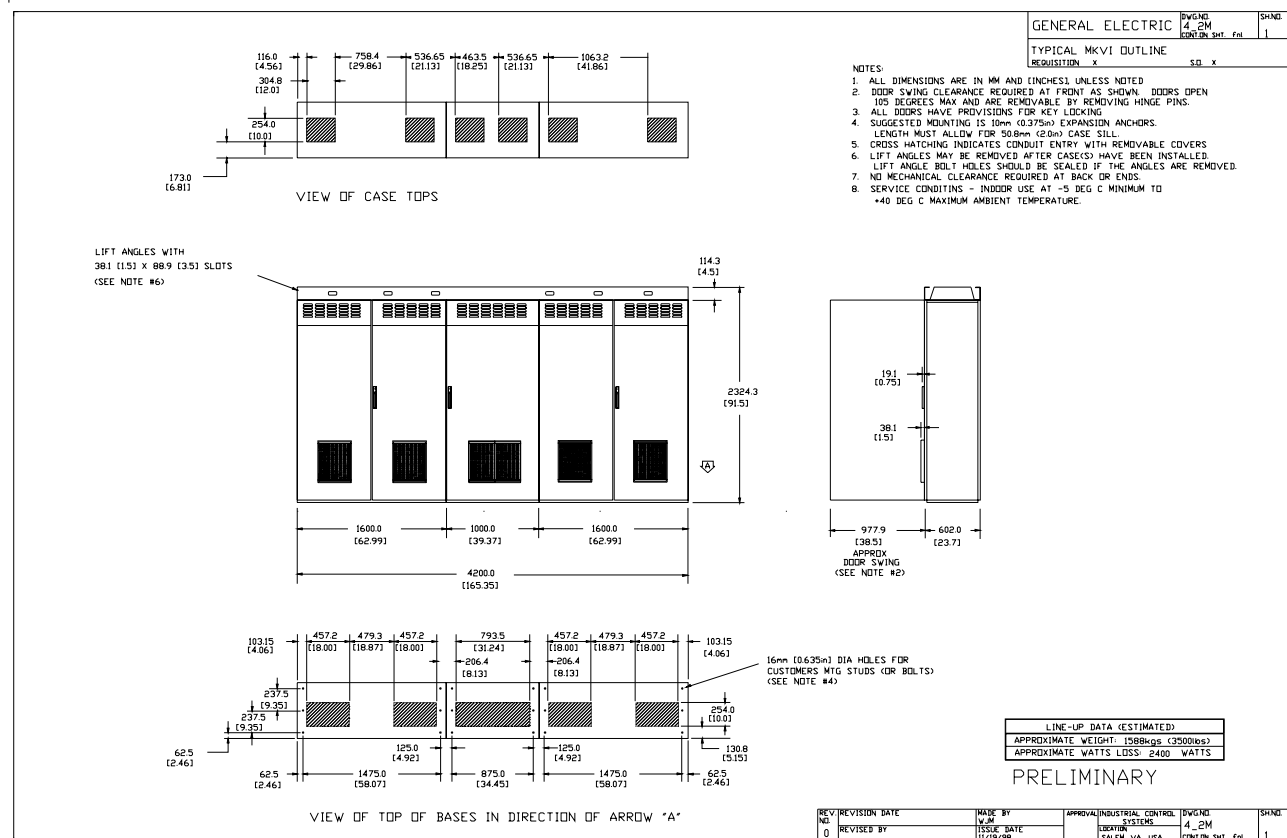
This section describes GE installation support drawings. These drawings are usually B-size AutoCAD drawings covering all hardware aspects of the system. A few sample drawings include:

- System Topology
- Cabinet Layout
- Cabinet Layout
- Circuit Diagram

In addition to the installation drawings, site personnel will need the I/O Assignments (IO Report).

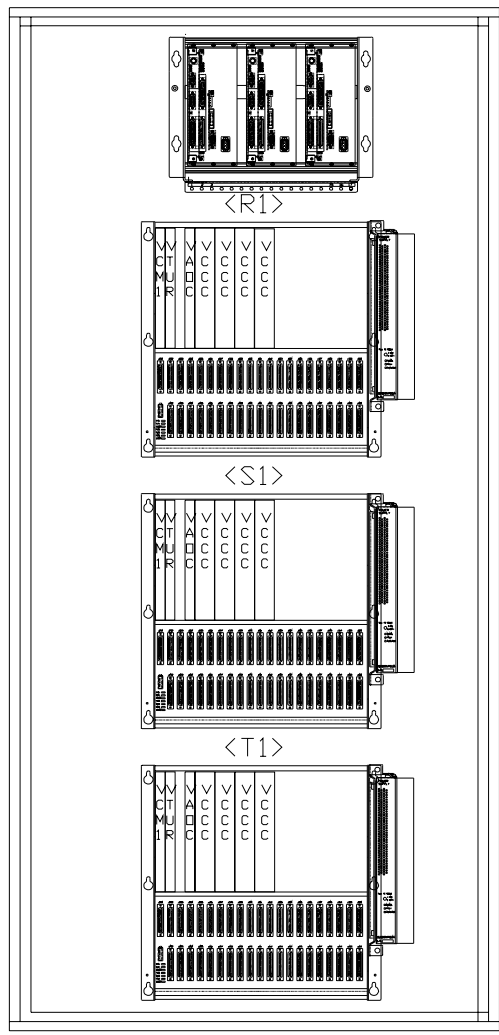


Typical System Topology Showing Interfaces



Typical I/O Cabinet Drawing showing Dimensions, Cable Access, Lifting Angles, and Mounting

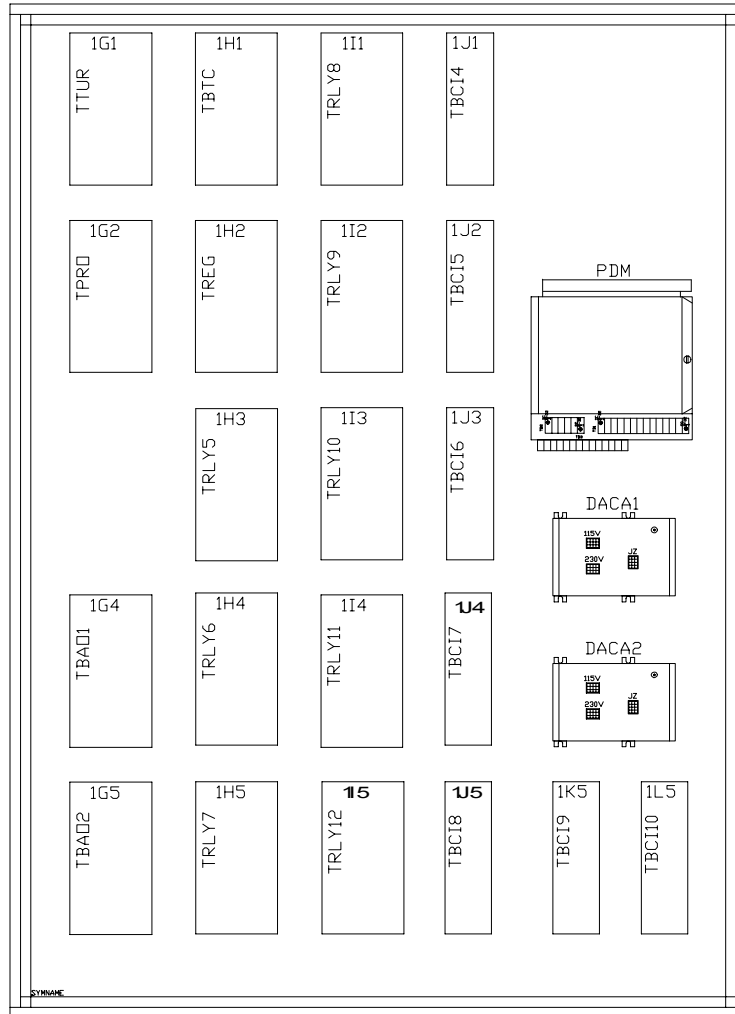
CENTER



REVISION NO. 0	CASE SIZE (1000) X (2324) X (600)	ISSUE DATE 12/2/98	GENERAL ELECTRIC Industrial Control Systems SALEM, VA. U.S.A.	PANEL LAYOUT DIAGRAM 1000 CONTROLLER PANEL R, S, T VME RACKS	
REVISION DATE	TECHNICIAN	REQUISITION		2_6MID	SH. NO.
REVISED BY	DRAWN BY WJM	SHOP ORDER NO.		CONT. ON SH. 2	1

Panel Layout with Protection Module

RIGHT PANEL



I/O Panel with Terminal Boards and Power Supplies

Grounding

This section defines grounding and signal-referencing practices for the Mark VI system. This can be used to check for proper grounding and Signal Reference Structure (SRS) after the equipment is installed. If checking the equipment after the power cable has been connected or after power has been applied to the cabling, be sure to follow all safety precautions for working around high voltages.



To prevent electric shock, make sure that all power supplies to the equipment are turned off. Then discharge and ground the equipment before performing any act requiring physical contact with the electrical components or wiring. If test equipment cannot be grounded to the equipment under test, the test equipment's case must be shielded to prevent contact by personnel.

Equipment Grounding

Equipment grounding and signal referencing have two distinct purposes:

- Equipment grounding protects personnel and equipment from risk of electrical shock or burn, fire, or other damage caused by ground faults or lightning.
- Signal referencing helps protect equipment from the effects of internal and external electrical noise such as from lightning or switching surges.

Installation practices must simultaneously comply with all codes in effect at the time and place of installation, and practices, which improve the immunity of the installation. In addition to codes, IEEE Std 142-1991 *IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems* and IEEE Std 1100-1992 *IEEE Recommended Practice for Powering and Grounding Sensitive Electronic Equipment* provide guidance in the design and implementation of the system. Code requirements for safety of personnel and equipment must take precedence in the case of any conflict with noise control practices.

The Mark VI system has no special or nonstandard installation requirements, if installed in compliance with all of the following:

- The NEC® or local codes
- With a signal reference structure (SRS) designed to meet IEEE Std 1100
- Interconnected with signal/power-level separation as defined later

This section provides equipment grounding and bonding guidelines for control and I/O cabinets. These guidelines also apply to motors, transformers, brakes, and reactors. Each of these devices should have its own grounding conductor going directly to the building ground grid.

- Ground each cabinet or cabinet lineup to the equipment ground at the source of power feeding it.
 - See NEC Article 250 for sizing and other requirements for the equipment grounding conductor.
 - For dc circuits only, the NEC allows the equipment grounding conductor to be run separate from the circuit conductors.

- With certain restrictions, the NEC allows the metallic raceways or cable trays containing the circuit conductors to serve as the equipment grounding conductor:
 - This use requires that they form a continuous, low-impedance path capable of conducting anticipated fault current.
 - This use requires bonding across loose-fitting joints and discontinuities. See NEC Article 250 for specific bonding requirements. This chapter includes recommendations for high frequency bonding methods.
 - If metallic raceways or cable trays are not used as the primary equipment grounding conductor, they should be used as a supplementary equipment grounding conductor. This enhances the safety of the installation and improves the performance of the Signal Reference Structure (see later).
- The equipment grounding connection for the Mark VI cabinets is plated copper bus or stub bus. This connection is bonded to the cabinet enclosure using bolting that keeps the conducting path's resistance at 1 ohm or less.
- There should be a bonding jumper across the ground bus or floor sill between all shipping splits. The jumper may be a plated metal plate.
- The non-current carrying metal parts of the equipment covered by this section should be bonded to the metallic support structure or building structure supporting this equipment. The equipment mounting method may satisfy this requirement. If supplementary bonding conductors are required, size them the same as equipment grounding conductors.

Building Grounding System

This section provides guidelines for the building grounding system requirements. For specific requirements, refer to NEC article 250 under the heading Grounding Electrode System.

The guidelines below are for metal framed buildings. For non-metal framed buildings, consult the GE factory.

The ground electrode system should be composed of steel reinforcing bars in building column piers bonded to the major building columns.

- A buried ground ring should encircle the building. This ring should be interconnected with the bonding conductor running between the steel reinforcing bars and the building columns.
- All underground, metal water piping should be bonded to the building system at the point where the piping crosses the ground ring.
- NEC Article 250 requires that separately derived systems (transformers) be grounded to the nearest effectively grounded metal building structural member.
- Braze or exothermically weld all electrical joints and connections to the building structure, where practical. This type of connection keeps the required good electrical and mechanical properties from deteriorating over time.

Signal Reference Structure (SRS)

On modern equipment communicating at high bandwidths, signals are typically differential and/or isolated electrically or optically. The modern SRS system replaces the older single-point grounding system with a much more robust system. The SRS system is also easier to install and maintain.

The goal of the SRS is to hold the electronics at or near case potential to prevent unwanted signals from disturbing operation. The following conditions must all be met by an SRS:

- Bonding connections to the SRS must be less than 1/20 wavelength of the highest frequency to which the equipment is susceptible. This prevents standing waves. In modern equipment using high-frequency digital electronics, frequencies as high as 500 MHz should be considered, which translates to about 30 mm (1in).
- SRS must be a good high frequency conductor. (Impedance at high frequencies consists primarily of distributed inductance and capacitance.) Surface area is more important than cross-sectional area because of skin effect. Conductivity is less important (steel with large surface area is better than copper with less surface area).
- SRS must consist of multiple paths. This lowers the impedance and the probability of wave reflections and resonance

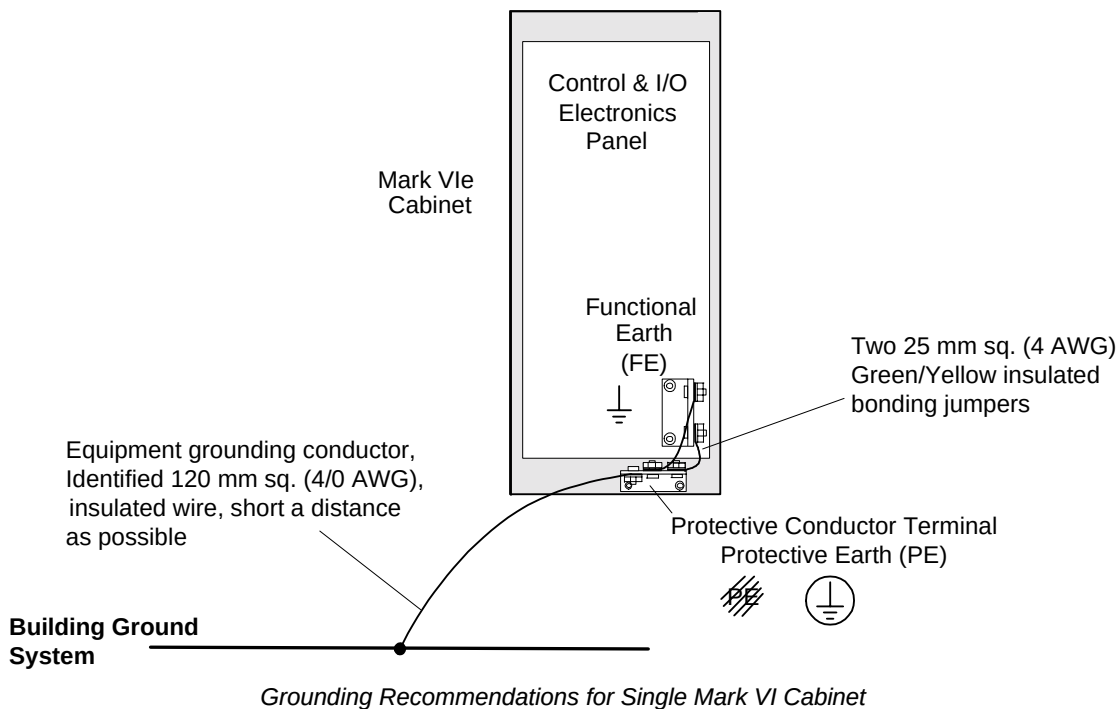
In general, a good signal referencing system can be obtained with readily available components in an industrial site. All of the items listed below can be included in an SRS:

- Metal building structural members
- Galvanized steel floor decking under concrete floors
- Woven wire steel reinforcing mesh in concrete floors
- Steel floors in pulpits and power control rooms
- Bolted grid stringers for cellular raised floors
- Steel floor decking or grating on line-mounted equipment
- Galvanized steel culvert stock
- Metallic cable tray systems
- Raceway (cableway) and raceway support systems
- Embedded steel floor channels

Note All provisions may not apply to an installation.

Connection of the protective earth terminal to the installation ground system must first comply with code requirements and second provide a low-impedance path for high-frequency currents, including lightning surge currents. This grounding conductor must not provide, either intentionally or inadvertently, a path for load current. The system should be designed such that in so far as is possible the control system is not an attractive path for induced currents from any source. This is best accomplished by providing a ground plane that is large and low impedance, so that the entire system remains at the same potential. A metallic system (grid) will accomplish this much better than a system that relies upon earth for connection. At the same time all metallic structures in the system should be effectively bonded both to the grid and to each other, so that bonding conductors rather than control equipment become the path of choice for noise currents of all types.

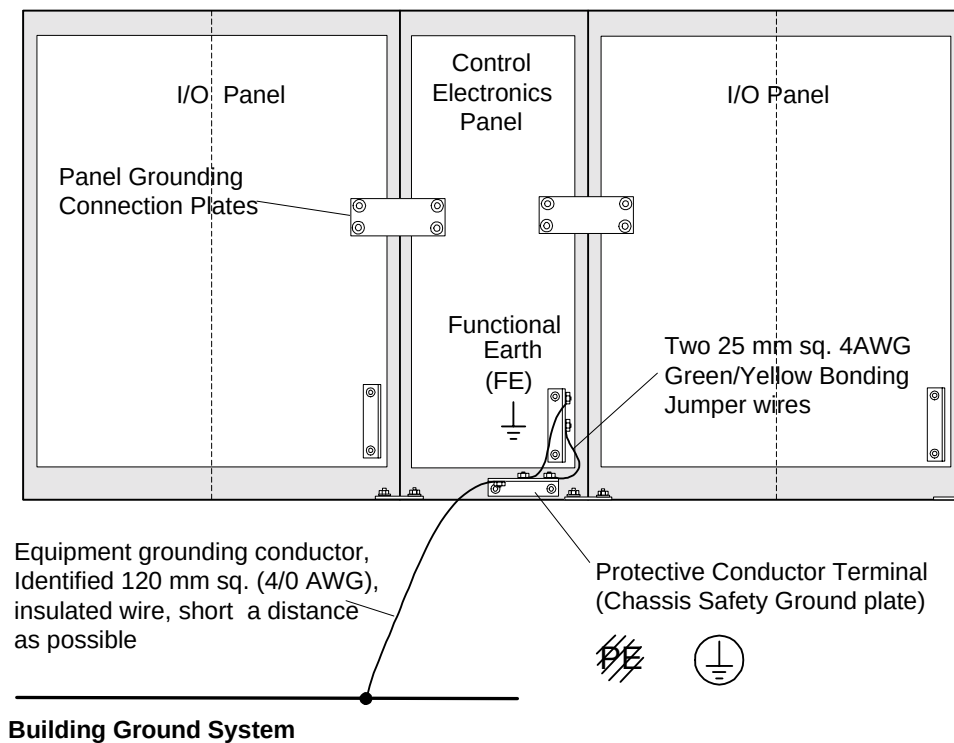
In the Mark VI cabinet, the electronics cabinet is insulated from the chassis and bonded at one point. The grounding recommendations shown in the following figure. Call for the equipment grounding conductor to be 120 mm² (AWG 4/0) gauge wire, connected to the building ground system. The Functional Earth (FE) is bonded at one point to the Protective Earth (PE) ground using two 25 mm² (4 AWG) green/yellow bonding jumpers.



If acceptable by local codes, the bonding jumpers may be removed and a 4/0 AWG identified insulated wire run from FE to the nearest accessible point on the building ground system, or to another ground point as required by the local code. The distance between the two connections to building ground should be approximately 4.6 m (15 ft), but not less than 3 m (10 ft).

Grounding for a larger system is shown in following figure. Here the FE is still connected to the control electronics section, but the equipment-grounding conductor is connected to the center cabinet chassis. Individual control and I/O panels are connected with bolted plates.

On a cable carrying conductors and/or shielded conductors, the armor is an additional current carrying braid that surrounds the internal conductors. This type cable can be used to carry control signals between buildings. The armor carries secondary lightning-induced earth currents, bypassing the control wiring, thus avoiding damage or disturbance to the control system. At the cable ends and at any strategic places between, the armor is grounded to the building ground through the structure of the building with a 360° mechanical and electrical fitting. The armor is normally terminated at the entry point to a metal building or machine. Attention to detail in installing armored cables can significantly reduce induced lightning surges in control wiring.



Grounding Recommendations for Mark VI Cabinet Lineup

Notes on Grounding

Bonding to building structure - The cable tray support system typically provides many bonding connections to building structural steel. If this is not the case, supplemental bonding connections must be made at frequent intervals from the cable tray system to building steel.

Bottom connected equipment - Cable tray installations for bottom connected equipment should follow the same basic principles as those illustrated for top connected equipment, paying special attention to good high frequency bonding between the cable tray and the equipment.

Cable spacing - Maintain cable spacing between signal levels in cable drops, as recommended here.

Conduit sleeves - Where conduit sleeves are used for bottom-entry cables, the sleeves should be bonded to the floor decking and equipment enclosure with short bonding jumpers.

Embedded conduits - Bond all embedded conduits to the enclosure with multiple bonding jumper connections following the shortest possible path.

Galvanized steel sheet floor decking - Floor decking can serve as a high frequency signal reference plane for equipment located on upper floors. With typical building construction, there will be a large number of structural connections between the floor decking and building steel. If this is not the case, then an electrical bonding connection must be added between the floor decking and building steel. These added connections need to be as short as possible and of sufficient surface area to be low impedance at high frequencies.

High frequency bonding jumpers - Jumpers must be short, less than 500 mm (20 in) and good high frequency conductors. Thin, wide metal strips are best with length not more than three times width for best performance. Jumpers can be copper, aluminum, or steel. Steel has the advantage of not creating galvanic half-cells when bonded to other steel parts.

Jumpers must make good electrical contact with both the enclosure and the signal reference structure. Welding is best. If a mechanical connection is used, each end should be fastened with two bolts or screws with star washers backed up by large diameter flat washers.

Each enclosure must have two bonding jumpers of short, random lengths. Random lengths are used so that parallel bonding paths are of different quarter wavelength multiples. Do not fold bonding jumpers or make sharp bends.

Metallic cable tray - System must be installed per NEC Article 318 with signal level spacing per the next section. This serve as a signal reference structure between remotely connected pieces of equipment. The large surface area of cable trays provides a low impedance path at high frequencies.

Metal framing channel - Metal framing channel cable support systems also serves as part of the signal reference structure. Make certain that channels are well bonded to the equipment enclosure, cable tray, and each other, with large surface area connections to provide low impedance at high frequencies.

Noise-sensitive cables - Try to run noise-sensitive cables tight against a vertical support to allow this support to serve as a reference plane. Cables that are extremely susceptible to noise should be run in a metallic conduit, preferably ferrous. Keep these cables tight against the inside walls of the metallic enclosure, and well away from higher-level cables.

Power cables - Keep single-conductor power cables from the same circuit tightly bundled together to minimize interference with nearby signal cables. Keep 3-phase ac cables in a tight triangular configuration.

Woven wire mesh - Woven wire mesh can serve as a high frequency signal reference grid for enclosures located on floors not accessible from below. Each adjoining section of mesh must be welded together at intervals not exceeding 500 mm (20 in) to create a continuous reference grid. The woven wire mesh must be bonded at frequent intervals to building structural members along the floor perimeter.

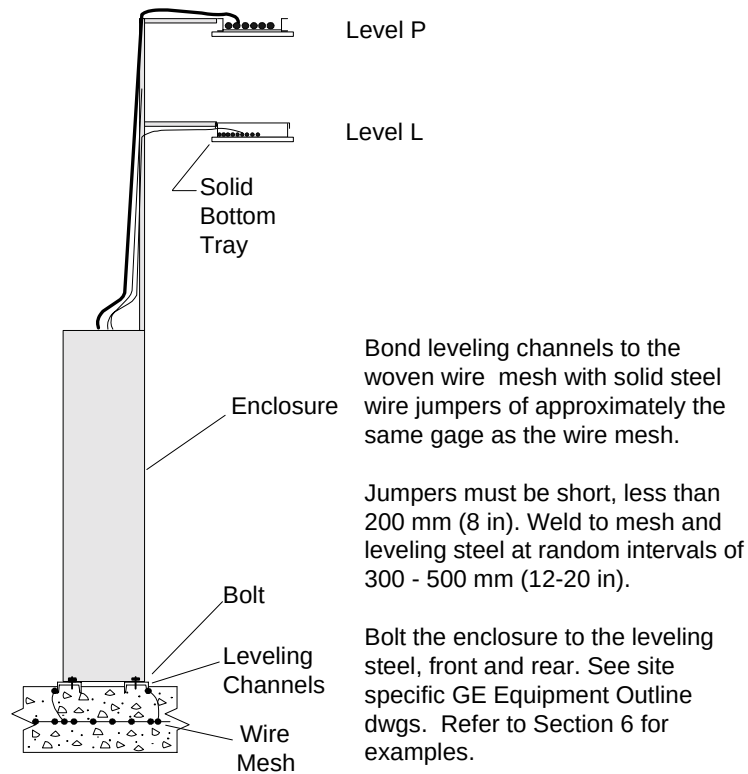
Conduit terminal at cable trays - To provide the best shielding, conduits containing level L cables (see Leveling channels) should be terminated to the tray's side rails (steel solid bottom) with two locknuts and a bushing. Conduit should be terminated to ladder tray side rails with approved clamps.

Where it is not possible to connect conduit directly to tray (such as with large conduit banks), conduit must be terminated with bonding bushings and bonded to tray with short bonding jumpers.

Leveling channels - If the enclosure is mounted on leveling channels, bond the channels to the woven wire mesh with solid-steel wire jumpers of approximately the same gauge as the woven wire mesh. Bolt the enclosure to leveling steel, front and rear.

Signal and power levels - See section, Cable Separation and Routing for guidelines.

Solid-bottom tray - Use steel solid bottom cable trays with steel covers for low-level signals most susceptible to noise.



Enclosure and Cable Tray Installation Guidelines

Cable Separation and Routing

This section provides recommended cabling practices to reduce electrical noise. These include signal/power level separation and cable routing guidelines.

Note Electrical noise from cabling of various voltage levels can interfere with microprocessor-based control systems, causing a malfunction. If a situation at the installation site is not covered in this document, or if these guidelines cannot be met, please contact GE before installing the cable.

Early planning enables the customer's representatives to design adequate separation of embedded conduit. On new installations, sufficient space should be allowed to efficiently arrange mechanical and electrical equipment. On revamps, level rules should be considered during the planning stages to help ensure correct application and a more trouble-free installation.

Signal/Power Level Definitions

Signal/power carrying cables are categorized into four defining levels: low, medium, high, and power. Each level can include classes.

Low-Level Signals (Level L)

Low-level signals are designated as level L. In general these consist of:

- Analog signals 0 through ± 50 V dc, <60 mA
- Digital (logic-level) signals less than 28 V dc
- 4 – 20 mA current loops
- Ac signals less than 24 V ac

The following are specific examples of level L signals used in the Mark VI cabling:

- All analog and digital signals including LVDTs, Servos, RTDs, Analog Inputs and Outputs, and Pyrometer signals
- Thermocouples are in a special category (Level LS) because they generate millivolt signals with very low current.
- Network communication bus signals: Ethernet, IONet, UDH, PDH, RS-232C, and RS-422
- Phone circuits

Note Signal input to analog and digital blocks or to programmable logic control (PLC)-related devices should be run as shielded twisted-pair (for example, input from RTDs).

Medium-Level Signals (Level M)

Medium-level signals are designated as level M. Magnetic pickup signals are examples of level M signals used in the Mark VI. These signals consist of:

- Analog signals less than 50 V dc with less than 28 V ac ripple and less than 0.6 A current
- 28 V dc light and switching circuits
- 24 V dc switching circuits
- Analog pulse rate circuits

Note Level M and level L signals may be run together only inside the control cabinet.

High-Level Signals (Level H)

High-level signals are designated as level H. These signals consist of:

- Dc switching signals greater than 28 V dc
- Analog signals greater than 50 V dc with greater than 28 V ac ripple
- Ac feeders less than 20 A, without motor loads

The following are specific examples of level H signals used in Mark VI cabling:

- Contact inputs
- Relay outputs
- Solenoid outputs
- PT and CT circuits

Note Flame detector (GM) type signals, 335 V dc, and Ultraviolet detectors are a special category (Level HS). Special low capacitance twisted shielded pair wiring is required.

Power (Level P)

Power wiring is designated as level P. This consists of ac and dc buses 0 – 600 V with currents 20 A – 800 A. The following are specific examples of level P signals used in plant cabling:

- Motor armature loops
- Generator armature loops
- Ac power input and dc outputs
- Primaries and secondaries of transformers above 5 kVA
- SCR field exciter ac power input and dc output
- Static exciters (regulated and unregulated) ac power and dc output
- 250 V shop bus
- Machine fields

Class Codes

Certain conditions can require that specific wires within a level be grouped in the same cable. This is indicated by class codes, defined as follows:

S Special handling of specified levels can require special spacing of conduit and trays. Check dimension chart for levels. These wires include:

- Signals from COMM field and line resistors
- Signals from line shunts to regulators

U High voltage potential unfused wires over 600 V dc

PS Power greater than 600 V dc and/or greater than 800 A

If there is no code, there are no grouping restrictions

Marking Cables to Identify Levels

It is good practice to mark the cableway cables, conduit, and trays in a way that clearly identifies their signal/power levels. This helps ensure correct level separation for proper installation. It can also be useful during equipment maintenance.

Cables can be marked by any means that makes the level easy to recognize (for example, coding or numbering). Conduit and trays should be marked at junction points or at periodic intervals.

Cableway Spacing Guidelines

Spacing (or clearance) between cableways (trays and conduit) depends on the level of the wiring inside them. For correct level separation when installing cable, the customer should apply the general practices along with the specific spacing values for tray/tray, conduit/tray, conduit/conduit, cable/conduit, and cable/cable distances as discussed below.

General Practices

The following general practices should be used for all levels of cabling:

- All cables of like signal levels and power levels must be grouped together in like cableways.
- In general, different levels must run in separate cableways, as defined in the different classes. Intermixing cannot be allowed, except as noted by exception.
- Interconnecting wire runs should carry a level designation.
- If wires are the same level and same type signal, group those wires from one cabinet to any one specific location together in multiconductor cables.
- When unlike signals must cross in trays or conduit, cross them in 90° angles at maximum spacing. Where it is not possible to maintain spacing, place a grounded steel barrier between unlike levels at the crossover point.
- When entering terminal equipment where it is difficult to maintain the specific spacing guidelines shown in the following tables, keep parallel runs to a minimum, not to exceed 1.5 m (5 ft) in the overall run.

- Where the tables show tray or conduit spacing as 0, the levels can be run together. Spacing for other levels must be based on the worst condition.
- Trays for all levels should be galvanized steel and solidly grounded with good ground continuity. Conduit should be metal to provide shielding.

The following general practices should be used for specific levels of cabling:

- When separate trays are impractical, levels L and M can be combined in a common tray if a grounded steel barrier separates levels. This practice is not as effective as tray separation, and may require some rerouting at system startup. If levels L and M are run side-by-side, a 50 mm (2-inch) minimum spacing is recommended.
- Locate levels L and M trays and conduit closest to the control panels.
- Trays containing level L and level M wiring should have solid galvanized steel bottoms and sides and be covered to provide complete shielding. There must be positive and continuous cover contact to side rails to avoid high-reluctance air gaps, which impair shielding.
- Trays containing levels other than L and M wiring can have ventilation slots or louvers.
- Trays and conduit containing levels L, M, and H(S) should not be routed parallel to high power equipment enclosures of 100 kV and larger at a spacing of less than 1.5 m (5 ft) for trays, and 750 mm (2-1/2 ft) for conduit.
- Level H and H(S) can be combined in the same tray or conduit but cannot be combined in the same cable.
- Level H(S) is listed only for information since many customers want to isolate unfused high voltage potential wires.
- Do not run levels H and H(S) in the same conduit as level P.
- Where practical for level P and/or P(S) wiring, route the complete power circuit between equipment in the same tray or conduit. This minimizes the possibility of power and control circuits encircling each other.

Tray and Conduit Spacing

The following tables show the recommended distances between metal trays and metal conduit carrying cables with various signal levels, and the cable-to-cable distance for non-metal conduit and trays.

Table 1. Spacing Between Metal Cable Trays, inches(mm)

Level	L	M	H	H(S)	P	P(S)
L	0	1(25)	6(150)	6(150)	26(660)	26(660)
M		0	6(150)	6(150)	18(457)	26(660)
H			0	0	8(302)	12(305)
H(S)				0	8(302)	12(305)
P					0	0
P(S)						0

Recommended minimum distances between trays from the top of one tray to the bottom of the tray above, or between the sides of adjacent trays.

Table 1 also applies if the distance between trays and power equipment up to 100 kVA is less than 1.5 m (5 ft).

Table 2. Spacing Between Metal Trays and Conduit, inches(mm)

Level	L	M	H	H(S)	P	P(S)
L	0	1(25)	4(102)	4(102)	18(457)	18(457)
M		0	4(102)	4(102)	12(305)	18(457)
H			0	0	4(102)	8(203)
H(S)				0	4(102)	8(203)
P					0	0
P(S)						0

Recommended minimum distance between the outside surfaces of metal trays and conduit.

Use Table 1 if the distance between trays or conduit and power equipment up to 100 kVA is less than 1.5 m (5 ft).

Table 3. Spacing Between Metal Conduit Runs, inches(mm)

Level	L	M	H	H(S)	P	P(S)
L	0	1(25)	3(76)	3(76)	12(305)	12(305)
M		0	3(76)	3(76)	9(229)	12(305)
H			0	0	3(76)	6(150)
H(S)				0	3(76)	6(150)
P					0	0
P(S)						0

Recommended minimum distance between the outside surfaces of metal conduit run in banks.

Table 4. Spacing Between Cable and Steel Conduit, inches(mm)

Level	L	M	H	H(S)	P	P(S)
L	0	2(51)	4(102)	4(102)	20(508)	48(1219)
M		0	4(102)	4(102)	20(508)	48(1219)
H			0	0	12(305)	18(457)
H(S)				0	12(305)	18(457)
P					0	0
P(S)						0

Recommended minimum distance between the outside surfaces of cables and metal conduit.

Table 5. Spacing Between Cable and Cable, inches(mm)

Level	L	M	H	H(S)	P	P(S)
L	0	2(51)	6(150)	6(150)	28(711)	84(2134)
M		0	6(150)	6(150)	28(711)	84(2134)
H			0	0	20(508)	29(737)
H(S)				0	20(508)	29(737)
P					0	0
P(S)						0

Recommended minimum distance between the outside surfaces of cables.

Cable, Tray, and Conduit Spacing

Cable Routing Guidelines

Pullboxes and Junction Boxes

Keep signal/power levels separate inside pullboxes and junction boxes. Use grounded steel barriers to maintain level spacing. Tray-to-conduit transition spacing and separation are a potential source of noise. Be sure to cross unlike levels at right angles and maintain required separation. Protect transition areas per the level spacing recommendations.

Transitional Areas

When entering or leaving conduit or trays, make sure that cables of unlike levels do not intermix. If the installation needs parallel runs over 1.5 m (5 ft), grounded steel barriers may be needed for proper level separation.

Cabling for Retrofits

Reducing electrical noise on retrofits requires careful planning. Lower and higher levels should never encircle each other or run parallel for long distances. It is practical to use existing conduit or trays as long as the level spacing can be maintained for the full length of the run. Existing cables are generally of high voltage potential and noise producing. Therefore, route levels L and M in a path apart from existing cables when possible. Use barriers in existing pullboxes and junction boxes for level L wiring to minimize noise potential. Do not loop level L signals around high control or level P conduit or trays.

Conduit Around and Through Machinery Housing

Care should be taken to plan level spacing on both embedded and exposed conduit in and around machinery. Runs containing mixed levels should be minimized to 1.5 m (5 ft) or less in the overall run. Conduit running through and attached to machinery housing should follow level spacing recommendations. This should be discussed with the contractor early in the project.

Trunnions entering floor mounted operator station cabinets should be kept as short as possible when used as cableways. This helps minimize parallel runs of unlike levels to a maximum of 1.5 m (5 ft) before entering the equipment. Where different signal/power levels are running together for short distances, each level should be connected by cord ties, barriers, or some logical method. This prevents intermixing.

RF Interference

To prevent radio frequency (RF) interference, take care when routing power cables in the vicinity of radio-controlled devices (for example, cranes) and audio/visual systems (public address and closed-circuit television).

Suppression

Unless specifically noted otherwise, suppression (for example, a snubber) is required on all inductive devices controlled by an output. This suppression minimizes noise and prevents damage caused by electrical surges. Standard Mark VI relay and solenoid output boards have suppression.

Cable Specifications

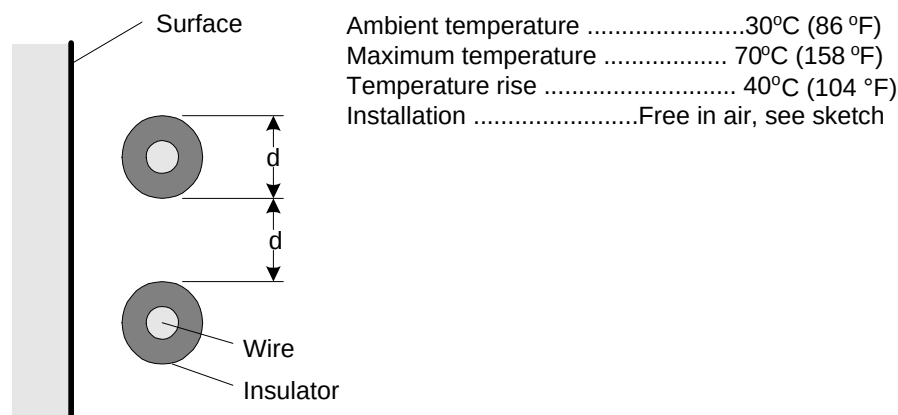
Wire Sizes

The recommended current carrying capacity for flexible wires up to 1,000 V, PVC insulated, based on DIN VDE 0298 Part 4, is shown in following table. Cross section references of mm² versus AWG are based on EN 60204 Part 1, VDE 0113 Part 1. NFPA 70 (NEC) may require larger wire sizes based on the type of wire used.

Current Amp	Cross Section Area (mm ²)	Wire Size AWG No.	Circular mils
15	0.75		
	0.82	18	
19	1		
	1.31	16	
24	1.5		
	2.08	14	
32	2.5		
	3.31	12	
42	4		
	5.26	10	
54	6		
	8.36	8	
73	10		
	13.3	6	
98	16		
	21.15	4	
129	25		
	33.6	2	
158	35		69,073
	42.4	1	
198	50		92,756
	53.5	1/0	
	67.4	2/0	
245	70		138,146
	85	3/00	
292	95		187,484
	107	4/00	
344	120		236,823
391	150		296,000
448	185		365,102
528	240		473,646
608	300		592,057
726	400		789,410

General Specifications

- Maximum length (unless specified) 300 m (1000 ft)
- Individual minimum stated wire size is for electrical needs
- Clamp-type terminals accept two 14 AWG wires or one 12 AWG wire
- Mark VI terminal blocks accept two 12 AWG wires
- PTs and CTs use 10 AWG stranded wire



It is standard practice to use shielded cable with control equipment. Shielding provides the following benefits:

- Generally, shielding protects a wire or grouping of wires from its environment.
- Because of the capacitive coupling effect between two sources of potential energy, low-level signals may require shielding to prevent signal interference.

Low Voltage Shielded Cable

This section defines minimum requirements for low voltage shielded cable. These guidelines should be used along with the level practices and routing guidelines provided previously.

Note The specifications listed are for sensitive computer-based controls. Cabling for less sensitive controls should be considered on an individual basis.

Single-Conductor Shielded Cable, Rated 300 V

- 18 AWG minimum, stranded single-conductor insulated with minimum 85% to 100% coverage shield
- Protective insulating cover for shield
- Wire rating: 300 V minimum
- Maximum capacitance between conductor and shield: 492 pF/m (150 pF/ft)

Multi-conductor Shielded Cable, Rated 300 V

- 18 AWG minimum, stranded conductors individually insulated per cable with minimum 85% to 100% coverage shield
- Protective insulating cover for shield
- Wire rating: 300 V minimum
- Mutual capacitance between conductors with shield grounded: 394 pF/m (120 pF/ft) maximum
- Capacitance between one conductor and all other conductors and grounded shield: 213 pF/m (65 pF/ft)

Shielded Twisted-Pair Cable, Rated 300 V

- Two 18 AWG minimum, stranded conductors individually insulated with minimum 85% to 100% coverage shield
- Protective insulating cover for shield
- Wire rating: 300 V minimum
- Mutual capacitance between conductors with shield grounded: 394 pF/m (120 pF/ft) maximum
- Capacitance between one conductor and the other conductor and grounded shield: 213 pF/m (65 pF/ft) maximum

Coaxial Cable RG-58/U (for IONet and UDH)

- 20 AWG stranded tinned copper conductor with FEP insulation with a 95% coverage braid shield
- Protective Flamarrest insulating jacket for shield
- Normal attenuation per 30.48 m (100 ft): 4.2 dB at 100 MHz
- Nominal capacitance: 50.5 pF/m (25.4 pF/ft)
- Nominal impedance: 50 Ω
- Example supplier: Belden Coax Cable no. 82907

UTP Cable (for Data Highways)

- High quality, category 5 UTP cable, for 10BaseTX Ethernet
- Four pairs of twisted 22 or 24 AWG wire
- Protective plastic jacket
- Impedance: 75 – 165 Ω
- Connector: RJ45 UTP connector for solid wire

RS-232C Communications

- Modbus communication from the HMI: for short distances use RS-232C cable; for distances over 15 m (50 feet) add a modem
- Modbus communication from the controller COM2 port: for use on small systems, RS-232C cable with Micro-D adapter cable (GE catalog No. 336A4929G1). For longer distances over 15 m (50 feet), add a modem.

Note For more information on Modbus and wiring, refer to Chapter 3, *Networks*.

Instrument Cable, 4 – 20 mA

- With Tefzel® insulation and jacket: Belden catalog no. 85231 or equivalent
- With plastic jacket: Belden catalog no. 9316 or equivalent

Note Belden refers to the Belden Wire & Cable Company, a subsidiary of Belden, Inc.

Fiber-optic Cable, Outdoor Use (Data Highways)

- Multimode fiber, 62.5/125 micron core/cladding, 850 nm infra-red light
- Four sub-cables with elastomeric jackets and aramid strength members, and plastic outer jacket
- Cable construction: flame retardant pressure extruded polyurethane, Cable diameter: 8.0 mm, Cable weight: 65 kg/km
- Optical Cable Corporation Part No. RK920929-A

Fiber-Optic Cable, Heavy Duty Outdoor Use

- Multimode fiber, 62.5/125 micron core/cladding, 850 nm infra-red light
- Four sub-cables with elastomeric jackets and aramid strength members, and armored outer jacket
- Cable construction: flame retardant pressure extruded polyurethane. Armored with 0.155 mm steel tape, wound with 2 mm overlap, and covered with polyethylene outer jacket, 1 to 1.5 mm thick. Cable diameter: 13.0 mm, Cable weight: 174 kg/km
- Optical Cable Corporation Part No. RK920929-A-CST

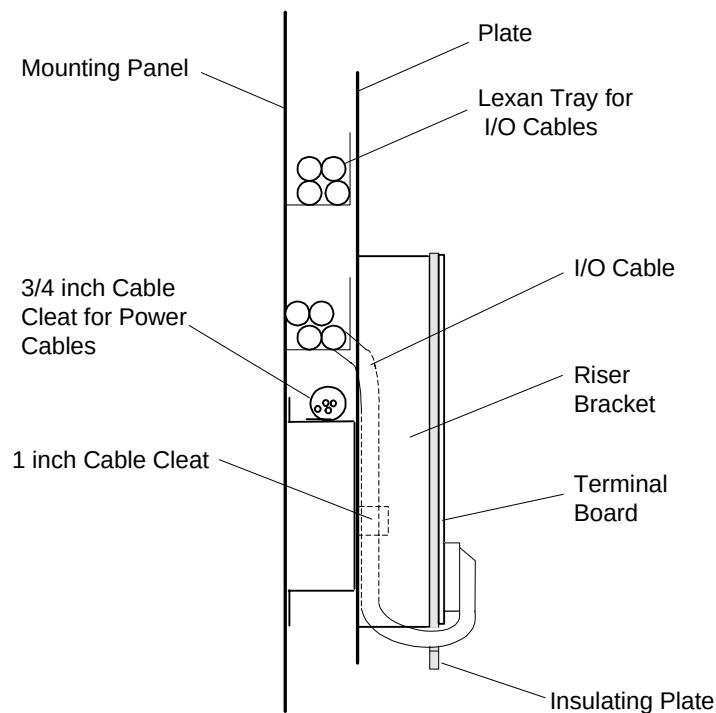
Fiber-Optic Cable, Indoor Use (Data Highways)

- Multimode fiber, 62.5/125 micron core/cladding, 850 nm infra-red light
- Twin plastic jacketed cables (Zipcord) for indoor use
- Cable construction: tight-buffered fibers surrounded by aramid strength members with a flexible flame retardant jacket
Cable dimensions: 2.9 mm dia x 5.8 mm width, Cable weight: 15 kg/km
- Siecor Corporation Part No. 002K58-31141

Connecting the System

The panels come complete with the internal cabling. This cabling will probably never need to be replaced. I/O cables between the control modules and interface modules and the I/O racks are run in plastic racks behind the mounting plates as shown in the following figure.

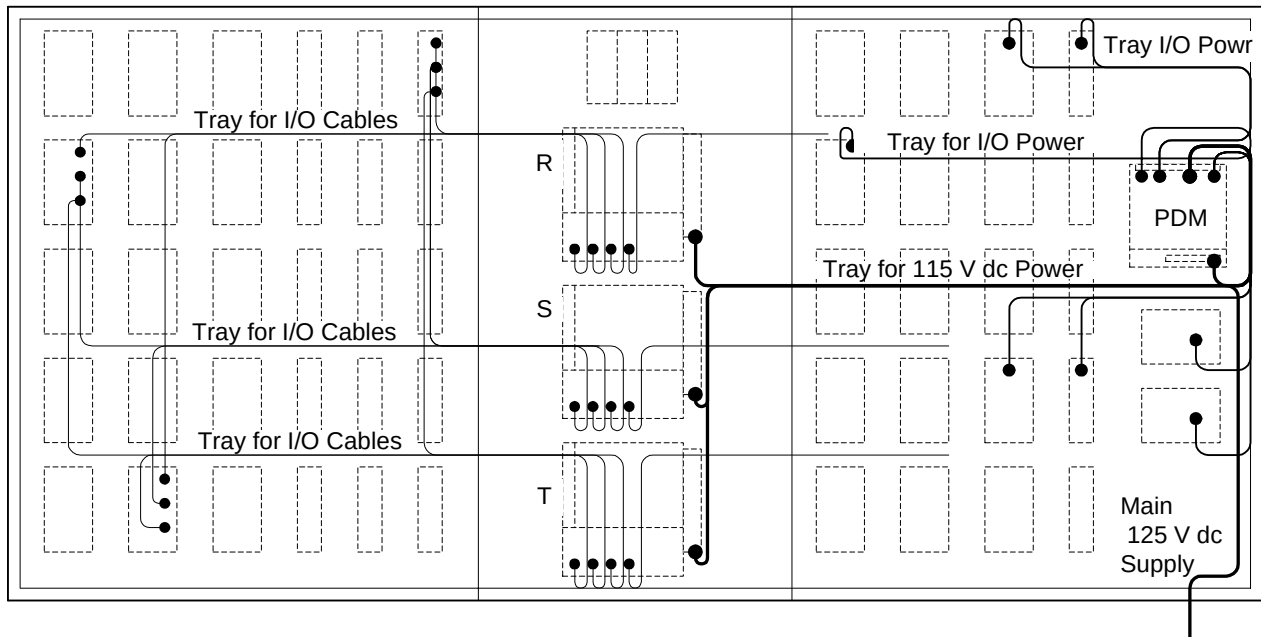
Power cables from the Power Distribution Module to the control modules, interface modules, and terminal boards are secured by plastic cable cleats located behind the riser brackets. Most of this cabling is covered by the mounting brackets and plates.



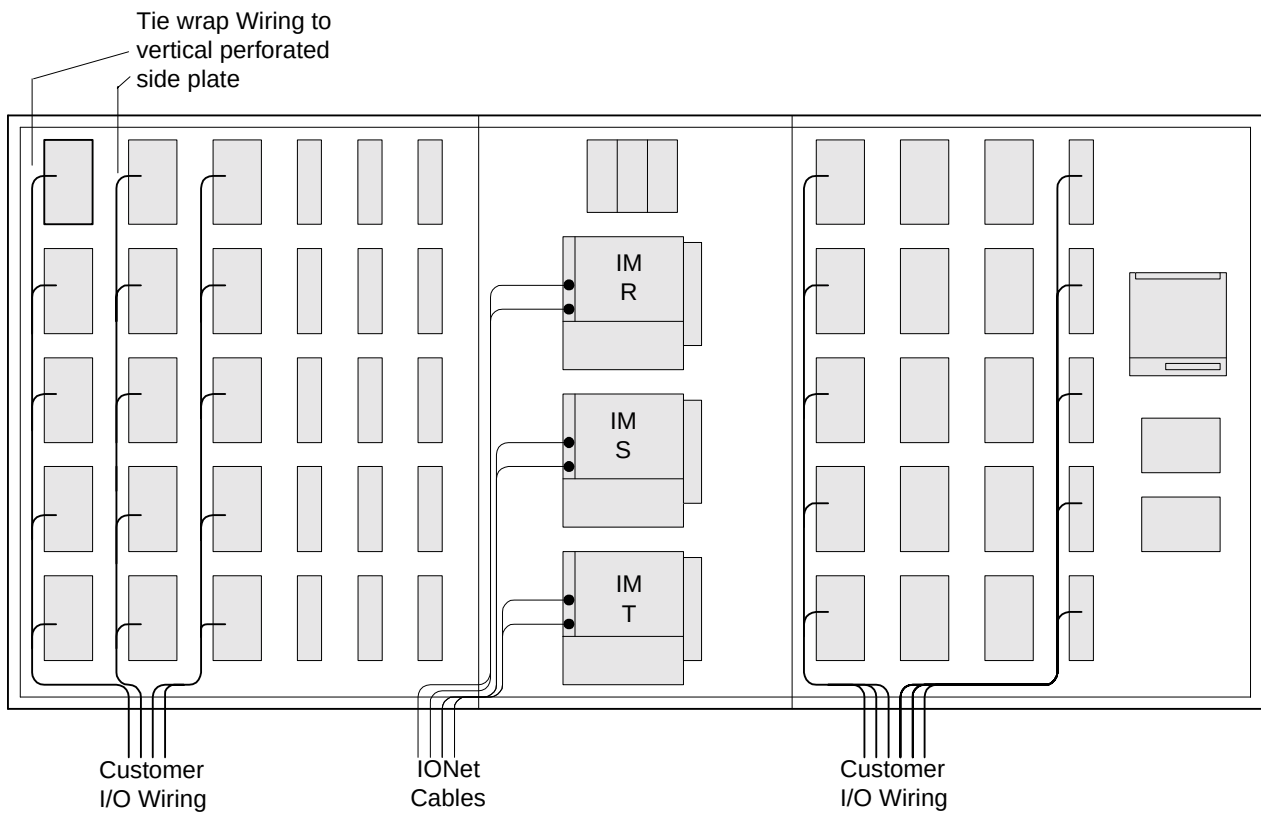
Cable Trays and Mounting Brackets for Terminal Boards

The upper diagram in the following figure shows routing of the I/O cables and power cables in a typical 1600 mm cabinet line-up. Dotted outlines show where terminal boards and I/O modules will be mounted on top. These cables are not visible from the front.

The following figure shows routing of IONet cables and customer field wiring to the I/O modules and terminal boards. This wiring is visible and accessible from the front so that boards and field wiring can be replaced.



Typical Power and I/O Cabling Behind Mounting Brackets

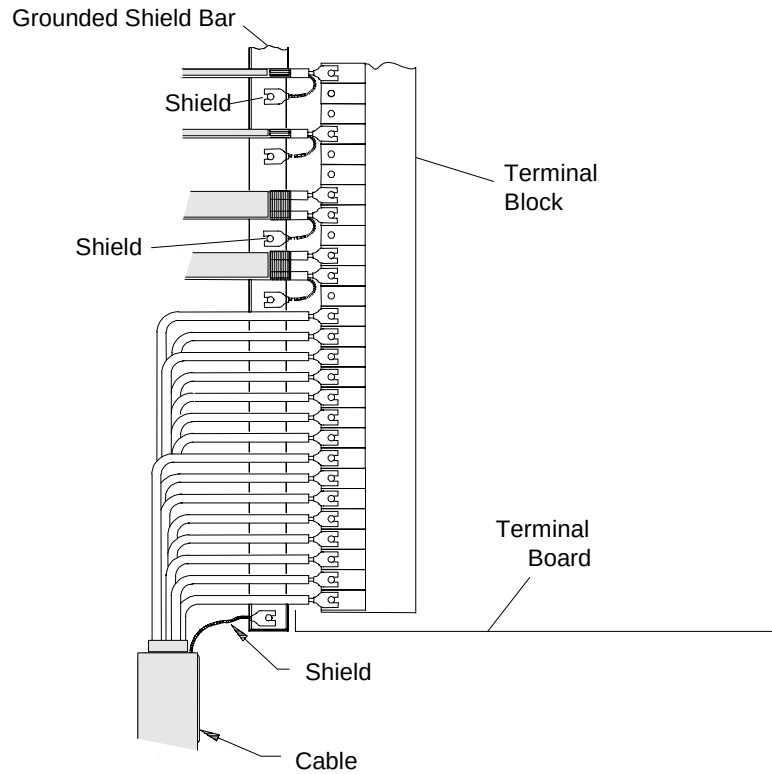


Typical Communication and Customer I/O Wiring in Front of Mounting Brackets

Typical Cabinet Wiring and Cabling

I/O Wiring

I/O connections are made to terminal blocks on the Mark VI terminal boards. The various terminal boards and types of I/O devices used are described in Volume II of the system guide. Shielding connections to the shield bar located to the left of the terminal board is shown in the following figure below.



I/O Wiring Shielding Connections to Ground Bar at Terminal Board

The grounded shield bars provide an equipotential ground plane to which all cable shield drain wires should be connected, with as short a *pigtail* as practical. The length should not exceed 5 cm (2 in) to reduce the high-frequency impedance of the shield ground. Reducing the length of the pigtail should take precedence over reducing the length of exposed wire within the cabinet. Pigtails should not be connected except at the grounding bars provided, to avoid loops and maintain a radial grounding system. Shields should be insulated up to the pigtail. In most cases shields should not be connected at the far end of the cable, to avoid circulating power-frequency currents induced by pickup.

A small capacitor may be used to ground the far end of the shield, producing a *hybrid ground system*, and may improve noise immunity. Shields must continue across junction boxes between the control and the turbine, and should match up with the signal they are shielding. Avoid hard grounding the shield at the junction boxes, but small capacitors to ground at junction boxes may improve immunity.

Terminal Block Features

Many of the terminal boards in the Mark VI use a 24-position pluggable barrier terminal block (179C9123BB). These terminal blocks have the following features:

- Made from a polyester resin material with 130°C (266 °F) rating
- Terminal rating is 300 V, 10 A, UL class C general industry, 0.375 in (9.525 mm) creepage, 0.250 in (6.35 mm) strike
- UL and CSA code approved
- Screws finished in zinc clear chromate and contacts in tin
- Each block screw is number labeled 1 through 24 or 25 through 48 in white
- Recommended screw tightening torque is 8 in lbs.

Power System

The 125 V dc supply must be installed and maintained such that it meets requirements of IEC 61010-1 cl. 6.3.1 to be considered Not Hazardous Live. The BJS berg jumper must be installed in the PDM to provide the monitored ground reference for the 125 V dc. If there are multiple PDMs connected to the dc mains, only one has the Berg jumper installed. If the dc mains are connected to a 125 V dc supply (battery) it must be floated, that is isolated from ground.

Note The DS200TCPD board in the PDM must provide the single, monitored, ground reference point for the 125 V dc system. Refer to section, *Wiring and Circuit Checks*.

Installing Ethernet

The Mark VI modules communicate over several different Ethernet LANs (refer to Chapter 3 *Networks*). IONet uses Ethernet 10Base2 cable. The data highways use a number of 10BaseT segments, and some 10Base2 segments and fiber-optic segments. These guidelines comply with IEEE 802.3 standards for Ethernet. For details on installing individual Ethernet LAN components, refer to the instructions supplied by the manufacturer of that equipment.

Installing Ethernet 10Base2 Coax Cable for IONet

10Base2 cable (Thinwire™) is a 20 AWG copper-centered wire used for connecting the interface modules and control modules. Use the following guidelines when installing 10Base2:

- The maximum length of a 10Base2 coax cable segment is 185 m (610 ft)
- Both ends of each segment should be terminated with a 50 Ω resistor
- All connectors and terminators must be isolated from ground to prevent ground loops (grounding of shield controlled by Mark VI boards)
- The maximum length of cable is 925 m (3035 ft) using the IEEE 5-4-3 rule
- Maximum length of a transceiver and repeater cable: 50 m (164 ft)
- Minimum distance between transceivers: 2.5 m (8.2 ft)
- Maximum device connections (taps) per segment: 100, including repeater taps
- In systems with repeaters, transceivers should have the SQE test (heartbeat) switch disabled

Preventing Reflections

Short segments should have no breaks with 50 Ω terminations on both ends. This produces minimal reflections from cable impedance discontinuities.

A coaxial barrel connector is used to join smaller segments. However, the joint between the two segments makes a signal reflection point. This is caused by impedance discontinuity from the batch-to-batch impedance tolerance of the manufactured cable. If cables are built from smaller sections, all sections should either come from the same manufacturer and lot, or with one of the IEEE recommended standard segment lengths.

Note Cables of non-standard length produce impedance mismatches that cause signal reflections and possible data loss.

IEEE standard segment lengths are:

23.4 m (76.75 ft) 117 m (383.76 ft)
70.2 m (230.25 ft) 500 m (1640 ft)

These standard sections can be used to build a cable segment up to 500 m (1640 ft) long. To prevent excessive reflections, the segment should be an odd multiple of 23.4 m (76.75 ft) lengths. For example:

3 x 23.4 m (or 3 x 76.75 ft)
7 x 23.4 m (or 7 x 76.75 ft)
9 x 23.4 m (or 9 x 76.75 ft)

These lengths are odd integral multiples of a half wavelength in the cable at 5 MHz. Any mix of these cable sections (only) can be used.

Ethernet Cable Component Descriptions

Component	Description	Part Number
10Base2 Connector	Connector for Ethernet 10Base2 trunk ThinWire coax cable	BNC coax connector with gold-plated pin, MilesTek catalog no. 10-02001-233 BNC F-Adapter, MilesTek catalog no. 10-02918 BNC Goal Post Adapter, MilesTek catalog no. 10-02914
10Base2 Terminator	BNC terminator for Ethernet trunk coax cable, 50 Ω	MilesTek catalog no. 10-02406-009
10Base2 Connection Tools	Quick crimp tool kit for crimping connectors on Ethernet trunk 10Base2 coax cable, including strip tool, flush cutter, and case.	MilesTek catalog no. 40-50156/GE

Startup Checks

All Mark VI control panels are pre-cabled and factory-tested before shipment. However, final checks should be made after installation and before starting the equipment.



This equipment contains a potential hazard of electrical shock or burn. Power is provided by the Mark VI control panel to various input and output devices. External sources of power may be present in the Mark VI panels that are NOT switched by the control power circuit breaker(s). Before handling or connecting any conductors to the equipment, use proper safety precautions to insure all power is turned off.

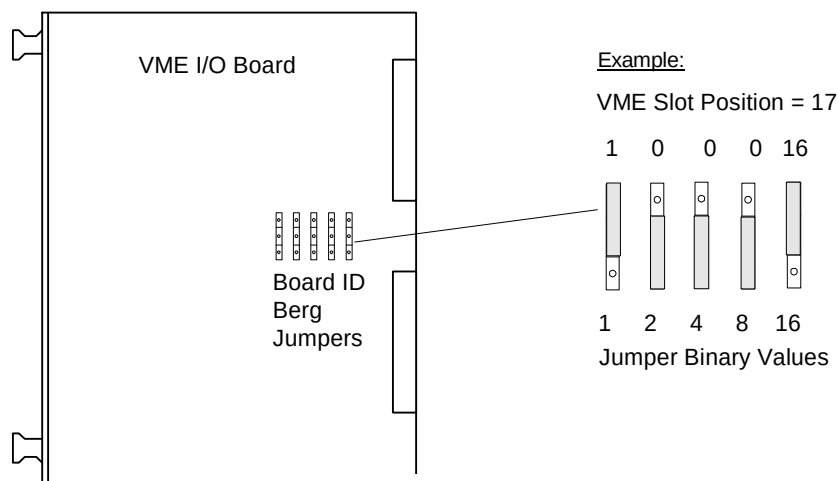
Inspect the control panel components for any damage, which might have occurred during shipping. Check for loose cables or wires, connections or loose components such as relays or retainer clips. Report any damage that may have occurred during shipping to GE Product Service.

Refer to section, *Grounding* for equipment grounding instructions.

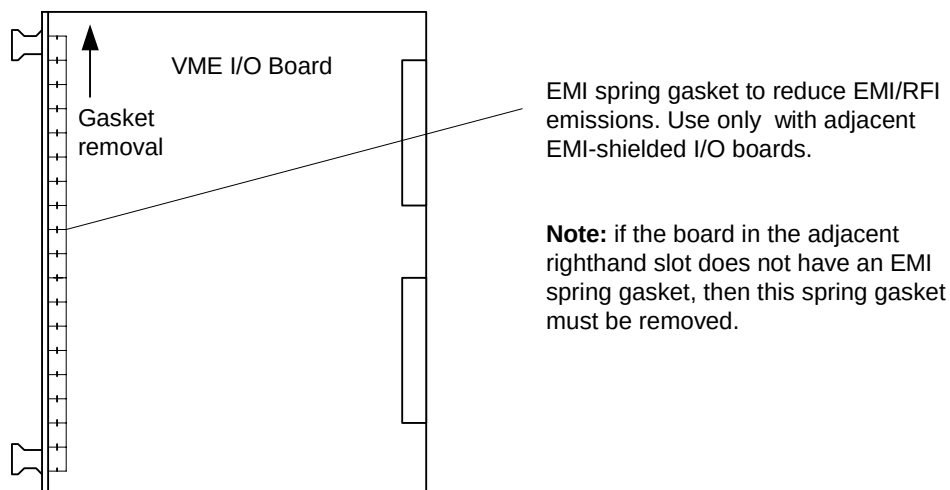
Board Inspections

Perform the following to inspect the printed circuit boards, jumpers, and wiring:

- Inspect the boards in each module checking for loose or damaged components.
- Verify the Berg jumpers on each I/O board are set correctly for the slot number in the VME rack (see the following figure). If the boards do not have Berg jumpers, then the VCMI identifies all the I/O boards during startup by communication over the VME backplane. At this point do not replug the I/O boards. This will be done after the rack power supply check.
- Check the EMI spring-gasket shield on the right hand side of the board front (see the following figure). If the installed boards do not have EMI emissions shielding, and a board with a shield gasket is present, remove this gasket by sliding it out vertically. Failure to do this could result in a damaged board.

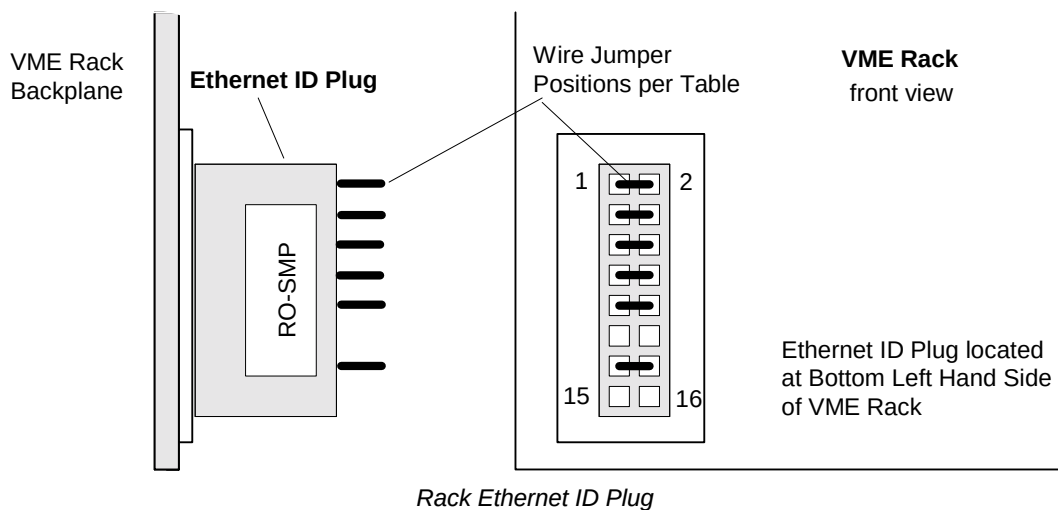


ID Jumper Positions on VME Board



EMI Emissions Shield Gasket

- Check wire harnesses and verify they are securely connected.
- Verify that the terminal board hardware jumpers match the toolbox configuration settings, and move the jumper(s) if necessary.
- Verify all plug-in relays are firmly inserted into their sockets (refer to Volume II of the system guide). Verify the jumpers on TRLY are removed.
- Check the Ethernet ID plug located at the left side of the rack under the power test points. The jumpers on this plug define the number of the rack (0, 1, 2, 3) in the IONet channel. The jumper positions are shown in the following figure.



Ethernet ID Plug Jumper Positions

Conn. P/N	Connector Label	Pins 1-2	Pins 3-4	Pins 5-6	Pins 7-8	Pins 9-10	Pins 11-12	Pins 13-14	Pins 15-16	Notes
10	R0-SMP	X	X	X	X	X		X		
11	R1		X	X	X	X		X		
12	R2	X		X	X	X		X		
13	R3			X	X	X		X		
14	R4	X	X		X	X		X		
15	R5		X		X	X		X		
16	R6	X			X	X		X		
17	R7				X	X		X		
18	R8	X	X	X		X		X		
19	R9		X	X		X		X		
20	R10	X		X		X		X		
21	R11			X		X		X		
22	R12	X	X			X		X		
23	R13		X			X		X		
Future										
28	R0-DPX	X	X	X	X	X	X			
29	R0-TPX	X	X	X	X	X				
30	R0-TMR	X	X	X	X	X		X	X	
Future										
40	S0-SMP	X	X	X	X	X	X			
41	S1		X	X	X	X	X			
42	S2	X		X	X	X	X			
43	S3			X	X	X	X			
44	S4	X	X		X	X	X			
45	S5									Future
46	S6									Future
47	S7									Future
48	S8	X	X	X		X	X			
Future										
60	S0-TMR	X	X	X	X	X	X		X	
Future										
70	T0-SMP	X	X	X	X	X				
71	T1		X	X	X	X				
72	T2	X		X	X	X				
73	T3			X	X	X				
74	T4	X	X		X	X				
75	T5									Future
76	T6									Future
77	T7									Future
78	T8	X	X	X		X				
Future										
90	T0-TMR	X	X	X	X	X			X	

Wiring and Circuit Checks



This equipment contains a potential hazard of electric shock or burn. Only personnel who are adequately trained and thoroughly familiar with the equipment and the instructions should install, operate, or maintain this equipment.

The following steps should be completed to check the cabinet wiring and circuits.

➤ To check the power wiring

- 1** Check that all incoming power wiring agrees with the supplied elementary drawings.
- 2** Make sure that the incoming power wiring conforms to approved wiring practices as described previously in this chapter.
- 3** Check that all electrical terminal connections are tight.
- 4** Make sure that no wiring has been damaged or frayed during installation. Replace if necessary.
- 5** Check that incoming power (125 V dc, 115 V ac, 230 V ac) is the correct voltage and frequency, and that it is clean and free of noise. Make sure the ac to dc converters, if used, are set to the correct voltage (115 or 230 V ac) by selecting the JTX1 or JTX2 jumper positions on the front of the converter.
- 6** If the installation includes more than one PDM on an interconnected 125 V dc system, the BJS jumper must be installed in one and only one PDM. This arrangement is required because the parallel connection of more than one ground reference circuit will reduce the impedance to the point where the 125 V dc no longer meets the Not Hazardous Live requirement.

To verify that the 125 V dc is properly grounded, a qualified person using appropriate safety procedures should make tests. Measure the current from first the P125 V dc, and then the N125 V dc, using a 2000 Ω , 10 W resistor to the protective conductor terminal of the Mark VI in series with a dc ammeter. The measured current should be 1.7 to 2.0 mA (the tolerance will depend on the test resistor and the PDM tolerances). If the measured current exceeds 2.0 mA, the system must be cleared of the extra ground(s). A test current of about 65 mA, usually indicates one or more hard grounds on the system, while currents in multiples of 1 mA usually indicate more than one BJS jumper is installed.

Note At this point the system is ready for initial energization.

Startup and Configuration



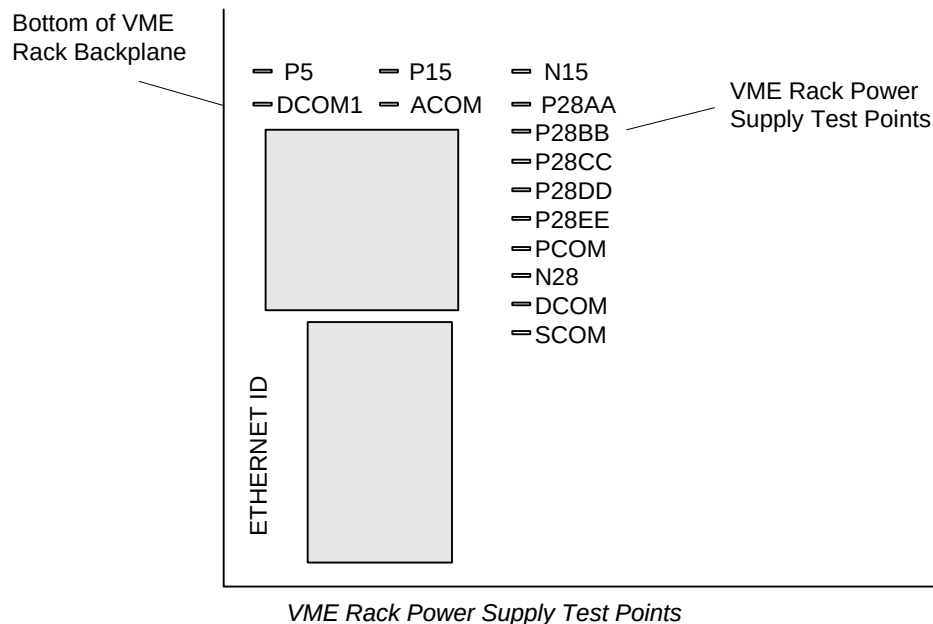
This equipment contains a potential hazard of electric shock or burn. Only personnel who are adequately trained and thoroughly familiar with the equipment and the instructions should install, operate, or maintain this equipment.

Assuming all the above checks are complete, use the following steps to apply power, load the application code, and startup the Mark VI system.

Note It is recommended that the initial rack energization be done with all the I/O boards removed to check the power supply in an unloaded condition.

➤ To energize the rack for the first time

- 1 Unlock the I/O boards and slide them part way out of the racks.
- 2 Apply power to the PDM and to the first VME I/O rack power supply.
- 3 Check the voltages at the test points located at the lower left side of the VME rack. These are shown in the following figure.
- 4 If the rack voltages check out, switch off the power supply, and carefully replace the boards in that rack.
- 5 Reapply power. All the I/O boards should flash green within five minutes displaying normal operation in the RUN condition.
- 6 Repeat steps 1-5 for all the racks.



If the system is a remote I/O system, the controller is in a separate rack. Apply power to this rack, wait for the controller and VCMI to boot up, and check that they are in the RUN condition. Check the VPRO modules, if present, to make sure all three are in the RUN condition.

Topology and Application Code Download

Network topology defines the location of the control and interface modules (racks) on the IONet network, and is stored in the VCMI.

Note If you have a new controller, before application code can be downloaded, the TCP/IP address must be loaded. Refer to *GEH-6403 Control System Toolbox for a Mark VI Controller* for details.

➤ To download topology and application code

- 1 From the toolbox Outline View, select the first VCMI (R0), and right click on it.
- 2 From the shortcut menu, select Download. The network topology configuration downloads to the Master VCMI in the first controller rack and now knows the location of the Interface Modules (R0, R1, R2, ...).
- 3 Repeat for all the Master VCMI's in the controller racks S, and T.
- 4 Cycle power to reboot all three controllers. The controllers reboot and initialize their VCMI's. The VCMI's expect to see the configured number of racks on IONet. If an Ethernet ID plug does not identify a rack, then communication with that rack is not possible. Similarly if a VCMI is not responding, then communication with that rack is not possible. The VCMI will work even if there are no I/O boards in its rack.
- 5 Following the above procedure, download the network topology to the slave VCMI in the I/O racks (R1, R2, R3 ...). The VCMI now knows what I/O boards are in its rack. Download to each rack in turn, or all racks at once.
- 6 Cycle power to reboot all racks.
- 7 Download the I/O configuration to all the I/O boards, one at a time or all at once. With all racks running you are now ready to check the I/O.

Online Download

When there are minor changes to the application code, the new code can be downloaded online using the toolbox. The advantage of online downloading is that it does not require restarting the controller (as in an offline download); the controllers continue to operate during and after the online download. The code is downloaded both to *memory* and *storage*.

Download Prerequisites

Before downloading new code, adhere to the following prerequisites to support continued turbine operation after the new code is downloaded.

- Diagnostic Messages and Alarms – Check the controller for diagnostic messages and alarms and do not download new code if any exist. Resolve and clear all diagnostic messages and alarms before downloading. Otherwise, the download may not proceed properly and cause the system to trip.

Note If conditions warrant downloading with existing diagnostic messages and alarms, record and examine every alarm message for potential failure modes and incident recovery after the controllers are powered up with the new code.

- Code Compatibility – Verify that the new code is compatible with the existing code and TMR interface to prevent inadvertent trips after the new code has been downloaded.
- Review TMR Test – Each time new code is downloaded, the TMR system must be tested online to verify that the new code is compatible, operates the system properly, and maintains TMR capability. Before beginning, review the records from the last TMR test from the previous download.

Performing an Online Download

➤ To perform an online download:

- 1 Refer to the section, *Download Prerequisites* and verify that these requirements have been met, prior to an online download.
- 2 From the toolbox, select the **Device** menu and select **Download, Application Code**

or

Click the **Download Application Code** button. The Download Application Code dialog box displays. The **Download to Memory** option and **Download to Storage** option are already checked by default indicating that the application code will be downloaded to memory and storage.

- 3 Click OK.
- 4 Perform the TMR Test from the procedures in the section, *Post-Download TMR Test*.

Offline Download

When there are major changes to the application code, the new code must be downloaded offline using the toolbox. An offline download consists of making a build image of the code, downloading the code, restarting the controller, and testing the TMR. The code is downloaded to storage.

➤ To perform an online download:

- 1 Refer to the section, *Download Prerequisites* and verify that these requirements have been met, prior to an offline download.
- 2 From the toolbox, select the **Device** menu and select **Download, Application Code**

or

Click the **Download Application Code** button. The Download Application Code dialog box displays. The **Download to Memory** option and **Download to Storage** option are already checked by default indicating that the application code will be downloaded to memory and storage.

- 3 Click OK.
- 4 Perform the TMR Test from the procedures in the section, *Post-Download TMR Test*.

Post-Download TMR Test

After downloading new code, test the TMR System online again to verify that the new code is compatible, operates the system properly, and maintains TMR capability. This test is required to assure online serviceability for continued system operation and trip reliability and prevent inadvertent hardware failures.

Prior to performing TMR testing, verify that the system is:

- Clear of all alarm messages
- Operational and could trip after a fault

➤ To perform the TMR test

- 1 Power down one controller/protective module at a time from the PDM. For R0, S0, T0, R8, S8, T8, and optional R7, S7, and T7 processors, power down one at a time in random order.
- 2 Wait 10 seconds, then power back up.
- 3 Wait for the processor to go back online.
- 4 Check for alarm messages.
- 5 Verify that there are no messages requesting a trip condition. Clear all alarm messages.
- 6 Once the system returns online, wait five minutes before powering down the next processor.

Controller Offline While System Online

Problem: After multiple online code downloads in the absence of TMR testing on previous downloads, including those with EGD page differences, one controller may remain offline while the other two controllers are online.

Corrective Action:

- Check and correct field wiring problems.
- Check the controller.
- Check compatibility of the application code with the TMR function.
- If there are no field wiring or code incompatibility problems, perform the following recovery procedure (which will keep the system running and protected):

➤ **To perform the recovery procedure:**

- 1** Power down the controller which is offline.
- 2** Download code to permanent storage as well as to memory of the powered-down controller.
- 3** Perform the TMR test as instructed in the section, Post-Download TMR Test.
- 4** Power up the controller. This controller should now come online with the other two controllers, running the new downloaded code that is compatible with the old code on the other two controllers.
- 5** Allow the restored online controller to run. at least 5 minutes.
- 6** Verify that there are no diagnostic messages or alarms.
- 7** Repeat this recovery procedure, one at a time on the remaining two controllers.

Offline Trip Analysis

Problem: System tripped – the usual cause is an application code issue (since the standard product has passed TMR testing). Corrective Action:

- 1** Review all alarm and trip logs.
- 2** If trip logs are unavailable, use the Trend Recorder to upload the individual capture block data from the controllers as follows:
 - a. From toolbox, select the File menu and New.
 - b. From the Utilities List, select Trend Recorder.
 - c. From the Trend Recorder, select the Edit menu and Configure. The Trend Recorder dialog box displays.
 - d. Under Trend Type, select Block Collected.
 - e. Select the Block Collected device and Capture Buffer.
 - f. Select each signal and upload.

As a result, approximately five trend files will be produced per controller.

- 3** Analyze the trip to determine the cause.
- 4** Correct the cause of the trip.

Notes

Chapter 6 Tools and System Interface

Toolbox	6-1
CIMPLICITY HMI	6-4
Computer Operator Interface (COI)	6-7
Turbine Historian	6-8

Introduction

This chapter summarizes the tools used for configuring, loading, and operating the Mark VI system. These include the Control System Toolbox (toolbox), CIMPLICITY HMI operator interface, and the Turbine Historian.

Toolbox

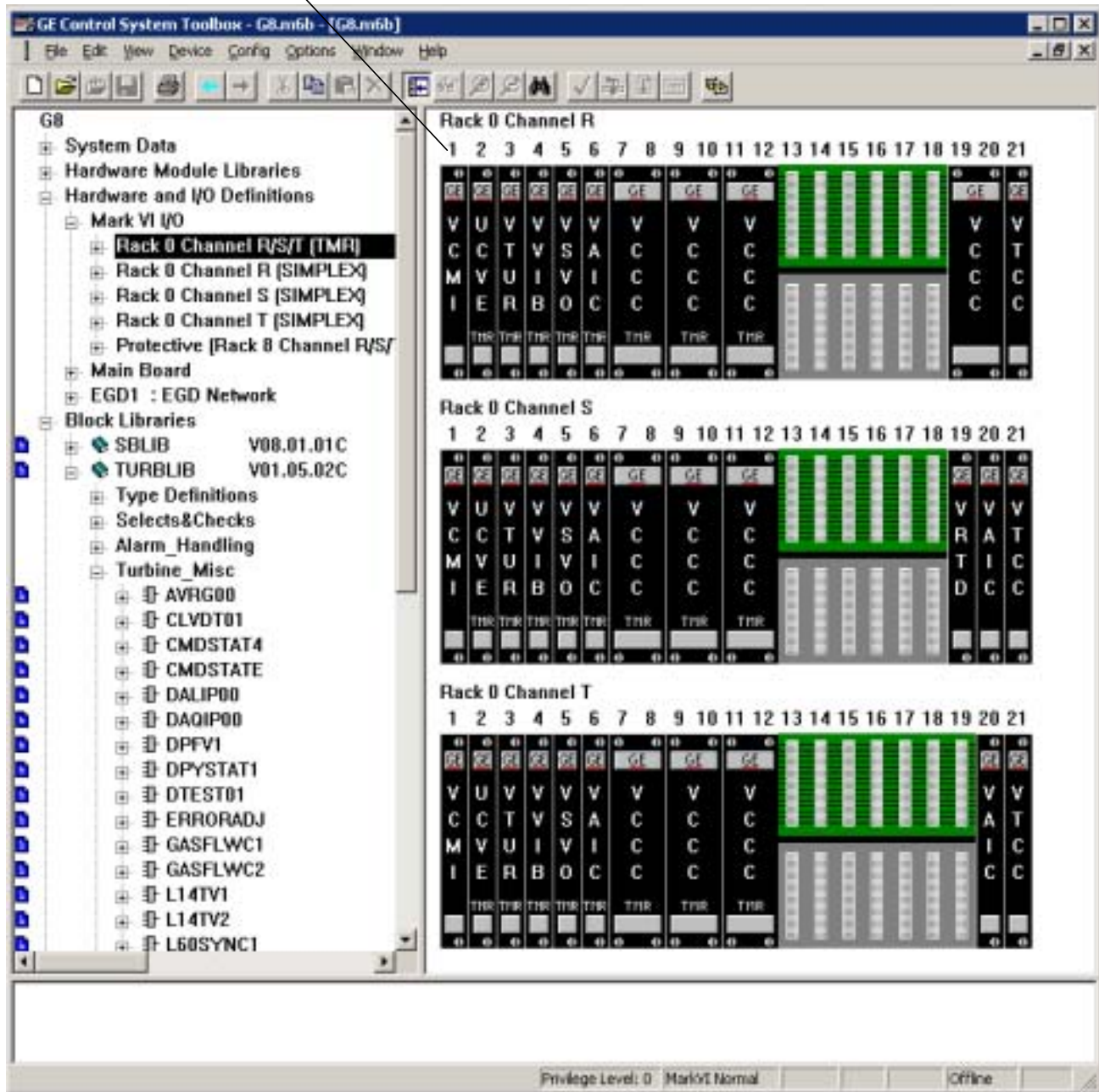
The toolbox is Windows®-based software for configuring and maintaining the Mark VI control system. The software usually runs on an engineering workstation or a CIMPLICITY HMI located on the Plant Data Highway. For details refer to GEH-6403, *Control System Toolbox for a Mark VI Controller*.

IONet communicates with all the control and interface racks. This network topology is configured using the toolbox. Similarly, the toolbox configures all the I/O boards in the racks and the I/O points in the boards. the following figure displays the toolbox screen used to select the racks.

The Outline View on the left side of the screen is used to select the racks required for the system. This view displays all the racks inserted under Mark VI I/O. In the example, three TMR Rack 0s are included under the heading *Rack 0 Channel R/S/T (TMR)*.

Click on the TMR rack in the Outline View (Rack 0 in this example) to view all the channels at the same time in the Summary View.

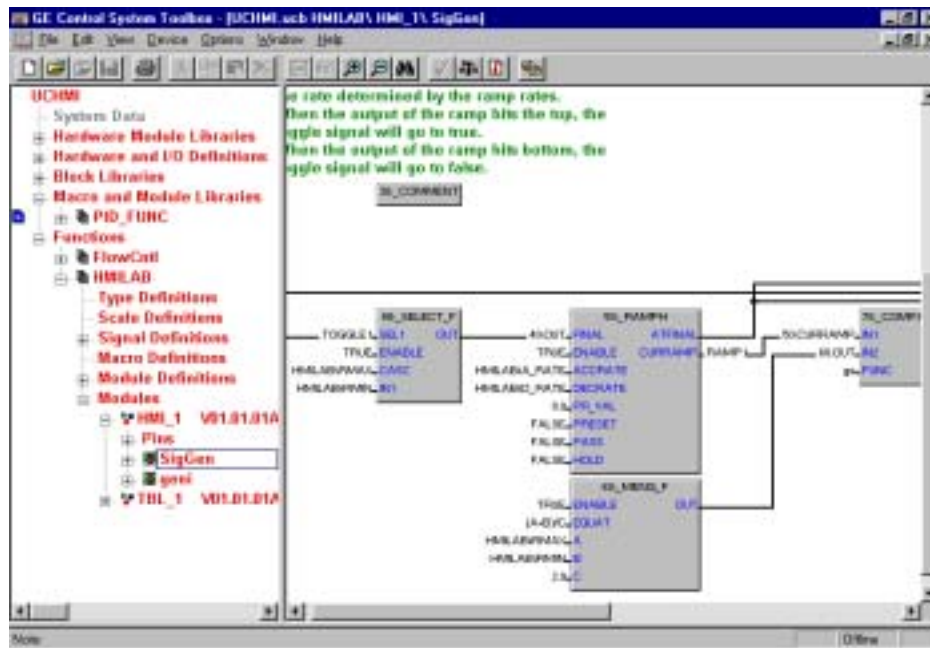
The Summary View displays a graphic of each rack and all the boards they contain.



Configuring the Equipment Racks

The turbine control application is configured in the toolbox using graphically connected control blocks, which display in the Summary View. These blocks consist of basic analog and discrete functions and a library of special turbine control blocks. The Standard Block library contains over 60 different control blocks designed for discrete and continuous control applications. Blocks provide a simple graphical way for the engineer to configure the control system. The turbine block library contains more than 150 additional blocks relating to turbine control applications.

The control system is configured in the toolbox work area, displayed in the following figure. The Outline View on the left side of the screen displays the control device. The Summary View on the right side of the screen displays the graphical configuration of the selected item. Block inputs and outputs are connected with signals to form the control configuration. These connections are created by dragging and dropping a signal from a block output to another block input. The connected blocks form macros, and at a higher level, the blocks and macros form tasks covering major sections of the complete control.



Connecting Control Blocks in the Work Area

CIMPLICITY HMI

The CIMPLICITY Human-Machine Interface (HMI) is the main operator interface to the Mark VI turbine control system. HMI is a computer with a Windows operating system and CIMPLICITY graphics display system, communicating with the controllers over Ethernet.

For details refer to *GEH-6126, HMI Application Guide*. Also refer to *GFK-1180, CIMPLICITY HMI for Windows NT and Windows 95 User's Manual*. For details on how to configure the graphic screens refer to *GFK-1396 CIMPLICITY HMI for Windows NT and Windows 95 CimEdit Operation Manual*.

Basic Description

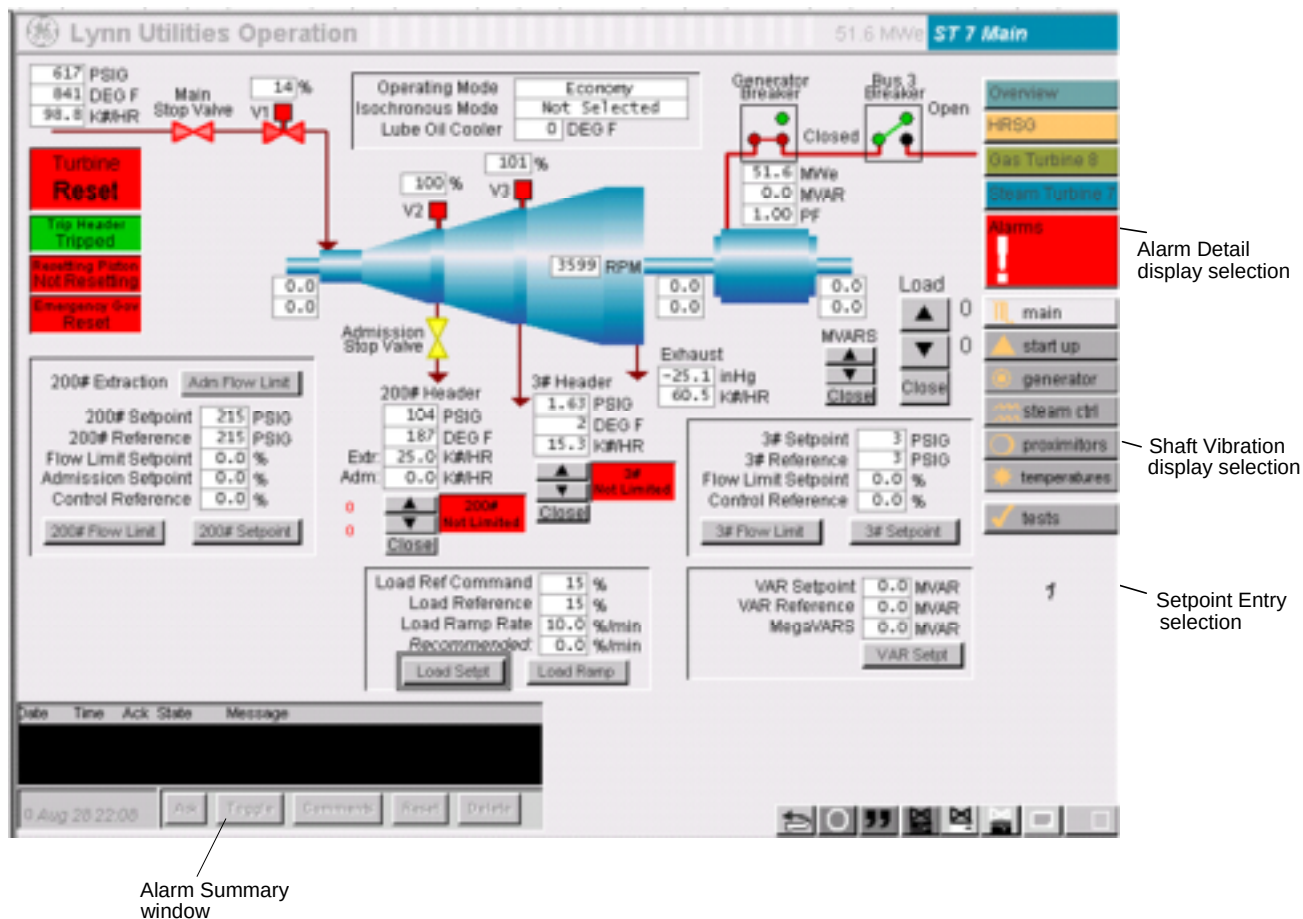
The Mark VI HMI consists of three distinct elements:

HMI server is the hub of the system, channeling data between the UDH and the PDH, and providing data support and system management. The server also provides device communication for both internal and external data interchanges.

System database establishes signal management and definition for the control system, provides a single repository for system alarm messages and definitions, and contains signal relationships and correlation between the controllers and I/O. The database is used for system configuration, but not required for running the system.

HMI viewer provides the visual functions, and is the client of the server. It contains the operator interface software, which allows the operator or maintenance personnel to view screen graphics, data values, alarms, and trends, as well as issue commands, edit control coefficient values, and obtain system logs and reports.

Depending on the size of the system, these three elements can be combined into a single computer, or distributed in multiple units. The modular nature of the HMI allows units to be expanded incrementally as system needs change. A typical Viewer screen using graphics and real-time turbine data is displayed in the following figure. In the graphic display, special displays can be obtained using the buttons in the column on the right side. Also note the setpoint button for numeric entry and the raise/lower arrows for opening and closing valves.



Interactive Operator Display for Steam Turbine & Generator

Product Features

The HMI contains a number of product features important for power plant control:

- Dynamic graphics
- Alarm displays
- Process variable trending
- Point control display for changing setpoints
- Database logger
- HMI access security
- Data Distribution Equipment (DDE) application interface

The graphic system performs key HMI functions and provides the operator with real time process visualization and control using the following:

CimEdit is an object-oriented program that creates and maintains the user graphic screen displays. Editing and animation tools, with the familiar Windows environment, provide an intuitive, easy to use interface. Features include:

- Standard shape library
- Object Linking and Embedding (OLE)
- Movement and rotation animation
- Filled object capabilities, and interior and border animation

CimView is the HMI run-time portion, displaying the process information in graphical formats. In CimView, the operator can view the system screens, and screens from other applications, using OLE automation, run scripts, and get descriptions of object actions. Screens have a 1-second refresh rate, and a typical graphical display takes 1second to repaint.

Alarm Viewer provides alarm management functions such as sorting and filtering by priority, by unit, by time, or by source device. Also supported are configurable alarm field displays, and embedding dynamically updated objects into CimView screens.

Trending, based on Active X technology, gives user's data analysis capabilities. Trending uses data collected by the HMI or data from other third-party software packages or interfaces. Data comparisons between current and past variable data can be made for identification of process problems. Trending includes multiple trending charts per graphic screen with unlimited pens per chart, and the operator can resize or move trend windows to convenient locations on the display.

The point control cabinet provides a listing of points in the system with real-time values and alarm status. Operators can view and change local and remote set points using the up/down arrows or by direct numeric entry. Alarms can be enabled and disabled, and alarm limits modified by authorized personnel.

The basic control engine allows users to define control actions in response to system events. A single event can invoke multiple actions, or one action can be invoked by many events. The program editor uses a Visual Basic for Applications compliant programming language.

Optional features include the Web Gateway that allows operators to access HMI data from anywhere in the world over the Internet. Third party interfaces allow the HMI to exchange data with distributed control systems (DCS), programmable logic controllers, I/O devices, and other computers.

Computer Operator Interface (COI)

The Computer Operator Interface (COI) consists of a set of product and application specific operator displays running on a small cabinet computer (10.4 or 12.1 inch touch screen) hosting the Embedded Windows operating system. This operating system uses only the components of the operating system required for a specific application. This results in all the power and development advantages of a Windows operating system. Development, installation or modification of requisition content requires the GE Control System Toolbox (toolbox). For details, refer to *GEH-6403, Control System Toolbox for a Mark VI Controller*.

The COI can be installed in many different configurations, depending on the product line and specific requisition requirements. For example, it can be installed in the cabinet door for Mark VI applications or in a control room desk for Excitation Control System applications. The only cabling requirements are for power and for the Ethernet connection to the UDH. Network communication is via the integrated auto-sensing 10/100BaseT Ethernet connection. Expansion possibilities for the computer are limited, although it does support connection of external devices through FDD, IDE, and USB connections.

The COI can be directly connected to the Mark VI or Excitation Control System, or it can be connected through an EGD Ethernet switch. A redundant topology is available when the controller is ordered with a second Ethernet port.

The networking of the COI to the Mark VI is requisitioned or customer-defined.

Interface Features

Numeric data displays are driven by EGD (Ethernet Global Data) pages transmitted by the controller. The refresh rate depends both on the rate at which the controller transmits the pages, and the rate at which the COI refreshes the fields. Both are set at configuration time in the toolbox.

The COI uses a touch screen, and no keyboard or mouse is provided. The color of pushbuttons are feedbacks and represent state conditions. To change the state or condition, press the button. The color of the button changes if the command is accepted and the change implemented by the controller.

Numeric inputs on the COI touch screen are made by touching a numeric field that supports input. A numeric keypad then displays and the desired number can be entered.

An Alarm Window is provided and an alarm is selected by touching it. Then Ack, Silence, Lock, or Unlock the alarm by pressing the corresponding button. Multiple alarms can be selected by dragging through the alarm list. Pressing the button then applies to all selected alarms.

Note For complete information, refer to *GEI-100434, Computer Operator Interface (COI) for Mark VI or EX2100 Systems*.

Turbine Historian

The Turbine Historian is a data archival system based on client-server technology, which provides data collection, storage, and display of power island and auxiliary process data. Depending on the requirements, the product can be configured for just turbine-related data, or for broader applications that include balance of plant process data.

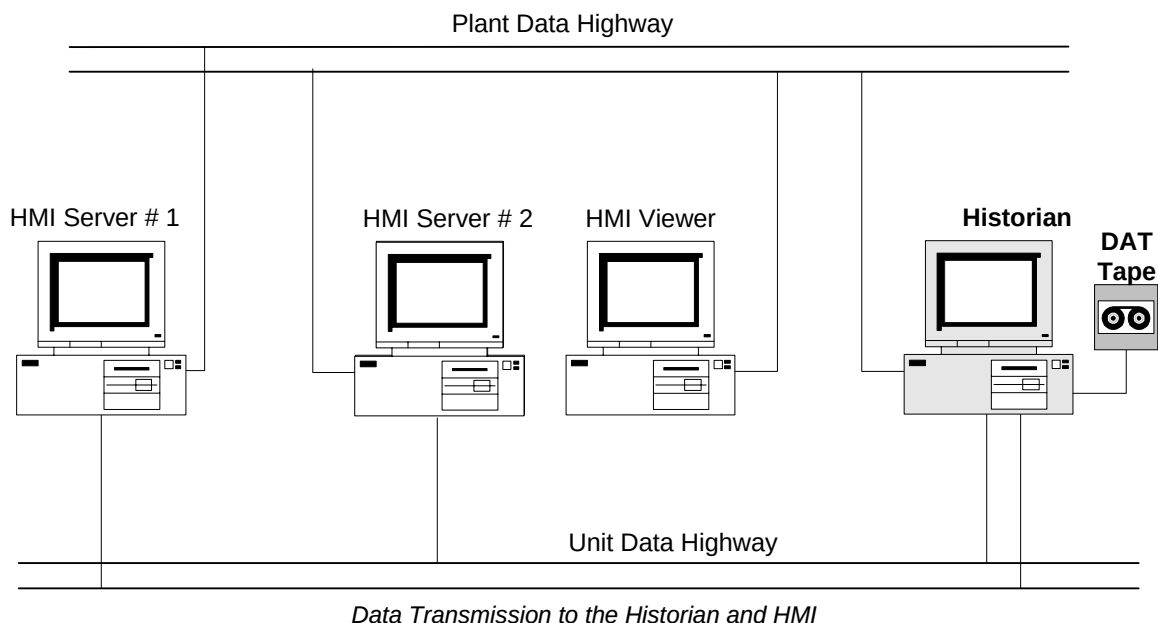
The Turbine Historian combines high-resolution digital event data from the turbine controller with process analog data to create a sophisticated tool for investigating cause-effect relationships. It provides a menu of predefined database query forms for typical analysis relating to the turbine operations. Flexible tools enable the operator to quickly generate custom trends and reports from the archived process data.

System Configuration

The Turbine Historian provides historical data archiving and retrieval functions. When required, the system architecture provides time synchronization to ensure time coherent data.

The Turbine Historian accesses turbine controller data via the UDH as shown in the figure below. Additional Turbine Historian data acquisition is performed through Modbus and/or Ethernet-based interfaces. Data from third-party devices such as Bently Nevada monitors, or non-GE PLCs is usually obtained via Modbus, while Ethernet is the preferred communication channel for GE/Fanuc PLC products.

The HMI and other operator interface devices communicate to the Turbine Historian through the PDH. Network technology provided by the Windows operating system allows interaction from network computers, including query and view capabilities, using the Turbine Historian Client Tool Set. The interface options include the ability to export data into spreadsheet applications.



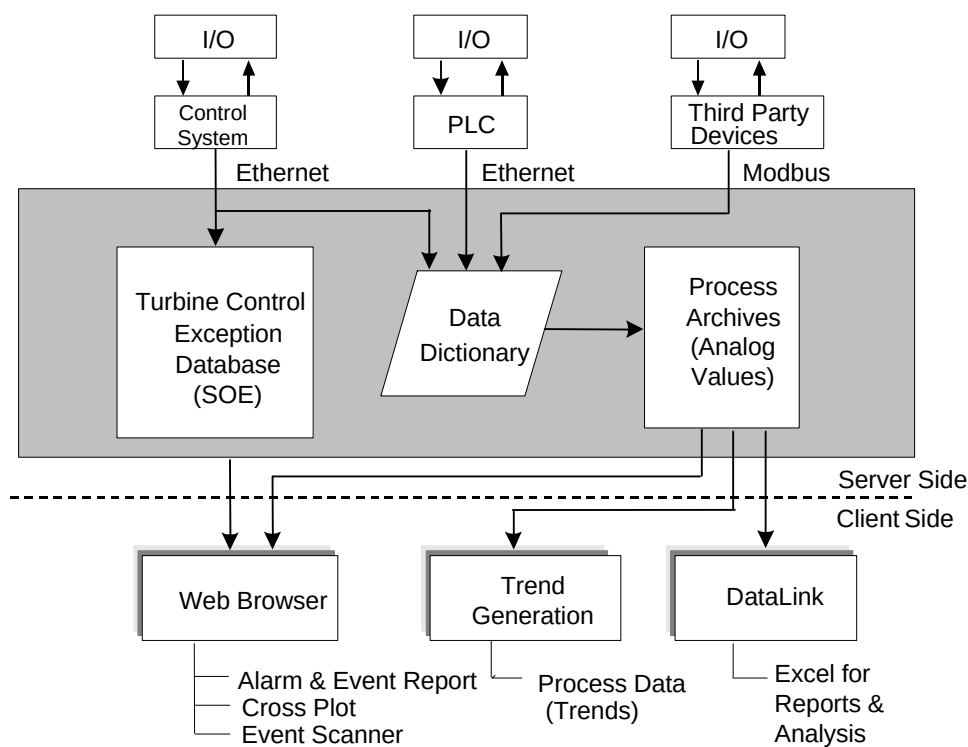
System Capability

The Turbine Historian provides an online historical database for collecting and storing data from the control system. Packages of 1,000, 5,000 or 10,000 point tags may be configured and collected from as many as eight turbine controls.

A typical turbine control application uses less than 1,000 points of time tagged analog and discrete data per unit. The length of time that the data is stored on disk, before offline archiving is required, depends upon collection rate, dead-band configuration, process rate of change, and the disk size.

Data Flow

The Turbine Historian has three main functions: data collection, storage, and retrieval. Data collection is over the UDH and Modbus. Data is stored in the Exception database for sequence of events (SOE), events, and alarms, and in the archives for analog values. Retrieval is through a web browser or standard trend screens.

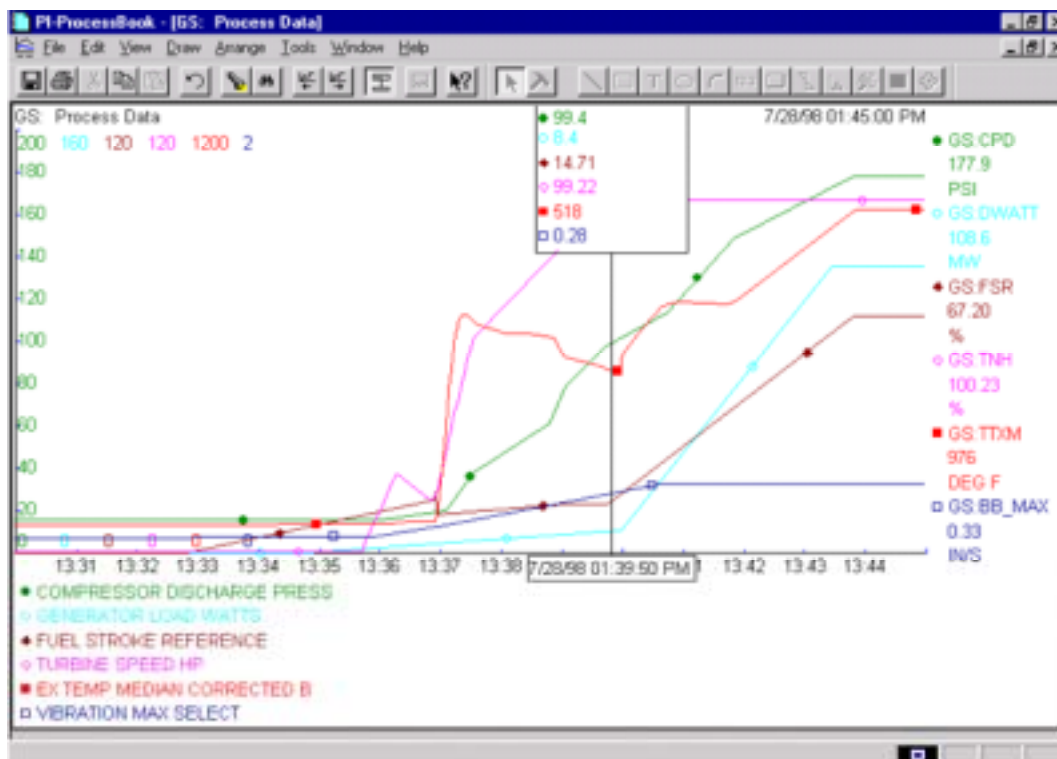


Turbine Historian Functions and Data Flow

Turbine Historian Tools

A selection of tools, screens, and reports are available to ensure that the operator can make efficient use of the collected data as follows:

- **Alarm and Event Report** is a tabular display of the alarms, events, and SOE for all Mark VI units connected to the Turbine Historian. This report presents the following information on a point's status: time of pickup (or dropout), unit name, status, processor drop number, and descriptive text. This is a valuable tool to aid in the analysis of the system, especially after an upset.
- **Historical Cross Plot** references the chronological data of two signal points, plotted one against another, for example temperature against revolutions per minute (RPM). This function permits visual contrasting and correlation of operational data.
- **Event Scanner** function uses logic point information (start, trip, shutdown, or user-defined) stored in the historical database to search and identify specific situations in the unit control.
- **Event/Trigger Query Results** shows the user's inputs and a tabular display of resulting event triggers. The data in the Time column represents the time tag of the specified Event Trigger.
- **Process Data (Trends)** is the graphical interface for the Turbine Historian and can trend any analog or digital point. It is fully configurable and can auto-range the scales or set fixed indexes. For accurate read out, the trend cursor displays the exact value of all points trended at a given point in time. The Turbine Historian can be set up to mimic strip chart recorders, analyze the performance of particular parameters over time, or help troubleshoot root causes of a turbine upset. The trend in the following figure is an example of a turbine startup.



Typical Multi-Pen Process Trend Display

Data Collection Details

Mark VI uses two methods to collect data. The first process uses EGD pages defined in the SDB. The Turbine Historian uses this collection method for periodic storage of control data. It also receives exception messages from the Mark VI controller for alarm and event state changes. When a state change occurs, it is sent to the Turbine Historian. Contact inputs or SOE changes are scanned, sent to the Turbine Historian and stored in the Exception database with the alarms and event state changes. These points are time-tagged by the Mark VI.

Time synchronization and time coherency are extremely important when the operator or maintenance technician is trying to analyze and determine the root cause of a problem. To provide this, the data is time-tagged at the controller that offers system time-sync functions as an option to ensure that total integrated system data remain time-coherent.

Data points configured for collection in the archives are sampled once per second from EGD. Analog data that exceeds an exception dead-band and digital data that changes state are sent to the archives. The Turbine Historian uses the swinging door compression method that filters on the slope of the value to determine when to save a value. This allows the Turbine Historian to keep orders of magnitude more data online than in conventional scanned systems.

The web browser interface provides access to the Alarm & Event Report, the Cross-Plot, the Event Scanner, and several Turbine Historian status displays. Configurable trend displays are the graphical interface to the history stored in the archives. They provide historical and real time trending of process data.

The PI DataLink (optional) is used to extract data from the archives into spreadsheets, such as Excel for report generation and analysis.

Notes

Chapter 7 Maintenance, Diagnostic & Troubleshooting

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Introduction

This chapter discusses board maintenance and component replacement, alarm handling, and troubleshooting in the Mark VI system. The configuration of process alarms and events is described, and also the creation and handling of diagnostic alarms caused by control system equipment failures.

Maintenance



Warning

This equipment contains a potential hazard of electric shock or burn. Only personnel who are adequately trained and thoroughly familiar with the equipment and the instructions should install, operate, or maintain this equipment.

Modules and Boards

System troubleshooting should be at the circuit board level. The failed board or module should be removed and replaced with a spare. (See section, *Component Replacement* for downloading.)

Note Return the failed board to GE for repair. Do not attempt to repair it on site.

After long service in a very dirty environment it may be necessary to clean the boards. If there is a dust build up it is advisable to vacuum around the rack and the front of the boards before removing them. Remove the boards from the cabinet before cleaning them. Dust can be removed with a low-pressure air jet. If there is dirt, which cannot be removed with the air jet, it should be cleaned off using deionized water. Shake off and allow the board to air-dry before re-applying power.

Component Replacement



This equipment contains a potential hazard of electric shock or burn. Only personnel who are adequately trained and thoroughly familiar with the equipment and the instructions should install, operate, or maintain this equipment.

Replacing a Controller

➤ To replace and reload the UCVx

- 1** If a controller has failed, the rack should be powered down, and all cables disconnected from the controller board front.
- 2** Remove the controller and replace it with a spare controller.
- 3** Pull the VCMI out of the rack far enough to disconnect it from the backplane.
- 4** Connect the serial loader cable between the computer and COM1 of the controller.
 - a. If the controller is a UCVB or UCVD, use the serial loader to download the flash file system to the controller
 - b. If the controller is a UCVE or later, use the compact flash programmer to download the flash file system. (The programmer is included in the service kit)
- 5** Use the serial loader to configure the controller with its TCP/IP address.
- 6** Reconnect the Ethernet cable to the controller and power up the rack.
- 7** Use the toolbox to download runtime to the controller.
- 8** Use the toolbox to download application code, to permanent storage only, in the controller.
- 9** Power down the rack.
- 10** Re-insert the VCMI into the backplane.
- 11** Power up the rack.

Replacing a VCM I

➤ To replace and reload the VCM I

- 1** If a VCM I or VPRO has failed, the rack should be powered down, and the IONet connector unplugged from the board front, leaving the network still running through the T-fitting.
- 2** Remove the VCM I and replace it with a spare VCM I that has a clear flash disk memory, then power up the rack.
- 3** From the toolbox Outline View, under item Mark VI I/O, locate the failed rack. Locate the VCM I, which is usually under the simplex rack, and right-click the VCM I.
- 4** From the shortcut menu, click Download. The topology downloads into the new board.
- 5** Cycle power to the rack to establish communication with the controller.

For a successful download, the flash disk memory in the replacement VCM I should be clear, because an old topology stored in flash can sometimes cause problems. If the flash memory needs to be cleared, contact GE.

Replacing an I/O Board in an Interface Module

➤ To replace an I/O Board

- 1** Power down the rack and remove the failed I/O board.
- 2** Replace the board with a spare board of the same type, first checking that the jumper positions match the slot number (the same as the old board).
- 3** Power up the rack.
- 4** From the toolbox Outline View, under item Mark VI I/O, locate the failed rack. Find the slot number of the failed board and right-click the board.
- 5** From the shortcut menu, click Download. The board configuration downloads.
- 6** Cycle power to the rack to establish communication with the controller.

Note Newer I/O boards do not have Berg jumpers.

Replacing a Terminal Board

The terminal boards do not contain software requiring reload, but some have power supplied to them.



This equipment contains a potential hazard of electric shock or burn. Power is provided by the Mark VI control cabinet to various input and output devices. External sources of power may be present in the Mark VI cabinet that are NOT switched by the control power circuit breaker(s). Before handling or connecting any conductors to the equipment, use proper safety precautions to ensure all power is turned off. To minimize risk of personal injury, damage to the control equipment, or damage to the controlled process, it is recommended that all power to a terminal board be removed before replacement of the terminal board. Most terminal boards are supplied from all three power supplies of a TMR system as well as multiple external sources and therefore may require shutdown of the turbine before replacement is made.

➤ To replace a terminal board

- 1** Disconnect any power cables coming into the terminal board, and unplug the I/O cables (J-plugs).
- 2** Loosen the two screws on the wiring terminal blocks and remove the blocks, leaving the field wiring attached.
- 3** Remove the terminal board and replace it with a spare board, checking that any jumpers are set correctly (the same as the old board).
- 4** Screw the terminal blocks back in place and plug in the J-plugs and the power cables.

Cable Replacement

The I/O cables or power cables are supported in plastic brackets behind the back base. Since these brackets are not continuous, it is not recommended that the replacement cable be pulled through behind the back bases.

➤ To replace an I/O cable

- 1** Power down the interface module and disconnect the failed cable from the module. Leave the cable in place.
- 2** Disconnect the failed cable from the terminal board.
- 3** Connect the replacement cable to the terminal board, and lay the new cable in the field-wiring trough at the side of the I/O terminal boards. Use space at the top and bottom of the cabinet to run the cable across the cabinet to the interface module.
- 4** Connect the cable to the interface module and power up the module. Secure the cable in place with tie wraps.

The power cables (125 V dc) are held in cable cleats behind the mounting panels. If a power cable needs to be replaced, it is recommended it be run across the top or bottom of the back base and down the side of the I/O wiring trough to the module power supply.

Note Additional cables that may be required for system expansion can be installed in this same way.

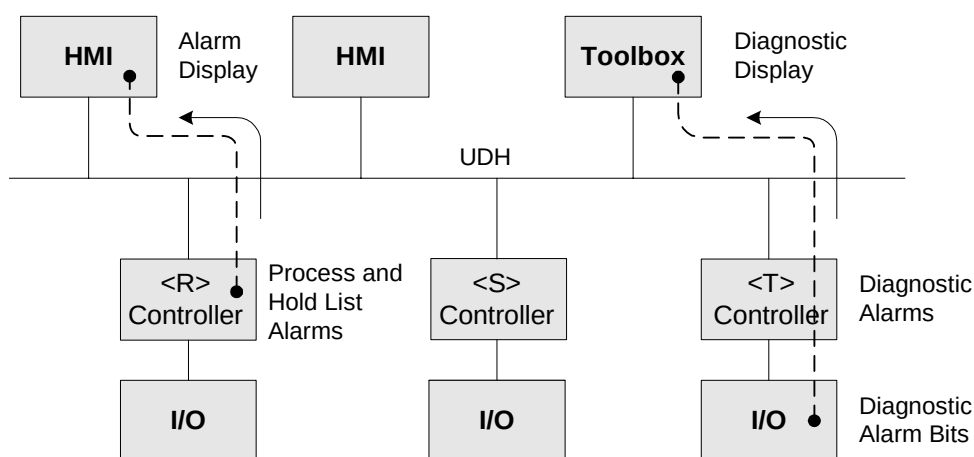
Alarms Overview

Three types of alarms are generated by the Mark VI system, as follows:

Process alarms are caused by machinery and process problems and alert the operator by means of messages on the HMI screen. The alarms are created in the controller using alarm bits generated in the I/O boards or in sequencing. The user configures the desired analog alarm settings in sequencing using the toolbox. As well as generating operator alarms, the alarm bits in the controller can be used as interlocks in the application program.

Hold list alarms are similar to process alarms with the additional feature that the scanner drives a specified signal True whenever any hold list signal is in the alarm state (hold present). This signal is used to disable automatic turbine startup logic at various stages in the sequencing. Operators may override a hold list signal so that the sequencing can proceed even if the hold condition has not cleared.

Diagnostic alarms are caused by Mark VI equipment problems and use settings factory-programmed in the boards. Diagnostic alarms identify the failed module to help the service engineer quickly repair the system. For details of the failure, the operator can request a display on the toolbox screen.



Three Types of Alarms generated by Mark VI

Process Alarms

Process Alarms are generated by the transition of Boolean signals configured by the toolbox with the alarm attribute. The signals may be driven by sequencing or they may be tied to input points to map values directly from I/O boards. Process alarm signals are scanned each frame after the sequencing is run. In TMR systems process signals are voted and the resulting composite signal is present in each controller.

A useful application for process alarms is the annunciation of system limit-checking. Limit-checking takes place in the I/O boards at the frame rate, and the resulting Boolean status information is transferred to the controller and mapped to process alarm signals.

Two system limits are available for each process input, including thermocouple, RTD, current, voltage, and pulse rate inputs. System limit 1 can be the high or low alarm setting, and system limit 2 can be a second high or low alarm setting. These limits are configured from the toolbox in engineering units.

There are several choices when configuring system limits. Limits can be configured as enabled or disabled, latched or unlatched, and greater than or less than the preset value. System out of limits can be reset with the RESET_SYS signal.

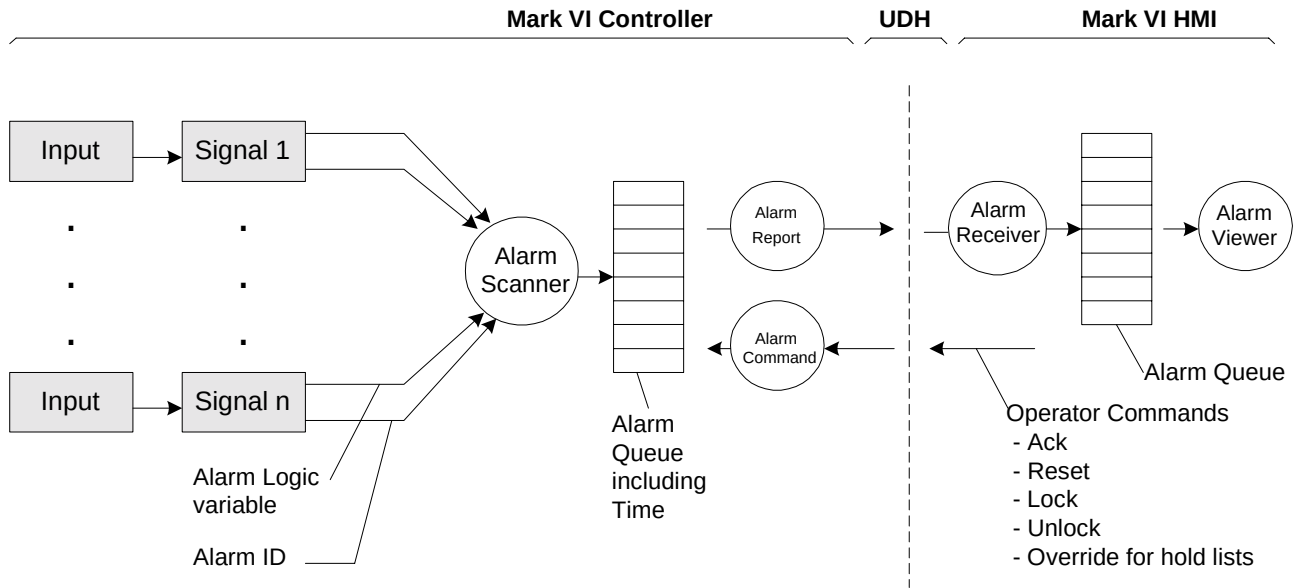
Process (and Hold) Alarm Data Flow

Process and Hold alarms are time stamped and stored in a local queue in the controller. Changes representing alarms are time stamped and sent to the alarm queue. Reports containing alarm information are assembled and sent over the UDH to the CIMPLICITY HMIs. Here the alarms are again queued and prepared for operator display by the alarm viewer.

Operator commands from the HMI, such as alarm Acknowledge, Reset, Lock, and Unlock, are sent back over the UDH to the alarm queue where they change the status of the appropriate alarms. An alarm entry is removed from the controller queue when its state has returned to normal and it has been acknowledged by an operator. Refer to the following figure.

Hold alarms are managed in the same fashion but are stored on a separate queue. Additionally, hold alarms cannot be locked but may be overridden.

Note The operator or the controller can take action based on process alarms.



Generating Process Alarms

To configure the alarm scanner on the controller, refer to *GEH-6403 Control System Toolbox for Mark VI Controller*. To configure the controller to send alarms to all HMIs, use the UDH broadcast address in the alarm IP address area.

Diagnostic Alarms

The controller and I/O boards all generate diagnostic alarms, including the VCM, which generates diagnostics for the power subsystem. Alarm bits are created in the I/O board by hardware limit-checking. Raw input-checking takes place at the frame rate, and resulting alarms are queued.

- Each type of I/O board has hardware limit-checking based on preset (non-configurable) high and low levels set near the ends of the operating range. If this limit is exceeded a logic signal is set and some types of input are removed from the scan.
- In TMR systems, a limit alarm associated with TMR Diff Limt is created if any of the three inputs differ from the voted value by more than a preset amount. This limit value is configured by the user and creates a voting alarm indicating a problem exists with a specific input.
- If any one of the diagnostic alarms is set, it creates a board composite diagnostic alarm, L3DIAG_xxxx, where xxxx is the board name. This signal can be used to trigger a process alarm. Each board has three L3DIAG_ signals, L3DIAG_xxxx1, 2, and 3. Simplex boards only use L3DIAG_xxxx1. TMR boards use all three with the first assigned to the board in <R>, the second assigned to the same board in <S>, and the third assigned to the same board in <T>.
- The diagnostic signals can be individually latched, and then reset with the RESET_DIA signal, typically in the form of a message from the HMI.
- Generally diagnostic alarms require two consecutive occurrences before being set True (process alarms only require one occurrence).

In addition to inputs, each board has its own diagnostics. The VCM and I/O boards have a processor stall timer which generates a signal SYSFAIL. This signal lights the red LED on the front cabinet. The watchdog timers are set as follows:

- VCM communication board 150 ms
- I/O boards 150 ms

If an I/O board times out, the outputs go to a fail-safe condition which is zero (or open contacts) and the input data is put in the default condition, which is zero.

The three LEDs at the top of the front cabinet provide status information. The normal RUN condition is a flashing green and FAIL is a solid red. The third LED is normally off but shows a steady orange if a diagnostic alarm condition exists in the board.

The controller has extensive self-diagnostics, most of which are available directly at the toolbox. In addition, UCVB and UCVD runtime diagnostics, which may occur during a program download, are displayed on LEDs on the controller front cabinet.

Each terminal board has its own ID device, which is interrogated by the I/O board. The board ID is coded into a read-only chip containing the terminal board serial number, board type, revision number, and the J type connector location.

Voter Disagreement Diagnostics

Each I/O board produces diagnostic alarms when it is configured as TMR and any of its inputs disagree with the voted value of that input by more than a configured amount. This feature allows the user to find and fix potential problems that would otherwise be masked by the redundancy of the control system. The user can view these diagnostics the same way one views any other diagnostic alarms. The VCM I triggers these diagnostic alarm when an individual input disagrees with the voted value for a number of consecutive frames. The diagnostic clears when the disagreement clears for a number of frames.

The user configures voter disagreement diagnostics for each signal. Boolean signals are all enabled or disabled by setting the DiagVoteEnab signal to enable under the configuration section for each input. Analog signals are configured using the TMR_DiffLimit signal under configuration for each point. This difference limit is defined in one of two ways. It is implemented as a fixed engineering unit value for certain inputs and as a percent of configured span for other signals. For example, if a point is configured as a 4-20 mA input scaled as 0-40 engineering unit, its TMR_DiffLimit is defined as a percent of (40-0). The type of limit-checking used is spelled out in the dialog box for the TMR_DiffLimit signal for each card type and is summarized in the following table.

<i>Type of TMR Limit-Checking</i>		
I/O Processor Board	Type of I/O	Delta Method
VAIC		% of Configured Span
VGEN	Analog	% of Configured Span
	PT, CT	Engineering Units
VPRO	Pulse rates	Engineering Units
	Thermocouples	Engineering Units
	Analog	% of Configured Span
VPYR	PT, CT	Engineering Units
	mA	% of Configured Span
	Gap	Engineering Units
VRTD	-----	Engineering Units
VSVO	Pulse rates	Engineering Units
	POS	Engineering Units
	mA	% of Configured Span
VTCC	-----	Engineering Units
VTURH1/H2	Pulse rates	Engineering Units
	PT	Engineering Units
	Flame	Engineering Units
	Shaft monitor	Engineering Units
VVIB	Vibration signals	Engineering Units

For TMR input configuration, refer to *GEH-6403 Control System Toolbox for a Mark VI Controller*. All unused signals will have the voter disagreement checking disabled to prevent nuisance diagnostics.

Totalizers

Totalizers are timers and counters that store critical data such as number of trips, number of starts, and number of fired hours. The Mark VI provides the special block, Totalizer, that maintains up to 64 values in a protected section of Non-volatile RAM.

The Totalizer block should be placed in a protected macro to prevent the logic driving its counters from being modified. Users with sufficient privilege may set and clear Totalizer counter values from a toolbox dialogue. An unprivileged user cannot modify the data, either accidentally or intentionally. The standard block library Help file provides more details on using the Totalizer block.

Troubleshooting

To start troubleshooting, be certain the racks have correct power supply voltages; these can be checked at the test points on the left side on the VME rack.

Refer to Help files as required. From the toolbox, click Help for files on Runtime Errors and the Block Library. Also, from the Start button, navigate to the Mark VI controller to see help files on Runtime, I/O networks, Serial Loader, Standard Block Library, and Turbine Block Library.

 **This equipment contains a potential hazard of electric shock or burn. Only personnel who are adequately trained and thoroughly familiar with the equipment and the instructions should install, operate, or maintain this equipment.**

Warning

First level troubleshooting uses the LEDs on the front of the I/O and VCMI boards. If more information on the board problems and I/O problems is required, use the toolbox diagnostic alarm display for details.

I/O Board LEDs

Green - Normal Operation

During normal operation all the Run LEDs on the board front panels flash green together. All boards and all racks should flash green in synchronism. If one light is out of sequence there could be a problem with the synchronizing on that board which should be investigated. Contact your turbine control representative and have the firmware revision number for that board available.

Orange - System Diagnostic in Queue

An orange Status LED lit on one board indicates there is an I/O or system diagnostic in queue in that board. This is not an I/O board failure, but may be a sensor problem.

➤ To view the diagnostic message

- 1** From the toolbox Outline View, select Online using the Go on/offline button.
- 2** Locate the rack in the Summary View and right-click the board. A pop-up menu displays.
- 3** From the pop-up menu, select View Diagnostic Alarms. The Diagnostic Alarms table displays. The following data is displayed in tabular form:
 - Time - The time when the diagnostic was generated
 - Fault Code - The fault code number
 - Status - A 1 indicates an active alarm, and a 0 indicates a cleared, but not reset (acknowledged), alarm
 - Description - A short message describing the diagnostic

This diagnostic screen is a snapshot, but not real time. For new data, select the Update command.

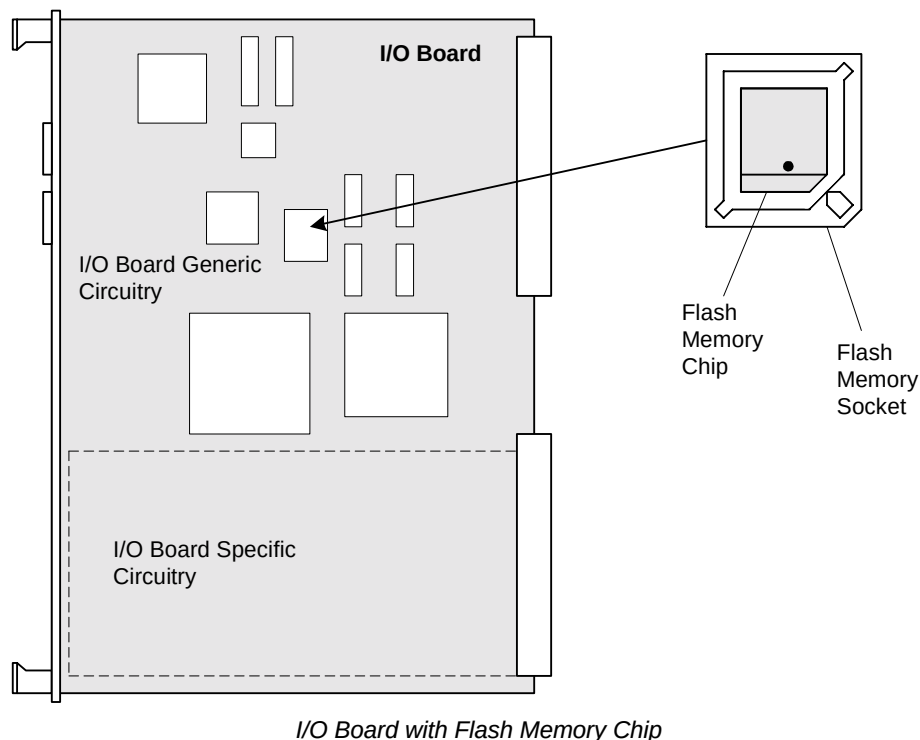
To display all of the real time I/O values in the Summary View, left-click the board on the screen. The I/O values will display. All the real time I/O values display in the Summary View. At the top of the list is the L3DIAG board alarm, followed by the board point system limit values, and with the I/O (sensor) values at the bottom. From these alarms and I/O values, determine whether the problem is in the terminal board or in the sensor.

For example, if all the I/O points in a board are bad, the board has failed, a cable is loose, or the board has not been configured. If only a few I/O points are bad, the I/O values are bad, or part of the terminal board is burned up.

Red - Board Not Operating

If a board has a red Fail LED lit, it indicates the board is not operating. Check if it is loose in its slot and, if so, switch off the rack power supply, push the board in, and turn on the power again.

If the red light still comes on, power down the rack, remove the board and check the firmware flash chip. If the board has a socketed flash chip, this chip can be plugged in the wrong way, which damages it; the following figure shows a typical I/O board with the chip location. The chamfer on the chip should line up with the chamfer on the receptacle, as shown. If no flash chip is installed, replace the board with a new one. Newer boards have a soldered flash chip so no adjustment is possible.



Earlier I/O board versions had a reset button on the front. If your board has this, check to see if this button is stuck in. If so replace the board with a new one.

It is possible the failure is in the rack slot and not in the board. This can be determined by board swapping, assuming the turbine is shut down. Remove the same good board from the same slot in an adjacent TMR rack, and move the bad board to this good slot. Be sure to power down the racks each time. If the problem follows the board, replace the board. If it does not, there may be a problem with the VME backplane. Inspect the board slot for damage; if no damage is visible, the original board may not have been seated properly. Check the board for proper seating.

If a whole rack of I/O boards show red LEDs, it is probably caused by a communication failure between the slave VCMi and the I/O boards in the rack. This can result from a controller or VCMi failure or an IONet cable break. The failure could also be caused by a rack power supply problem. Either the master or slave VCMi could be at fault, so check the Fail LEDs to see where the problem is.

If several but not all I/O boards in a rack show red, this is probably caused by a rack power supply problem.

Controller Failures

If the controller fails, check the VCMi and controller diagnostic queues for failure information. Power down the controller rack and reboot by bringing power back (do not use the Reset button). If the controller stays failed after reboot, replace it with a spare.

If a controller fails to start, this usually indicates a runtime error that is typically a boot-up or download problem. The runtime error number is usually displayed after an attempted online download. The controller Runtime Errors Help screen on the toolbox displays all the runtime errors together with suggested actions.

If the controller or its VCMi fails, then the IONet on this channel stops sending or receiving data. This drives the outputs on the failed channel to their fail-safe state. The failure does not affect the other two IONet channels, which keep running.

Power Distribution Module Failure

The PDM is a very reliable module with no active components. However, it does contain fuses and circuit switches, and may have an occasional cabling or connector problem. Most of the outputs have lights indicating voltage across their supply circuit. Open the PDM front door to see the lights, switches, and fuses.

PDM diagnostic information is collected by the VCMi, including the 125 V dc bus voltage and the status of the fuses feeding relay output boards. These can be viewed on the toolbox by right-clicking the VCMi board, and then selecting View Diagnostic Alarms.

Chapter 8 Applications

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Introduction

This chapter describes some of the applications of the Mark VI hardware and software, including the servo regulators, overspeed protection logic, generator synchronization, and ground fault detection. This chapter is organized as follows:

Generator Synchronization

This section describes the Mark VI Generator Synchronization system. Its purpose is to momentarily energize the breaker close coil, at the optimum time and with the correct amount of time anticipation, so as to close the breaker contact at top center on the synchroscope. Top center is often known as top dead center. Closure will be within one degree of top center. It is a requirement that a normally closed breaker auxiliary contact be used to interrupt the closing coil current.

The synchronizing system consists of three basic functions, each with an output relay, with all three relays connected in series. All three functions have to be true (relay picked up) simultaneously before the system applies power to the breaker close coil. Normally there will be additional external permissive contacts in series with the Mark VI system, but it is required that they be permissives only, and that the precise timing of the breaker closure be controlled by the Mark VI system. The three functions are:

- Relay K25P, a synchronize permissive; turbine sequence status
- Relay K25A, a synchronize check; checks that the slip and phase are within a window (rectangle shape); this window is configurable
- Relay K25, an auto synchronize; optimizes for top dead center

The K25A relay should close before the K25 otherwise the synch check function will interfere with the auto synch optimizing. If this sequence is not executed, a diagnostic alarm will be posted, a lockout signal will be set true in signal space, and the application code may prevent any further attempts to synchronize until a reset is issued and the correct coordination is set up.

Hardware

The synchronizing system interfaces to the breaker close coil via the TTUR terminal board as in the following figure. Three Mark VI relays must be picked up, plus external permissives must be true, before a breaker closure can be made.

The K25P relay is directly driven from the controller application code. In a TMR system, it is driven from <R>, <S>, and <T>, using 2/3 logic voting. For a simplex system, it may be configured by jumper to be driven from <R> only.

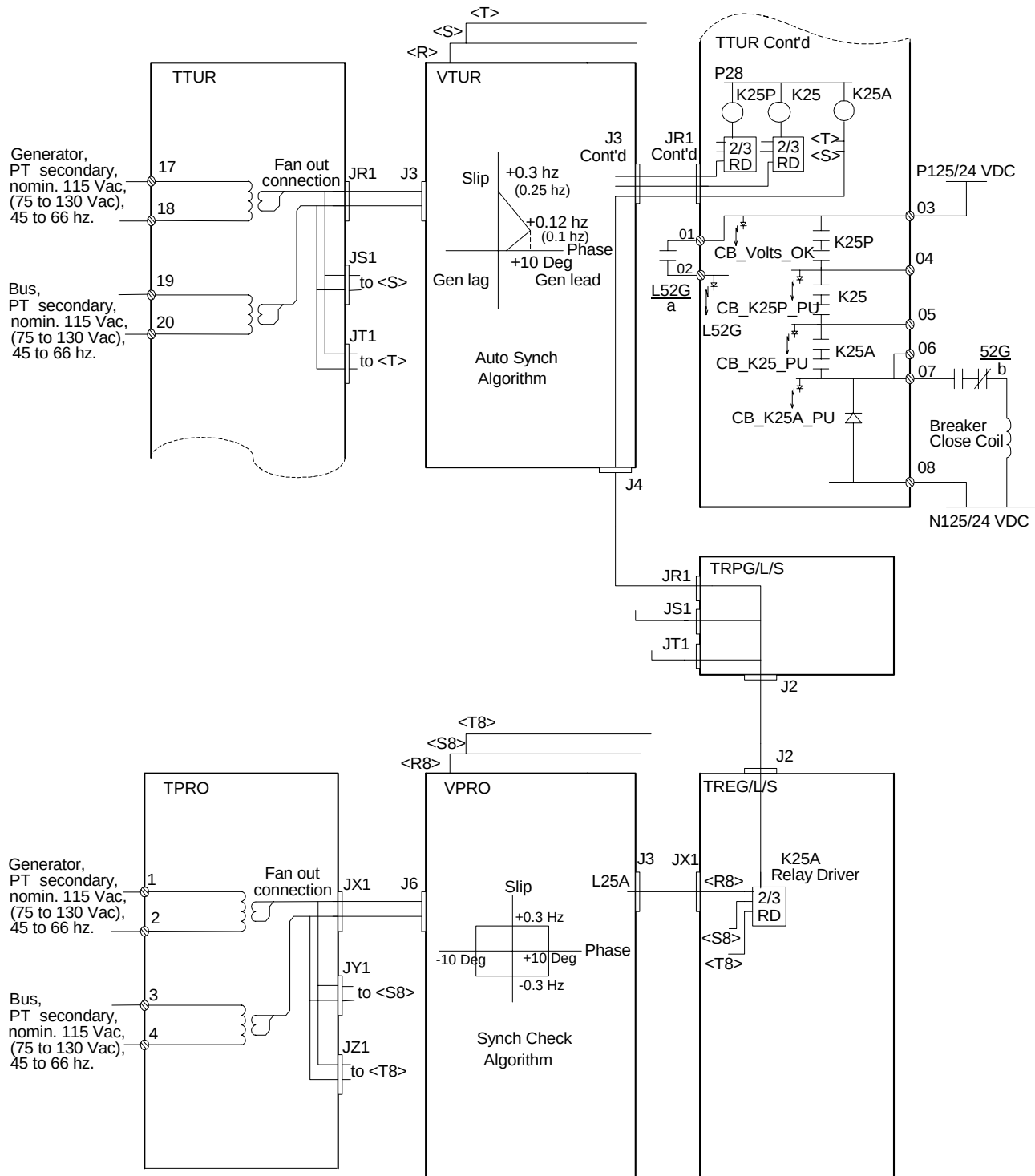
The K25 relay is driven from the VTUR auto synch algorithm, which is managed by the controller application code. In a TMR system, it is driven from <R>, <S>, and <T>, using 2/3 logic voting. Again for a simplex system, it may be configured by jumper to be driven from <R> only.

The K25A relay is located on TTUR, but is driven from the VPRO synch check algorithm, which is managed by the controller application code. The relay is driven from VPRO, <R8>, <S8>, and <T8>, using 2/3 logic voting in TREG/L/S.

The synch check relay driver (located on TREG/L/S) is connected to the K25A relay coil (located on TTUR) through cabling through J2 to TRPG/L/S. It then goes through JR1 (and JS1, JT1) to J4 and VTUR, then J3, JR1 to TTUR.

Both sides of the breaker close coil power bus must be connected to the TTUR board. This provides diagnostic information and also measures the breaker closure time, through the normally open breaker auxiliary contact for optimization.

The breaker close circuit is rated to make (close) 10 A at 125 V dc, but to open only 0.6 A. A normally open auxiliary contact on the breaker is required to interrupt the closing coil current.



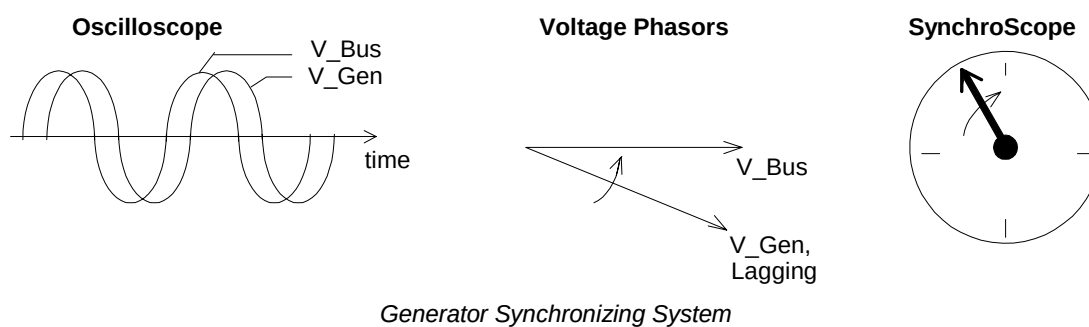
Generator Synchronizing System

Application Code

The application code must sequence the turbine and bring it to a state where it is ready for the generator to synchronize with the system bus. For automatic synchronization, the code must:

- Match speeds
- Match voltages
- Energize the synch permissive relay, K25P
- Arm (grant permission to) the synch check function (VPRO, K25A)
- Arm (grant permission to) the auto synch function (VTUR, K25)

The following illustrations represent positive slip (Gen) and negative phase (Gen).



Algorithm Descriptions

This section describes the synchronizing algorithms in the VTUR I/O processor, and then VPRO.

Automatic Synchronization Control in VTUR (K25)

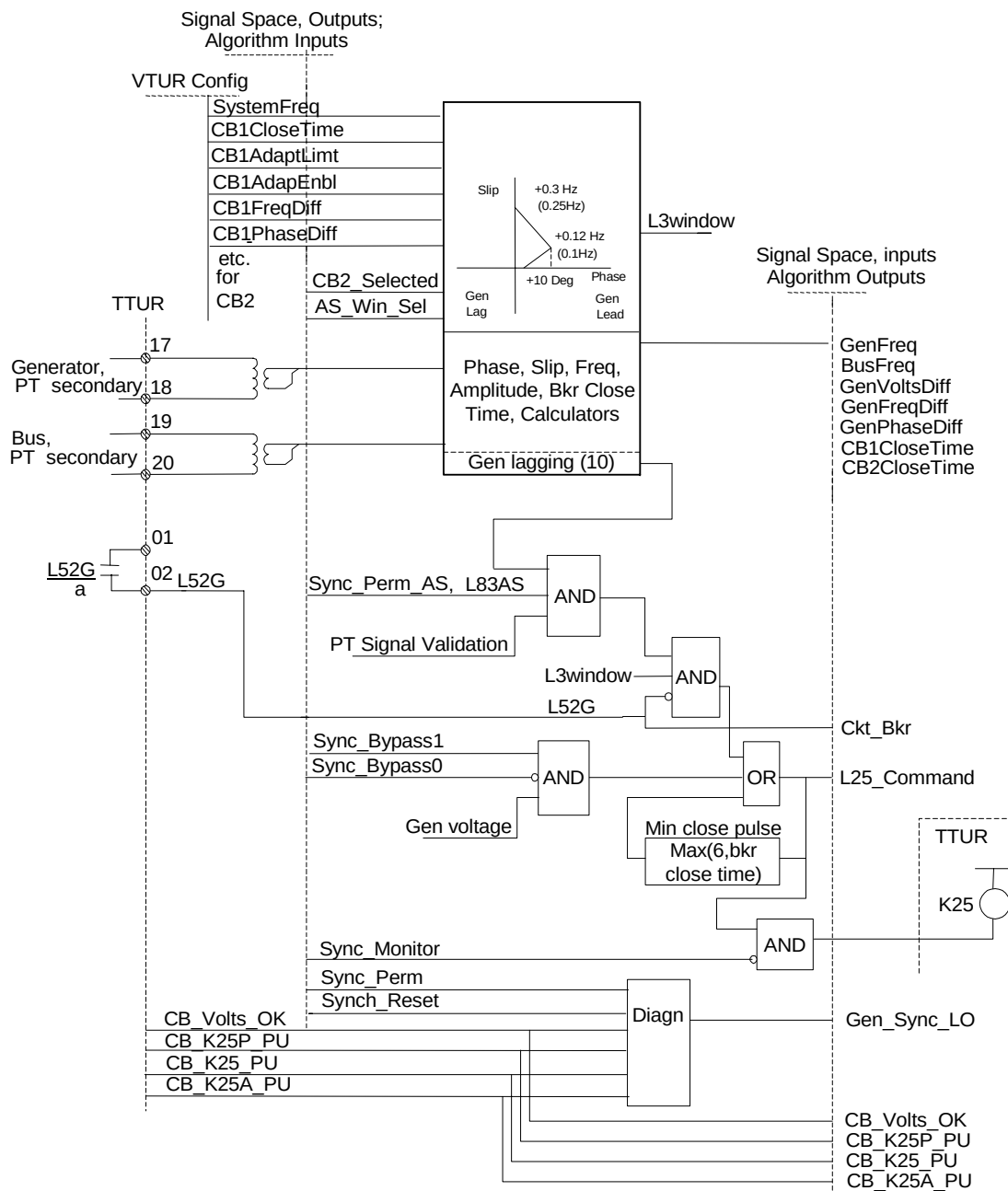
VTUR runs the auto synch algorithm. Its basic function is to monitor two Potential Transformer (PT) inputs, generator and bus, to calculate phase and slip difference, and when armed (enabled) from the application code, and when the calculations anticipate *top center*, to attempt a breaker closure by energizing relay K25. The algorithm uses the *zero voltage crossing* technique to calculate phase, slip, and acceleration. It compensates for breaker closure time delay (configurable), with self-adaptive control when enabled, with configurable limits. It is interrupt driven and must have generator voltage to function. The configuration can manage the timing on two separate breakers. For details, refer to the figure below.

The algorithm has a bypass function, two signals for redundancy, to provide dead bus and Manual Breaker Closures. It anticipates top dead center, therefore it uses a projected window, based on current phase, slip, acceleration, and breaker closure time. To pickup K25, the generator must be currently lagging, have been lagging for the last 10 consecutive cycles, and projected (anticipated) to be leading when the breaker actually reaches closure. Auto synch will not allow the breaker to close with negative slip. In this fashion, assuming the correct breaker closure time has been acquired, and the synch check relay is not interfering, breaker closures with less than 1 degree error can be obtained.

Slip is the difference frequency (Hz), positive when the generator is faster than the bus. Positive phase means the generator is leading the bus, the generator is ahead in time, or the right hand side on the synchroscope. The standard window is fixed and is not configurable. However, a special window has been provided for synchronous condenser applications where a more permissive window is needed. It is selectable with a signal space Boolean and has a configurable slip parameter.

The algorithm validates both PT inputs with a requirement of 50% nominal amplitude or greater; that is, they must exceed approximately 60 V rms before they are accepted as legitimate signals. This is to guard against cross talk under open circuit conditions. The monitor mode is used to verify that the performance of the system is correct, and to block the actual closure of the K25 relay contacts; it is used as a confidence builder. The signal space Input Gen_Sync_Lo will become true if the K25 contacts are closed when they should not be closed, or if the Synch Check K25A is not picked up before the Auto Synch K25. It is latched and can be reset with Synch_Reset.

The algorithm compensates for breaker closure time delay, with a nominal breaker close time, provided in the configuration in milliseconds. This compensation is adjusted with self-adaptive control, based upon the measured breaker close time. The adjustment is made in increments of one cycle (16.6/20 ms) per breaker closure and is limited in authority to a configurable parameter. If the adjustment reaches the limit, a diagnostic alarm *Breaker #n Slower/Faster Than Limits Allows* is posted.



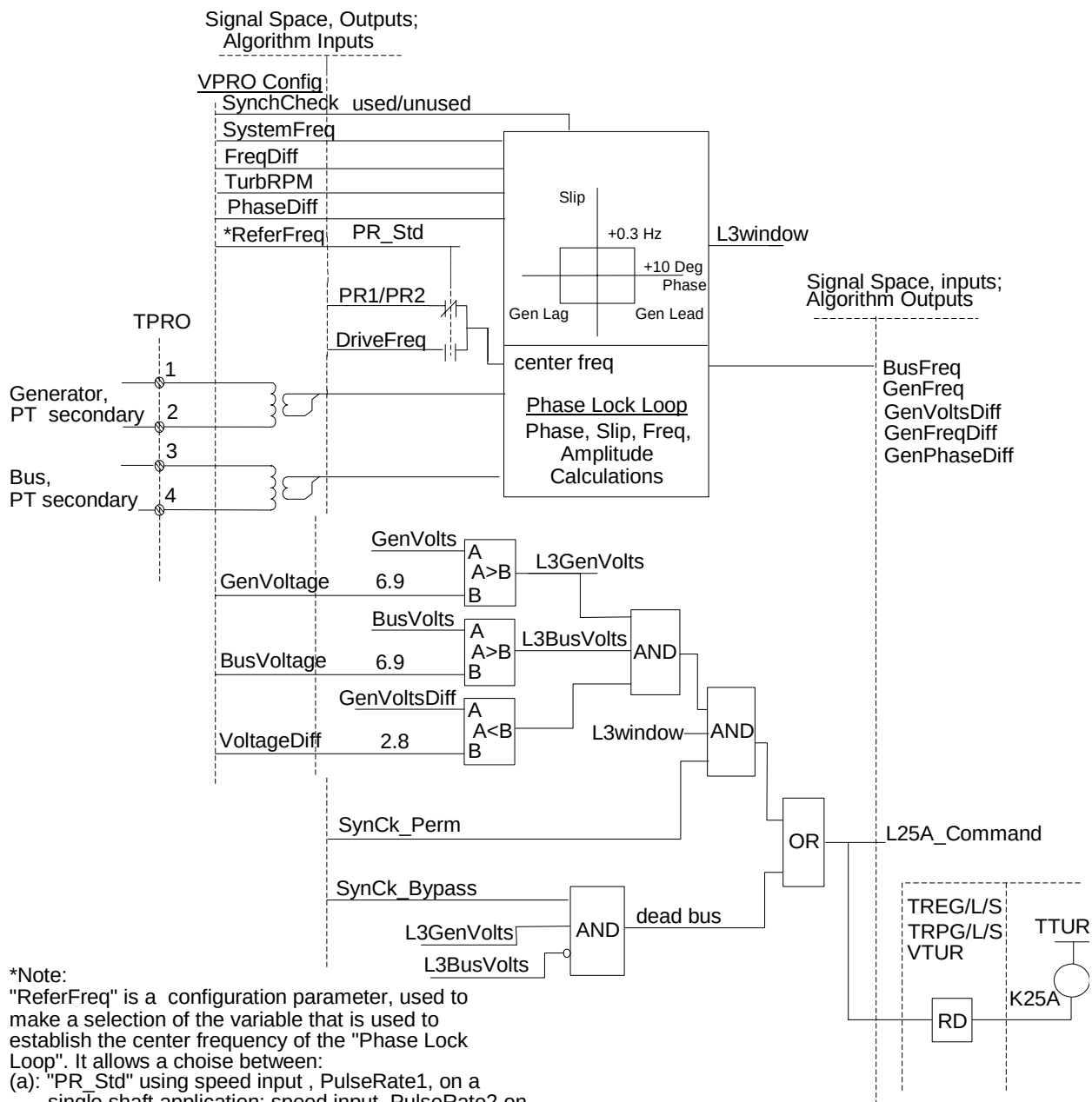
Automatic Synchronizing on VTUR

Synchronization Check in VPRO (K25A)

The synch check algorithm is performed in the VPRO boards. Its basic function is to monitor two Potential Transformer (PT) inputs, and to calculate generator and bus voltage amplitudes and frequencies, phase, and slip. When it is armed (enabled) from the application code, and when the calculations determine that the input variables are within the requirements, the relay K25A will be energized. The above limits are configurable. The algorithm uses the phase lock loop technique to derive the above input variables, and is therefore relatively immune from noise disturbances. For details, refer to the following figure.

The algorithm has a bypass function to provide dead bus closures. The window in this algorithm is the current window, not the projected window (as used on the auto synch function), therefore it does not include anticipation.

The Synch Check will allow the breaker to close with negative slip. Slip is the difference frequency (Hz), positive when the Generator is faster than the Bus. Positive phase means the generator is leading the Bus, the Generator is ahead in time, or the right hand side on the synchroscope. The window is configurable and both phase and slip are adjustable within predefined limits.



*Note:
"ReferFreq" is a configuration parameter, used to make a selection of the variable that is used to establish the center frequency of the "Phase Lock Loop". It allows a choice between:
(a): "PR_Std" using speed input, PulseRate1, on a single shaft application; speed input, PulseRate2, on all multiple shaft applications.
(b): or "SgSpace", the Generator freq (Hz), from signal space (application code), "DriveFreq".
Choice (b) is used when (a) is not applicable.

Synchronization Check on VTUR

Configuration

VTUR configuration of the auto synch function is shown the following table. The configuration is located under J3 J5: IS200VTUR, signal Ckt_Bkr.

TUR Auto Synch Configuration

VTUR Parameter	Description	Selection Choice
SystemFreq	System Frequency	50 Hz, 60 Hz
CB1CloseTime	Breaker #1 closing time	0 to 500 ms
CB1AdaptLimt	Breaker #1 adaption limit	0 to 500 ms
CB1AdaptEnabl	Breaker #1 adaption enable	Enable, disable
CB1FreqDiff	Breaker #1 allowable frequency difference for the special window	0.15 to 0.66 Hz
CB1PhaseDiff	Breaker #1 allowable phase difference for the special window	0 to 20 degrees
CB2CloseTime	Breaker #2 closing time	0 to 500 ms
CB2AdaptLimt	Breaker #2 adaption limit	0 to 500 ms
CB2AdaptEnabl	Breaker #2 adaption enable	Enable, disable
CB2FreqDiff	Breaker #2 allowable frequency difference for the special window	0.15 to 0.66 Hz
CB2PhaseDiff	Breaker #2 allowable phase difference for the special window	0 to 20 degrees

VPRO configuration of the Synch Check Function is shown in the following table. The configuration is located under J3: IS200TREX, signal K25A_Fdbk.

VTUR Auto Synch Configuration

VPRO Parameter	Description	Selection Choice
SynchCheck	Enable	Used, unused
SystemFreq	System Frequency	50 Hz, 60 Hz
ReferFreq	Phase Lock Loop center frequency	PR_Std, SgSpace Where PR_Std means use PulseRate1 on a single shaft application - use PulseRate2 on all multiple shaft applications SgSpace means use generator freq (Hz), from signal space (application code), DriveFreq
TurbRPM	Load Turbine rated RPM	0 to 20,000 Used to compensate for driving gear ratio between the turbine and the generator
VoltageDiff	Allowable voltage difference	1 to 1,000 Engineering units, kV or percent
FreqDiff	Allowable freq difference	0 to 0.5 Hz
PhaseDiff	Allowable phase difference	0 to 30 degrees
GenVoltage	Allowable minimum gen voltage	1 to 1,000 Engineering units, kV or percent
BusVoltage	Allowable minimum bus voltage	1 to 1,000 Engineering units, kV or percent

This section defines all inputs and outputs in signal space that are available to the application code for synchronization control. The breaker closure is not given directly from the application code, rather the synchronizing algorithms, located in the I/O boards, is armed from this code. In special situations the synch relays are operated directly from the application code, for example when there is a dead bus.

The VTUR signal space interface for the Auto Synch function is shown in the following table.

VTUR Auto Synch Signal Space Interface

VTUR Signal Space Output	Description	Comments
Sync_Perm_AS	Auto Synch permissive	Traditionally known as L83AS
Sync_Perm	Synch permissive mode, L25P	Traditionally known as L25P; interface to control the K25P relay
Sync_Monitor	Auto Synch monitor mode	Traditionally known as L83S_MTR; enables the Auto Synch function, except it blocks the K25 relays from picking up
Sync_Bypass1	Auto Synch bypass	Traditionally known as L25_BYPASS; to pickup L25 for Dead Bus or Manual Synch
Sync_Bypass0	Auto Synch bypass	Traditionally known as L25_BYPASSZ; to pickup L25 for Dead Bus or Manual Synch
CB2 Selected	#2 Breaker is selected	Traditionally known as L43SAUTO2; to use the breaker close time associated with Breaker #2
AS_WIN_SEL	Special Auto Synch window	New function, used on synchronous condenser applications to give a more permissive window
Synch_Reset	Auto Synch reset	Traditionally known as L86MR_TCEA; to reset the synch Lockout function
VTUR Signal Space Inputs		
Ckt_BKR	Breaker State (feedback)	Traditionally known as L52B_SEL
CB_Volts_OK	Breaker Closing Coil Voltage is present	Used in diagnostics
CB_K25P_PU	Breaker Closing Coil Voltage is present downstream of the K25P relay contacts	Used in diagnostics
CB_K25_PU	Breaker Closing Coil Voltage is present downstream of the K25 relay contacts	Used in diagnostics
CB_K25A_PU	Breaker Closing Coil Voltage is present downstream of the K25A relay contacts	Used in diagnostics
Gen_Synch_LO	Synch Lock out	Traditionally known as L30AS1 or L30AS2; it is a latched signal requiring a reset to clear (Synch_Reset). It detects a K25 relay problem (picked up when it should be dropped out) or a slow Synch Check (relay K25A) function

L25_Command	Breaker Close Command to the K25 relay	Traditionally known as L25
GenFreq	Generator frequency	Hz
BusFreq	Bus frequency	Hz
GenVoltsDiff	Difference Voltage between the Generator and the Bus	Engineering units, kV or percent
GenFreqDiff	Difference Frequency between the Generator and the Bus	Hz
GenPhaseDiff	Difference Phase between the Generator and the Bus	Degree
CB1CloseTime	Breaker #1 measured close time	ms
CB2CloseTime	Breaker #2 measured close time	ms
GenPT_Kvolts	Generator Voltage	Engineering units, kV or percent
BusPT_Kvolts	Bus Voltage	Engineering units, kV or percent

The VPRO signal space interface for the Synch Check function is shown in the following table.

VPRO Synch Check Signal Space Interface

VPRO Signal Space Outputs	Description	Comments
SynCk_Perm	Synch Check permissive	Traditionally known as L25X_PERM
SynCk_ByPass	Synch Check bypass	Traditionally known as L25X_BYPASS; used for dead bus closure
DriveRef	Drive (generator) frequency (Hz) used for Phase Lock Loop center frequency	Traditionally known as TND_PC; used only for non-standard drives where the center frequency can not be derived from the pulserate signals
VPRO Signal Space Inputs		
K25A_Fdbk	Feedback from K25A relay	
L25A_Cmd	The synch check relay close command	Traditionally known as L25X
BusFreq	Bus frequency	Traditionally known as SFL2, Hz
GenFreq	Generator frequency	Hz
GenVoltsDiff	The difference voltage between the gen and bus	Traditionally known as DV_ERR, engineering units kV or percent
GenFreqDiff	The difference frequency (slip) between the gen and bus	Traditionally known as SFDIFF2, Hz
GenPhaseDiff	The difference phase between the gen and bus	Traditionally known as SSDIFF2, degrees
GenPT_Kvolts	Generator voltage	Traditionally known as DV, engineering units kV or percent
BusPT_Kvolts	Bus voltage	Traditionally known as SVL, engineering units kV or percent

VTUR Diagnostics for the Auto Synch Function

L3BKR_GXS – Synch Check Relay is Slow. This means that K25 (auto synch) has picked up, but K25A (synch check) or K25P has not picked up, or there is no breaker closing voltage source. If it is due to a slow K25A relay, the breaker will close but the K25A is interfering with the K25 optimization. It will cause the input signal Gen_Sync_LO to become TRUE.

L3BKR_GES – Auto Synch Relay is Slow. This means the K25 (auto synch) relay has not picked up when it should have, or the K25P is not picked up, or there is no breaker closing voltage source. It will cause the input signal Gen_Sync_LO to become TRUE.

Breaker #1 Slower than Adjustment Limit Allows. This means, on breaker #1, the self-adaptive function adjustment of the Breaker Close Time has reached the allowable limit and can not make further adjustments to correct the Breaker Close Time.

Breaker #2 Slower than Adjustment Limit Allows. This means, on breaker #2, the self-adaptive function adjustment of the Breaker Close Time has reached the allowable limit and can not make further adjustments to correct the Breaker Close Time.

Synchronization Trouble – K25 Relay Locked Up. This means the K25 relay is picked up when it should not be. It will cause the input signal Gen_Sync_LO to become TRUE.

VPRO Diagnostics for the Auto Synch Function

K25A Relay (synch check) Driver mismatch requested state. This means VPRO cannot establish a current path from VPRO to the TReX terminal board.

K25A Relay (synch check) Coil trouble, cabling to P28V on TTUR. This means the K25A relay is not functional; it could be due to an open circuit between the TReX and the TTUR terminal boards or to a missing P28 V source on the TTUR terminal board.

Hardware Verification Procedure

The hardware interface may be verified by forcing the three synchronizing relays, individually or in combination. If the breaker close coil is connected to the TTUR terminal board, then the breaker must be disabled so as not to actually connect the generator to the system bus.

- 1 Operate the K25P relay by forcing output signal Sync_Perm found under VTUR, card points. Verify that the K25P relay is functional by probing TTUR screws 3 and 4. The application code has direct control of this relay.
- 2 Simulate generator voltage on TTUR screws 17 and 18. Operate the K25 relay by forcing TTUR, card point output signals Sync_Bypass1 =1, and Sync_Bypass0 = 0. Verify that the K25 relay is functional by probing screws 4 and 5 on TTUR.
- 3 Simulate generator voltage on TPRO screws 1 and 2. Operate the K25A relay by forcing TPRO, card point output signals SynCK_Bypass =1, and SynCk_Perm 1. The bus voltage must be zero (dead bus) for this test to be functional. Verify that the K25A relay is functional by probing screws 5 and 6 on TTUR.

Synchronization Simulation

➤ To simulate a synchronization

- 1 Disable the breaker
- 2 Establish the center frequency of the VPRO PLL; this depends on the VPRO configuration, under J3:IS200TREx, signal K25A_Fdbk, **ReferFreq**.
 - a. If ReferFreq is configured PR_Std, and <P> is configured for a single shaft machine, then apply rated speed (frequency) to input **PulseRate1**; that is TPRO screw pairs 31/32, 37/38, and 43/44.
 - b. If ReferFreq is configured PR_Std and <P> is configured for a multiple shaft machine, then apply rated speed (frequency) to input **PulseRate 2**, that is TPRO screw pairs 33/34, 39/40, and 45/46.
 - c. If ReferFreq is configured SgSpace, force VPRO signal space output **DriveRef** to 50 or 60 (Hz), depending on the system frequency.
- 3 Apply the bus voltage, a nominal 115 V ac, 50/60 Hz, to TTUR screws 19 and 20, and to TPRO screws 3 and 4.
- 4 Apply the generator voltage, a nominal 115 V ac, adjustable frequency, to TTUR screws 17 and 18 and to TPRO screws 1 and 2. Adjust the frequency to a value to give a positive slip, that is VTUR signal GenFreqDiff of 0.1 to 0.2 Hz. (10 to 5 sec scope).
- 5 Force the following signals to the TRUE state:
 - VTUR, **Sync_Perm**, then K25P should pick up
 - VTUR, **Sync_Perm_AS**, then K25 should pulse when the voltages are in phase
 - VPRO, **SynCK_Perm**, then K25A should pulse when the voltages are in phase
- 6 Verify that the TTUR breaker close interface circuit, screws 3 to 7, is being made (contacts closed) when the voltages are in phase.

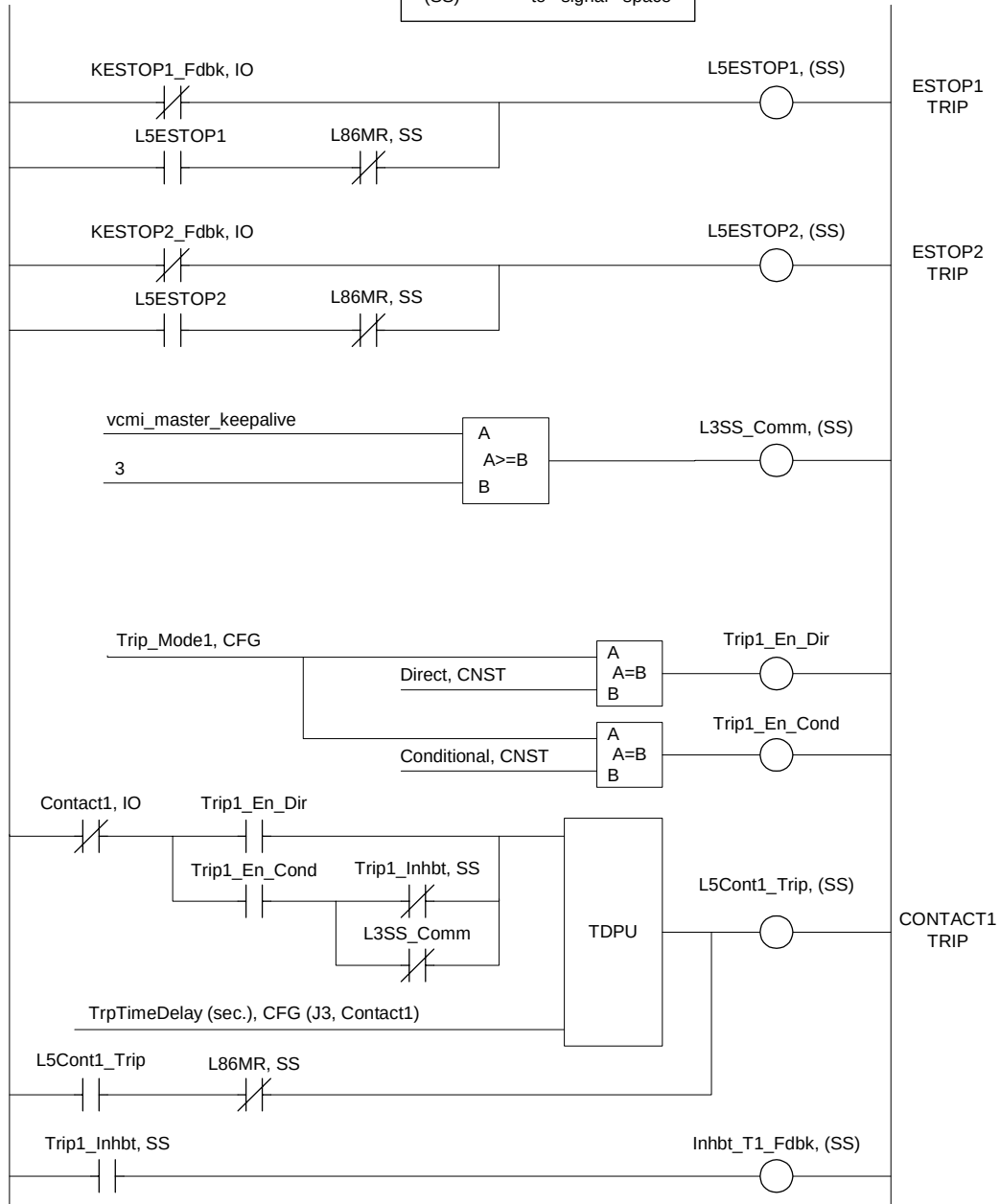
- 7** Run a trend chart on the following signals:
 - VPRO: GenFreqDiff, GenPhaseDiff, L25A_Command, K25A_Fdbk
 - VTUR: GenFreqDiff, GenPhaseDiff, L25_Command, CB_K25_PU, CB_K25A_PU
- 8** Use an oscilloscope, voltmeter, synchroscope, or a light to verify that the relays are pulsing at approximately the correct time.
- 9** Examine the trend chart and verify that the correlation between the phase and the close commands is correct.
- 10** Increase the slip frequency to 0.5 Hz and verify that K25 and K25A stop pulsing and are open.
- 11** Return the slip frequency to 0.1 to 0.2 Hz, and verify that K25 and K25A are pulsing. Reduce the generator voltage to 40 V ac and verify that K25 and K25A stop pulsing and are open.

Overspeed Protection Logic

The figures in this section define the protection algorithms coded in the VPRO firmware. VTUR contains similar algorithms. A parameter configurable from the toolbox is illustrated with the abbreviation CFG(xx), where xx indicates the configuration location. Some parameters/variables are followed with an SS indicating they are outputs from Signal Space (meaning they are driven from the CSDBase); other variables are followed with IO indicating they are hardware I/O points.

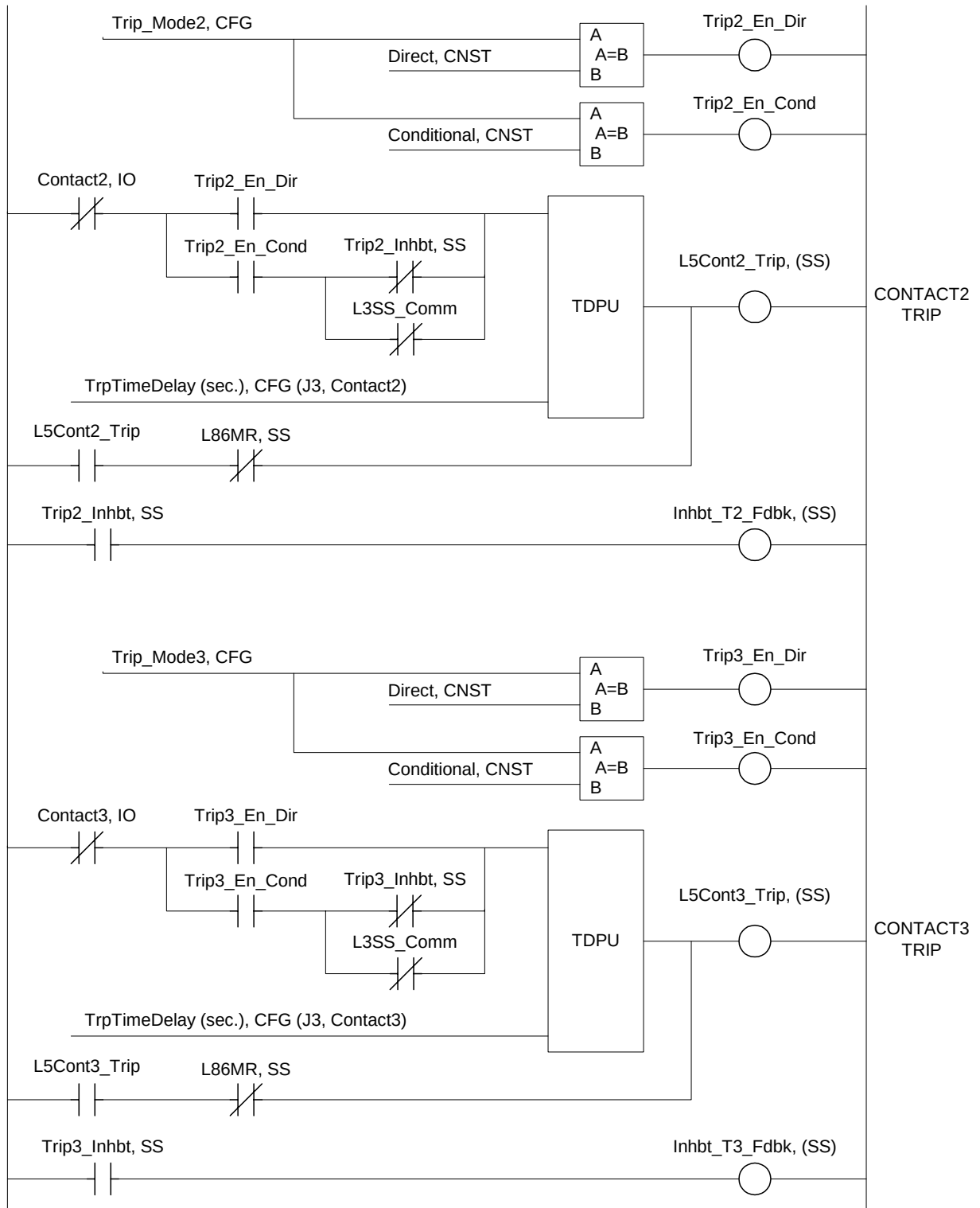
CONTACT INPUT TRIPS:

Notes:
,CFG == VPRO config data
,SS == from signal space
(SS) == to signal space



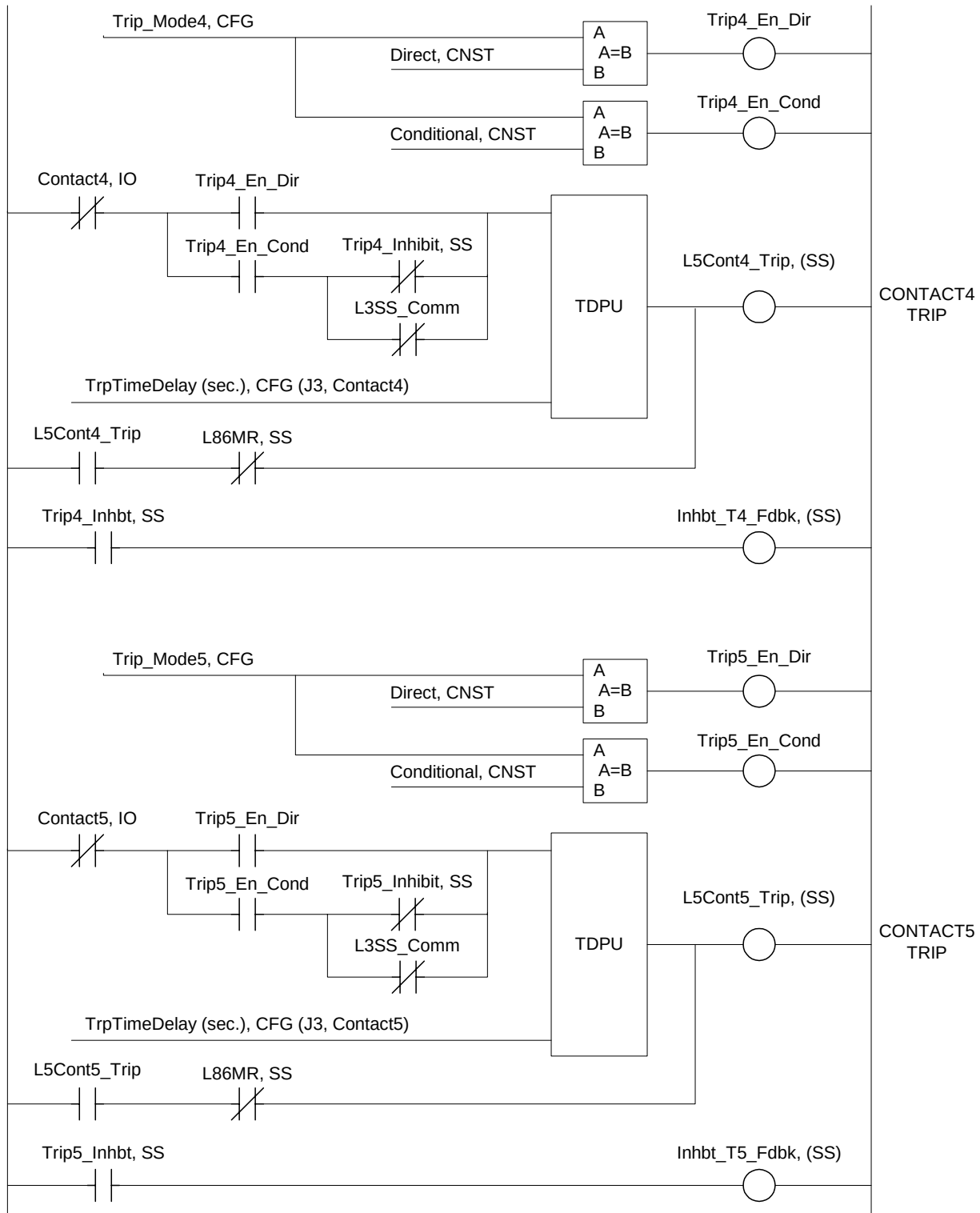
VPRO Protection Logic - Contact Inputs

CONTACT INPUT TRIPS (CONT.):



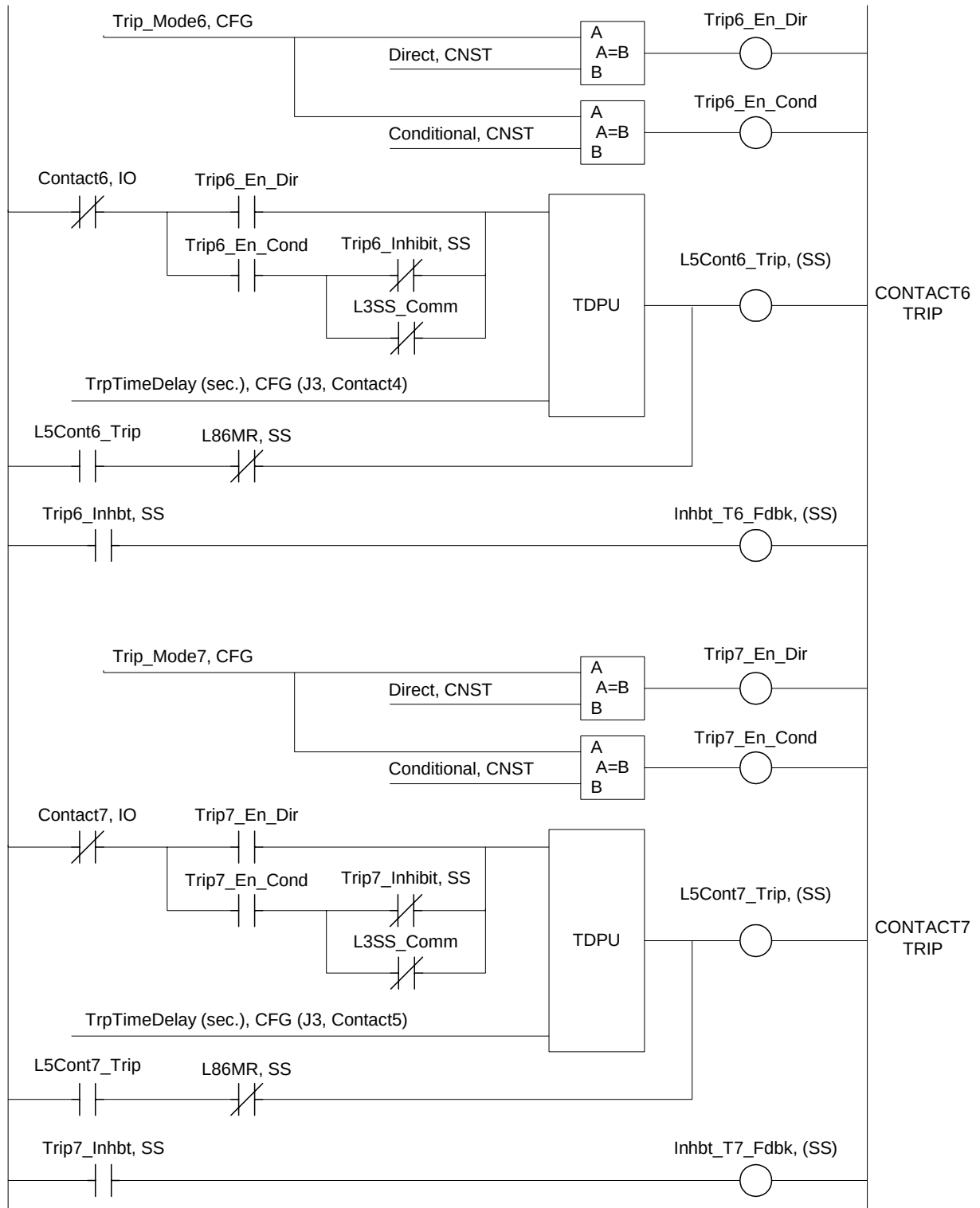
VPRO Protection Logic - Contact Inputs (continued)

CONTACT INPUT TRIPS (CONT.):



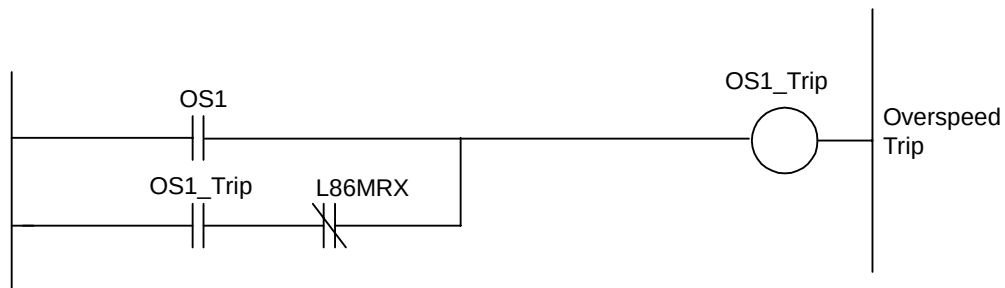
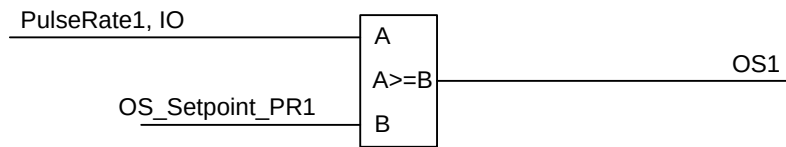
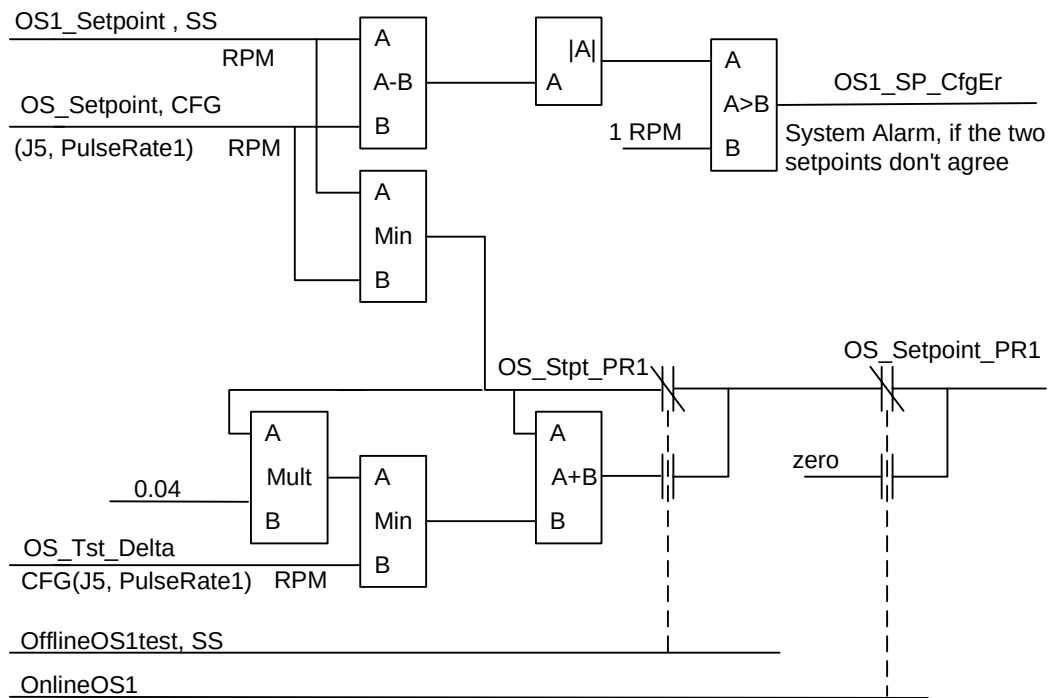
VPRO Protection Logic - Contact Inputs (continued)

CONTACT INPUT TRIPS (CONT.):

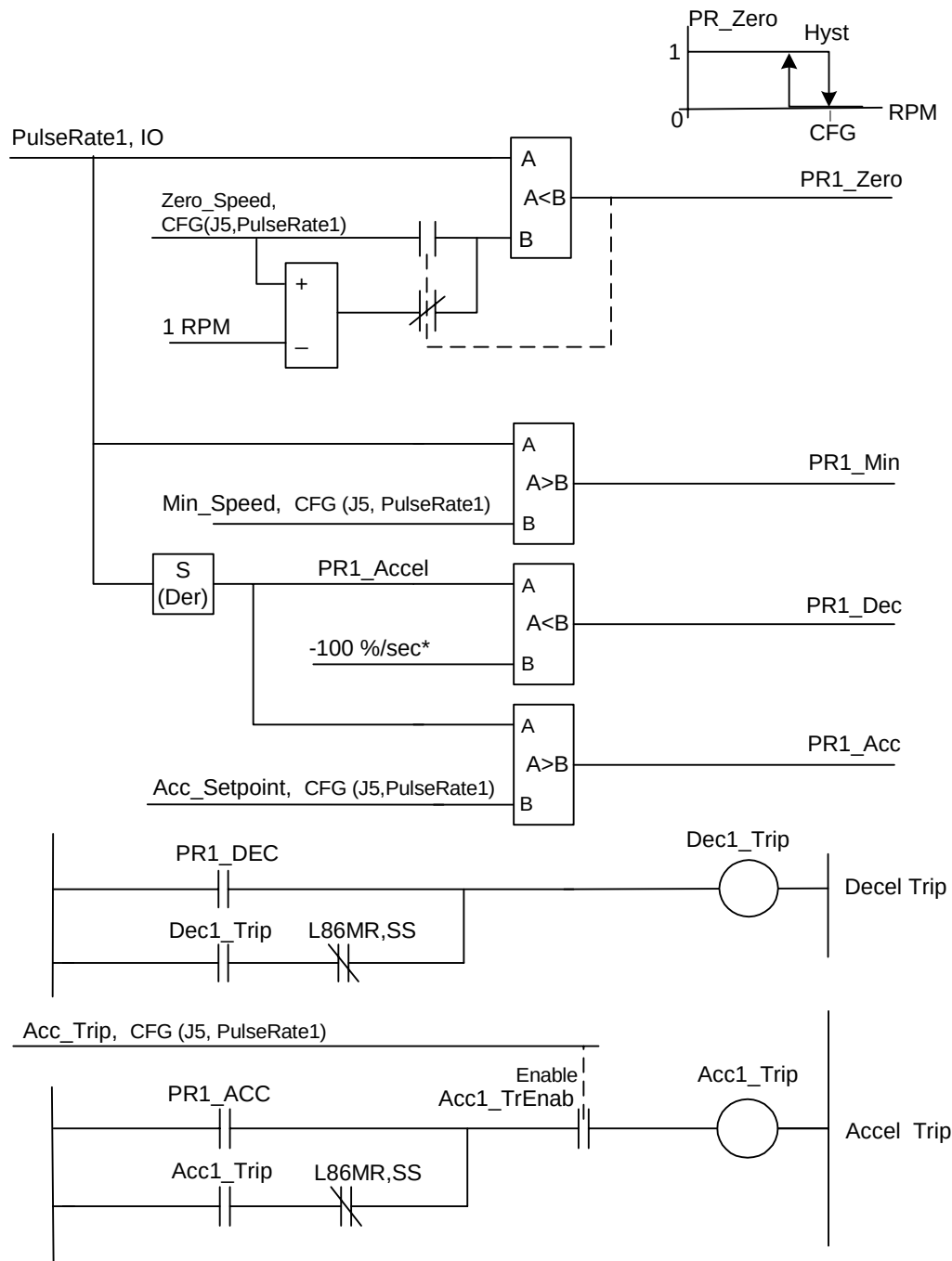


VPRO Protection Logic - Contact Inputs (continued)

VPRO Protection Logic - Online Overspeed Test

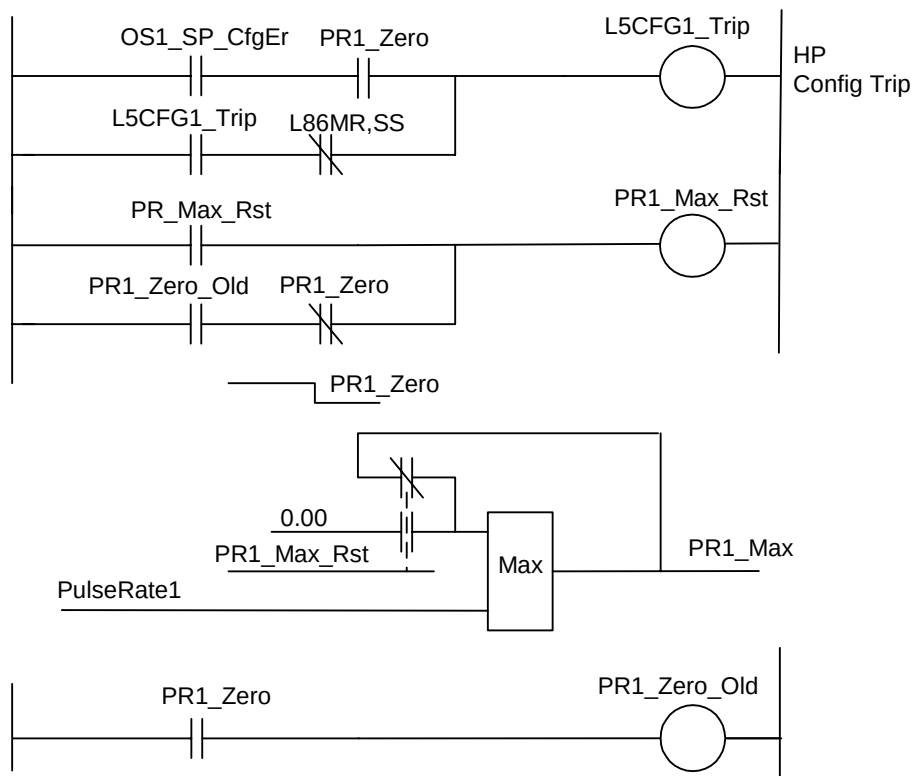


VPRO Protection Logic - Overspeed Trip, HP

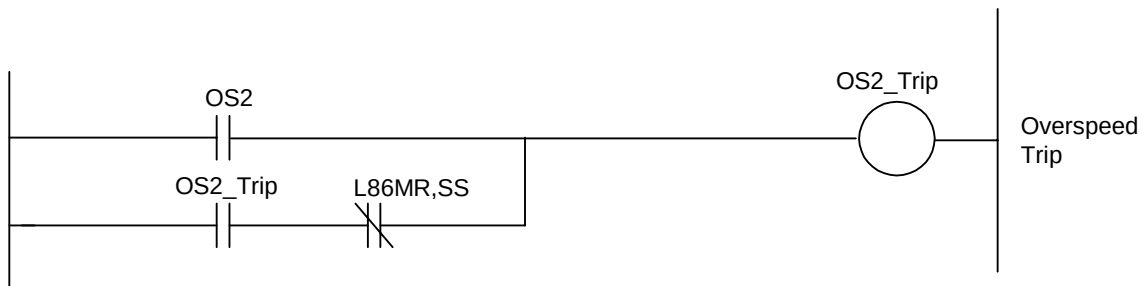
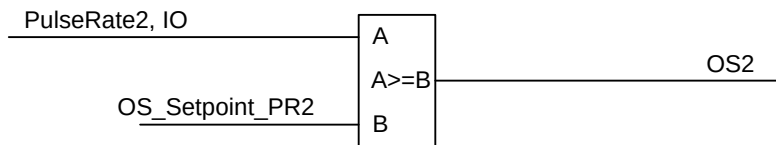
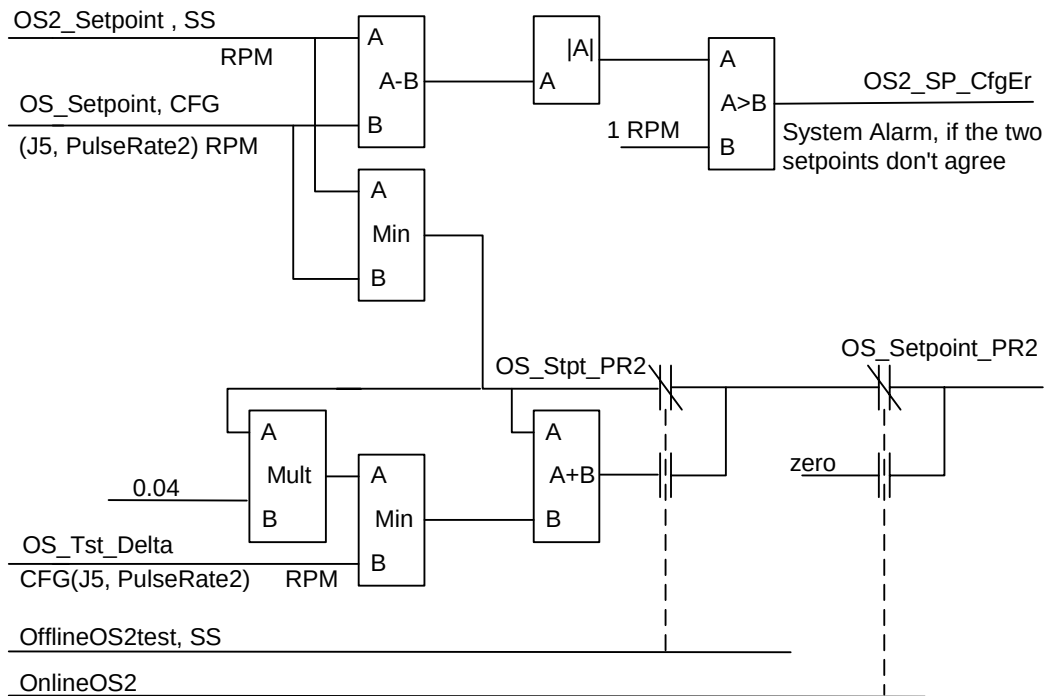


*Note: where 100% is defined as the configured value of OS_Stpt_PR1

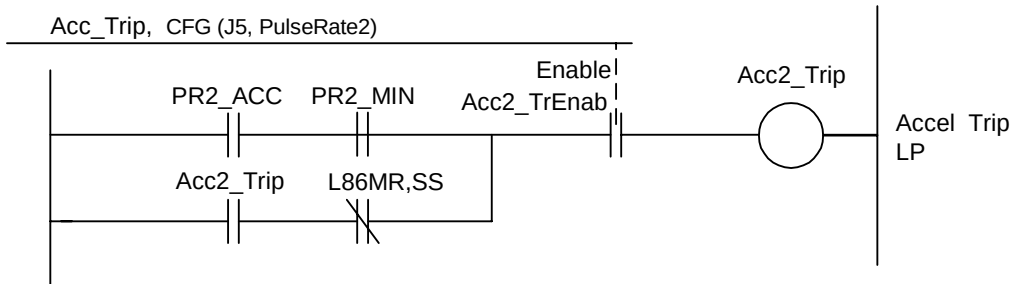
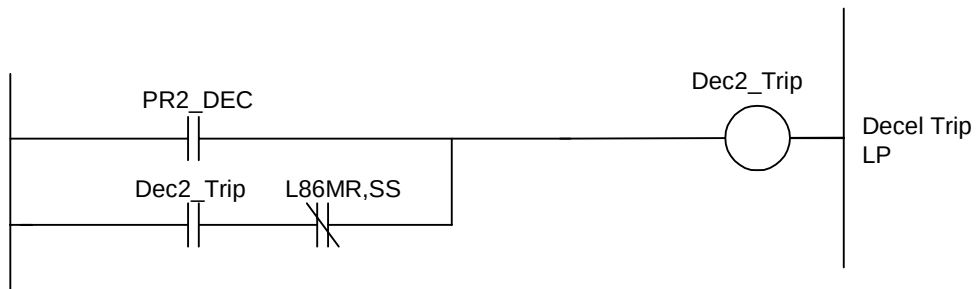
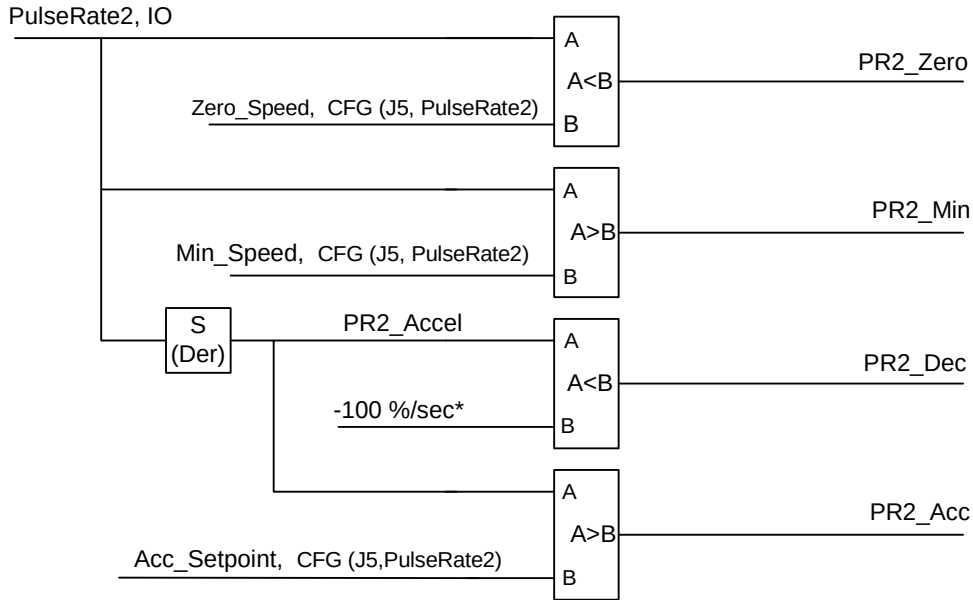
VPRO Protection Logic - Overspeed Trip, HP (continued)



VPRO Protection Logic - Overspeed Trip, HP (continued)

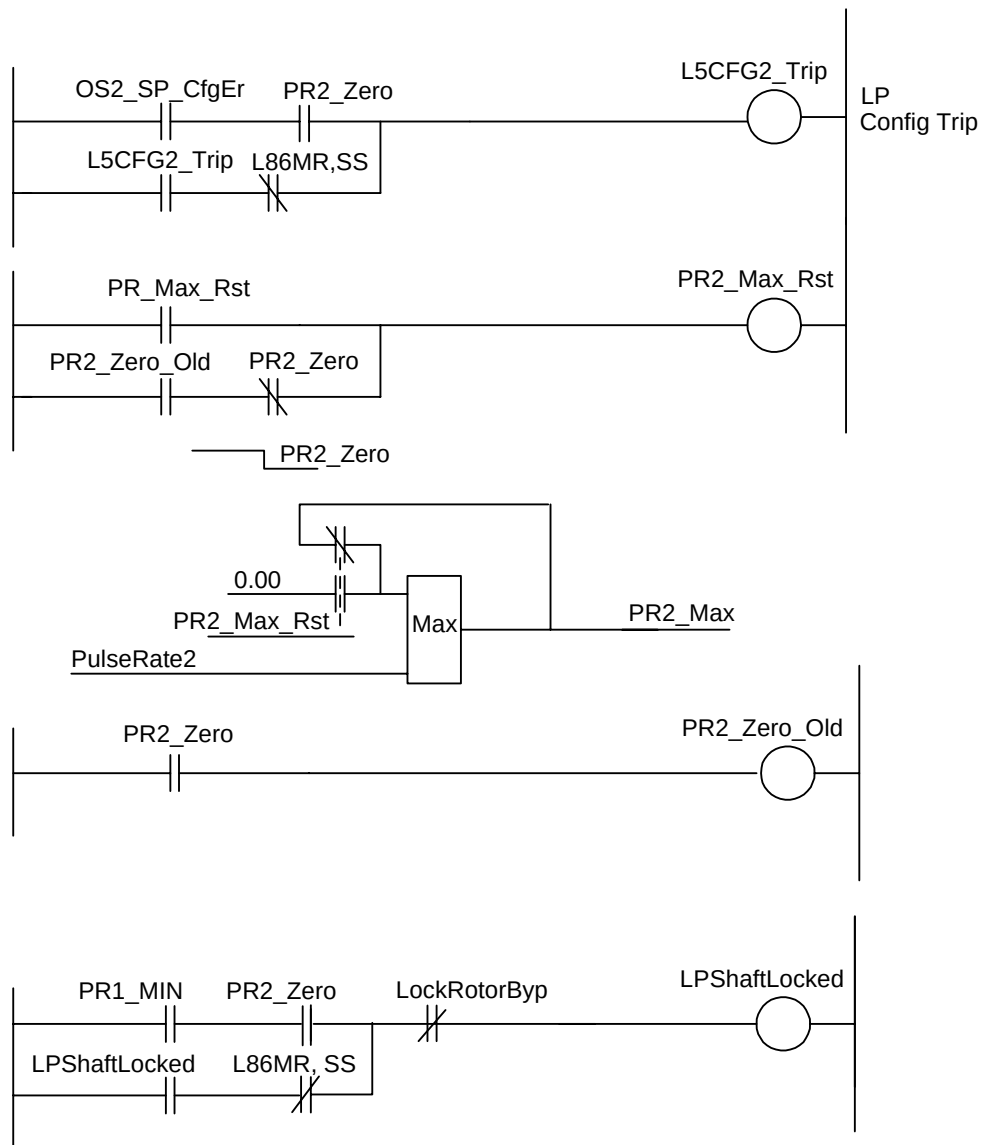


VPRO Protection Logic - Overspeed LP

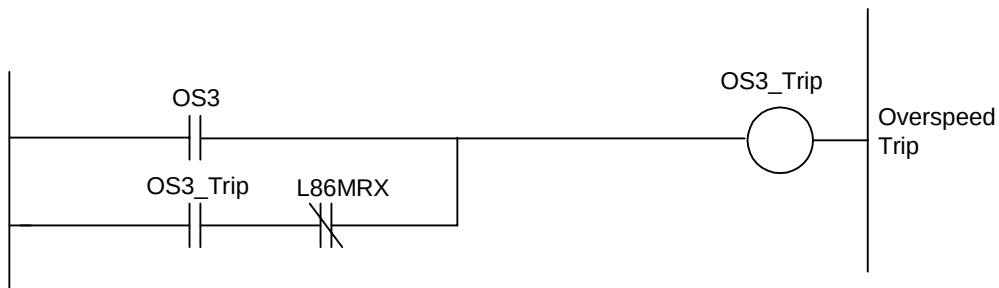
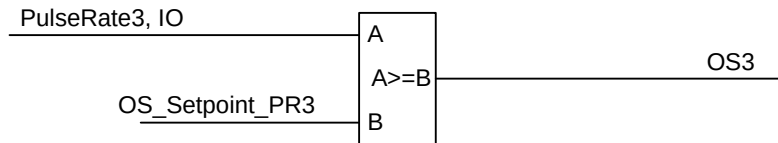
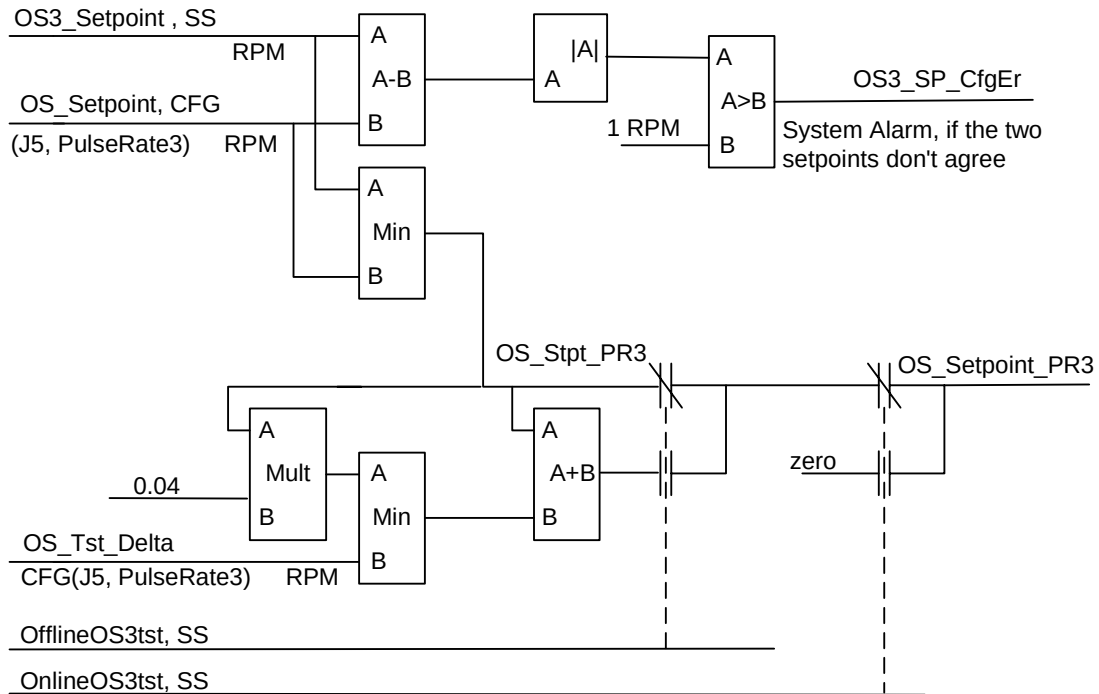


*Note: where 100% is defined as the configured value of OS_Stpt_PR2

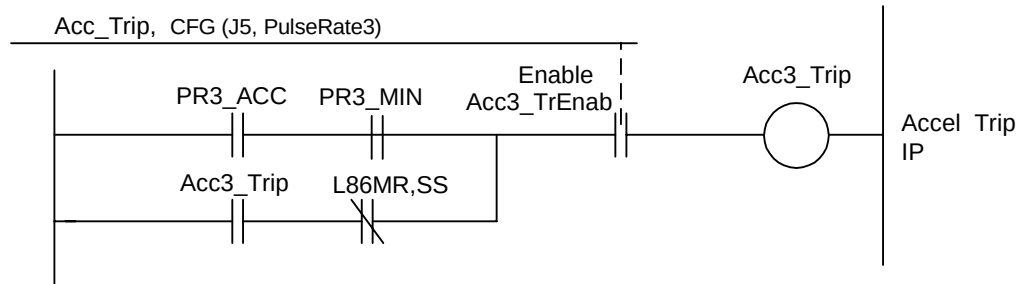
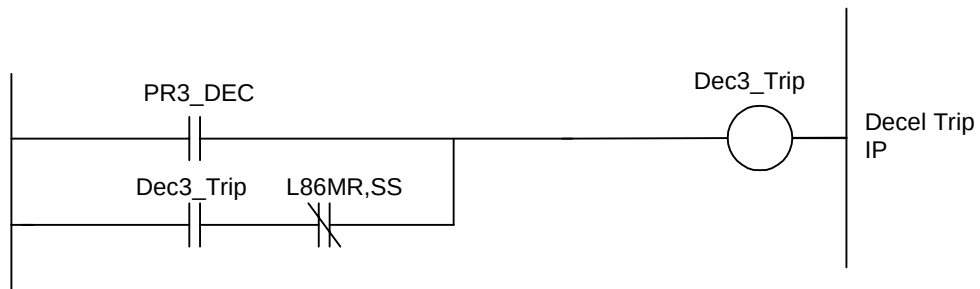
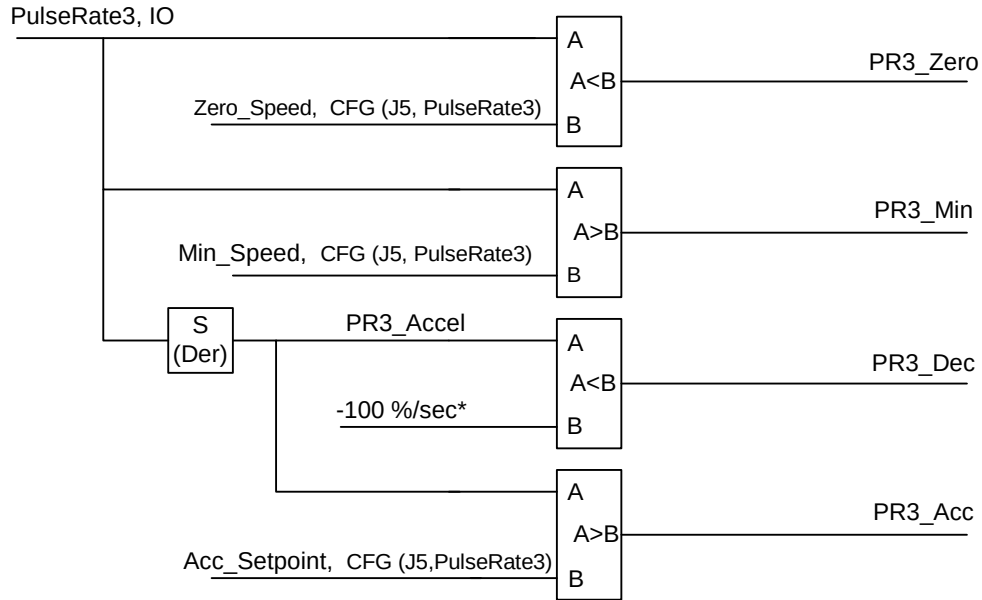
VPRO Protection Logic - Overspeed LP (continued)



VPRO Protection Logic - Overspeed LP (continued)

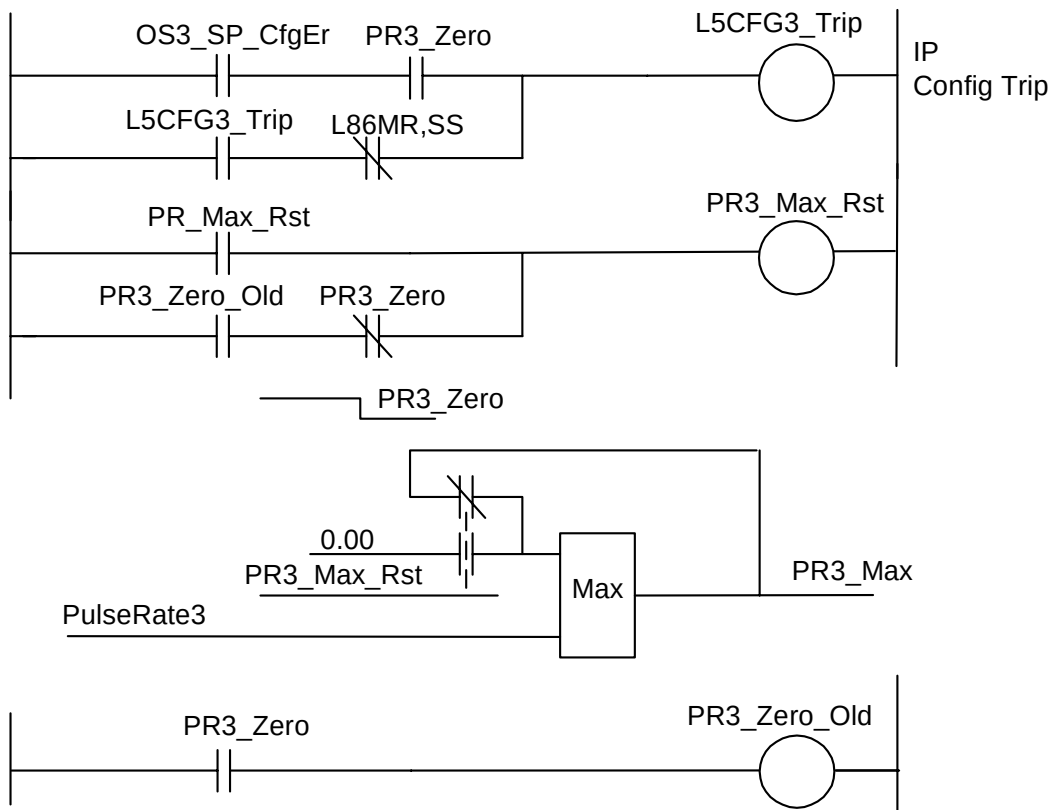


VPRO Protection Logic - Overspeed IP



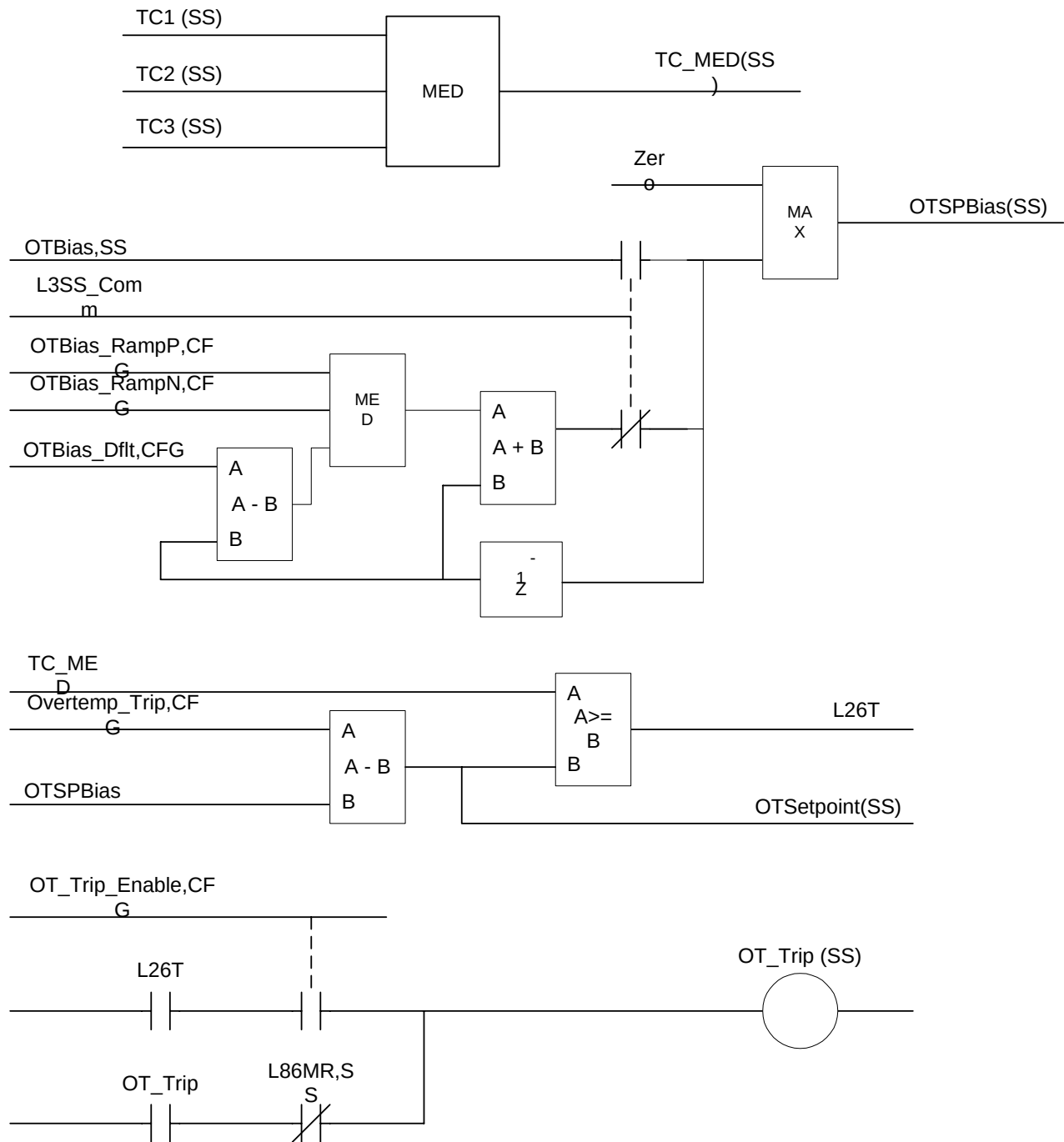
*Note: where 100% is defined as the configured value of OS_Stpt_PR2

VPRO Protection Logic - Overspeed IP (continued)

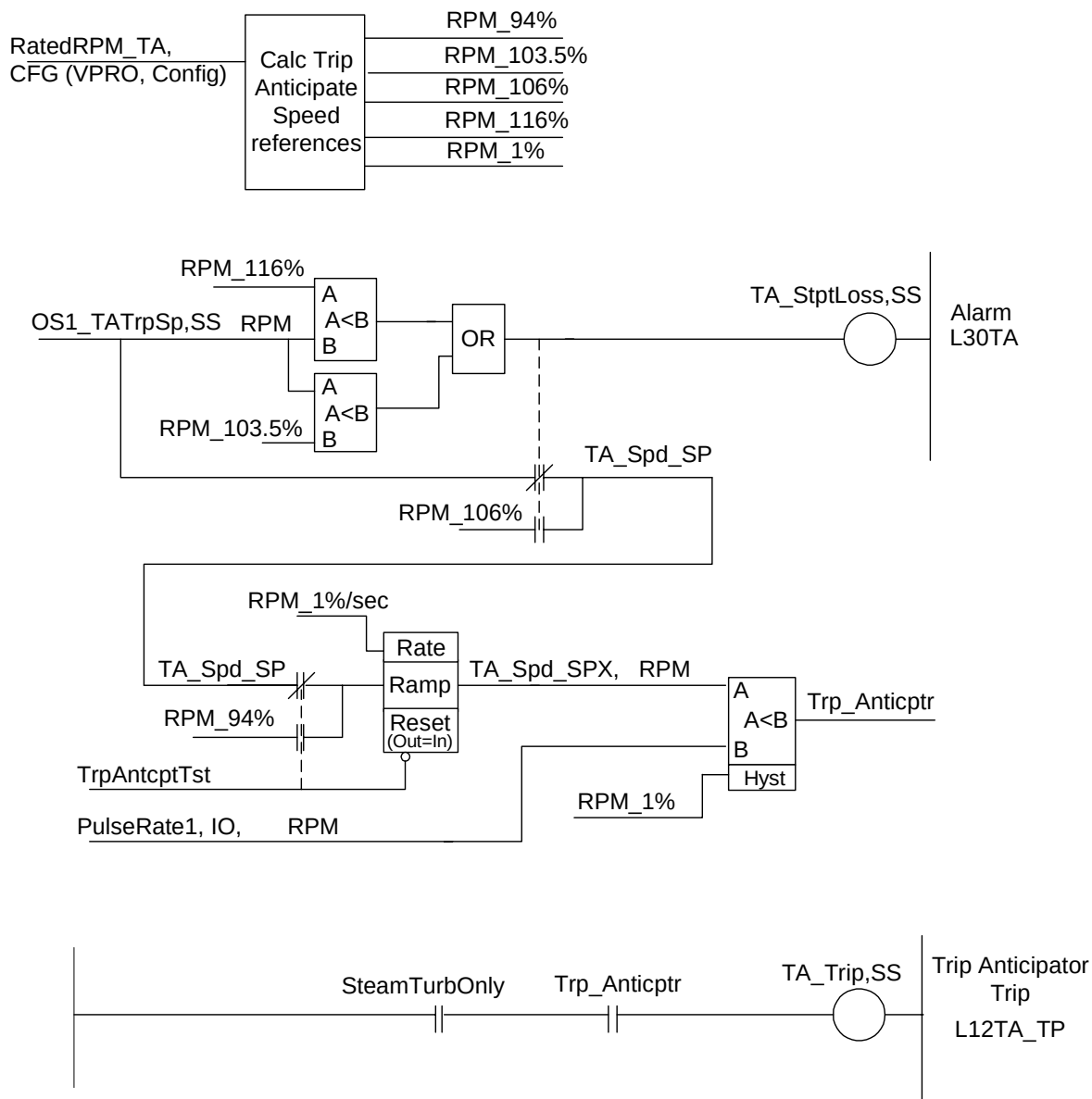


VPRO Protection Logic - Overspeed IP (continued)

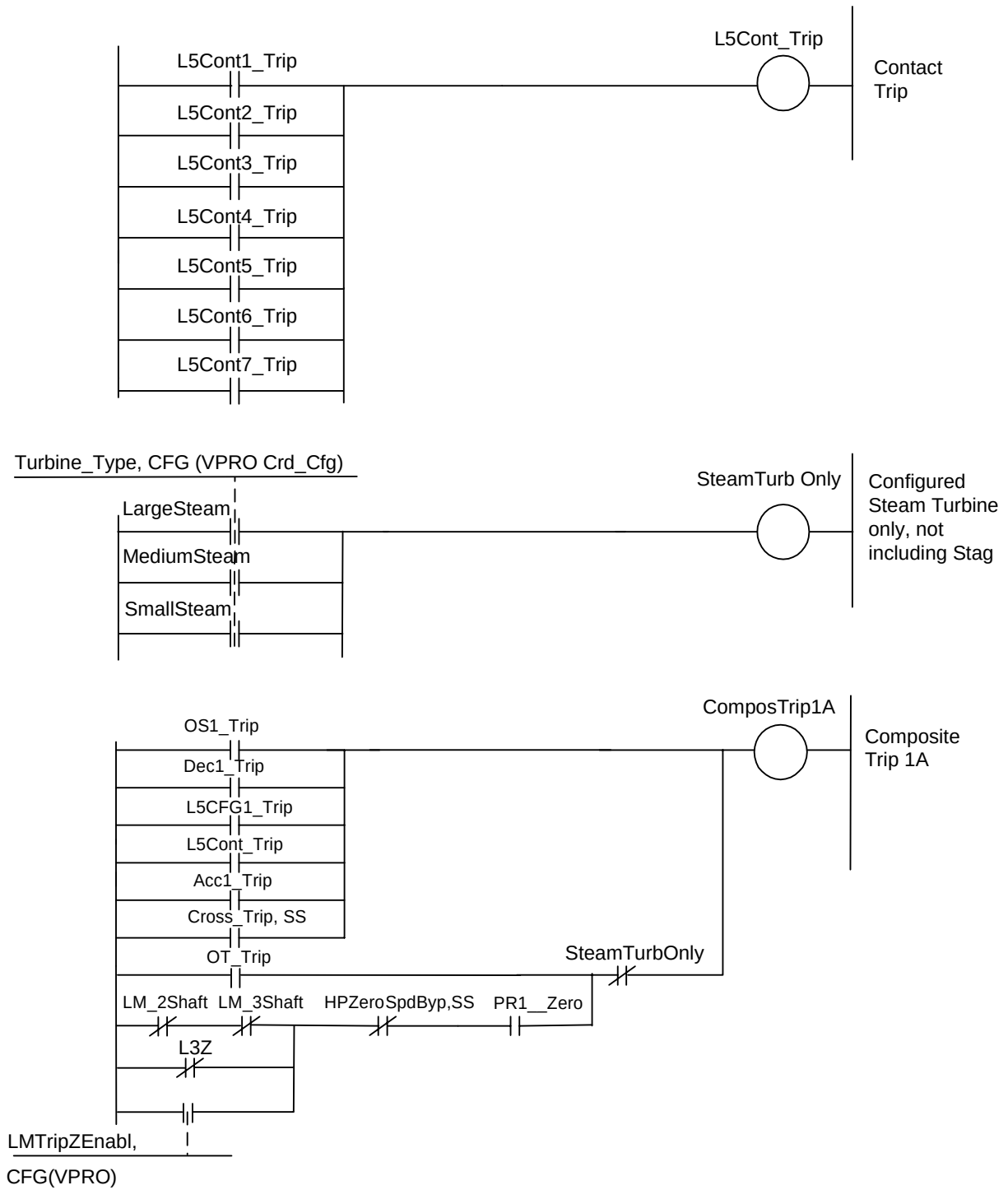
Notes:
,CFG == VPRO config data
,SS == from signal space
(SS) == to signal space



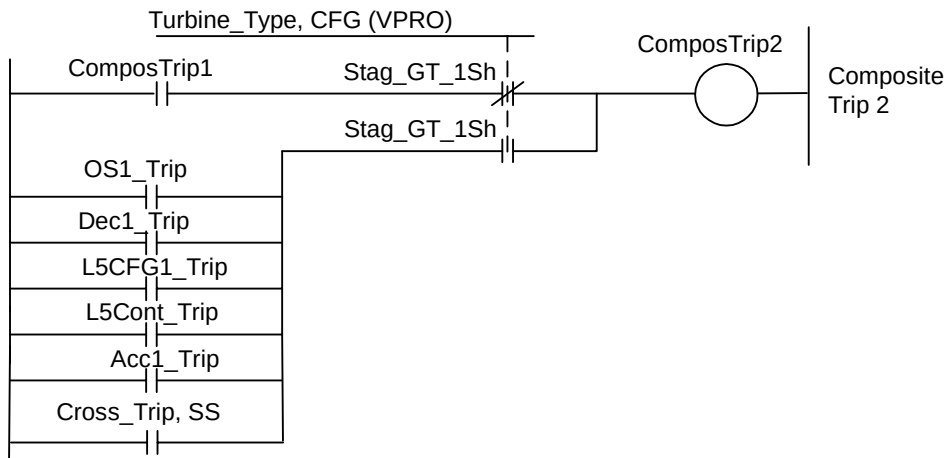
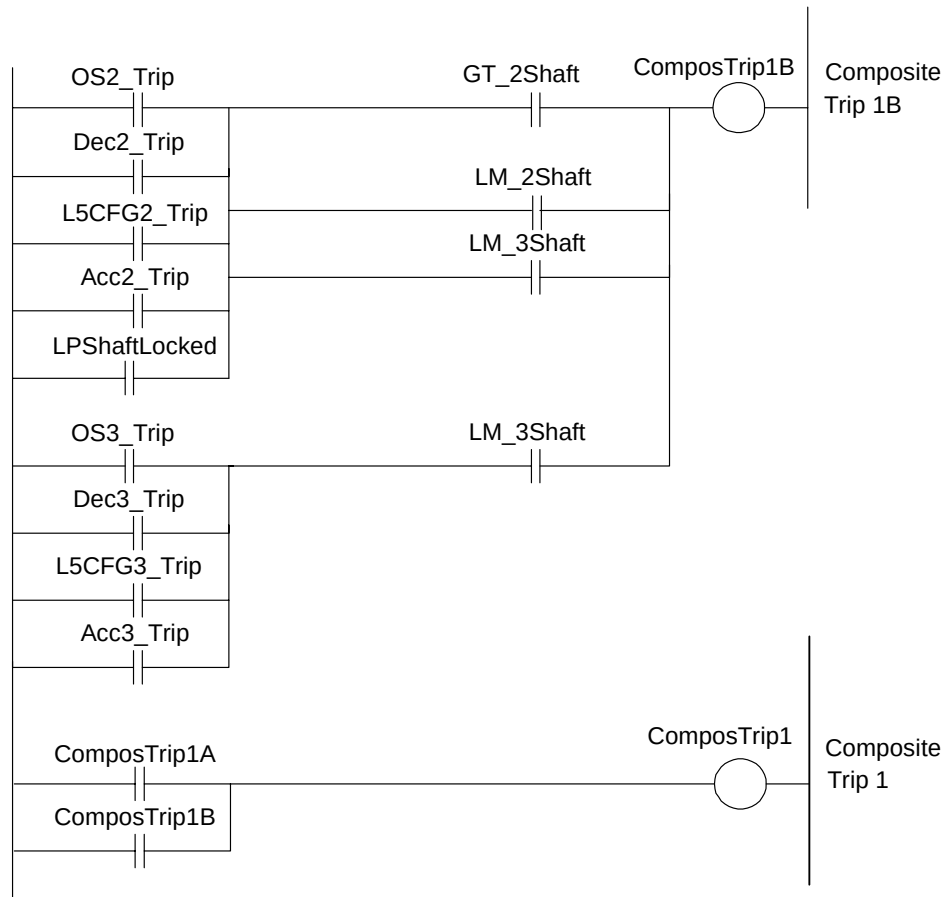
VPRO Protection Logic - Over-Temperature



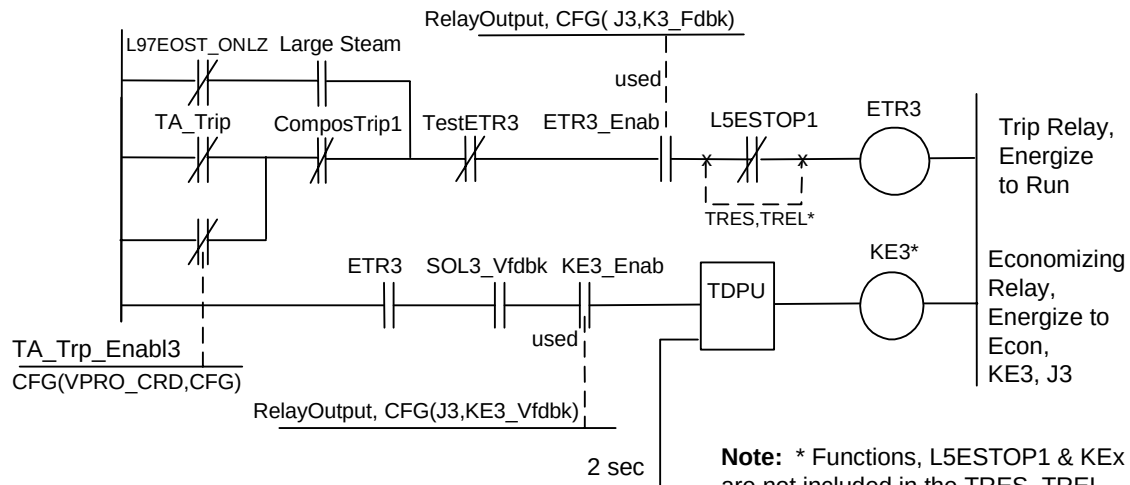
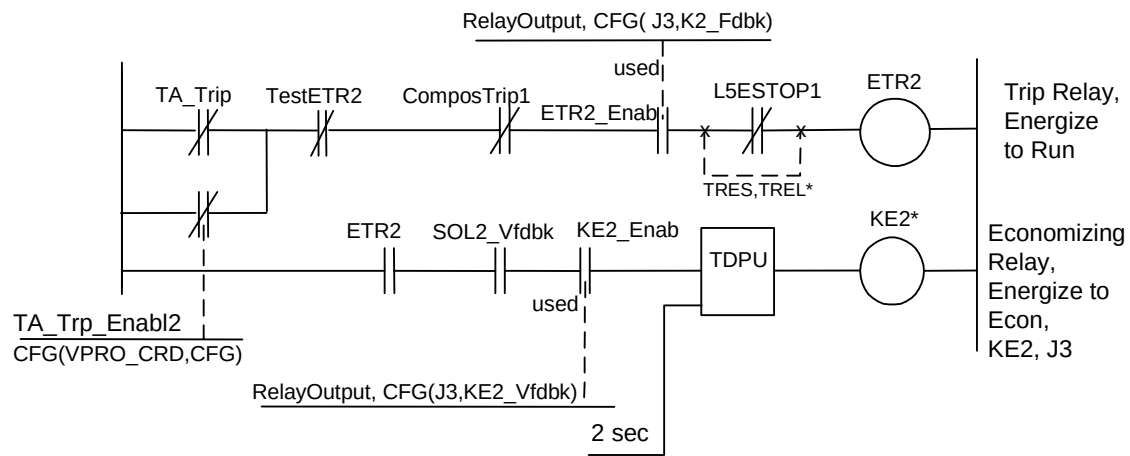
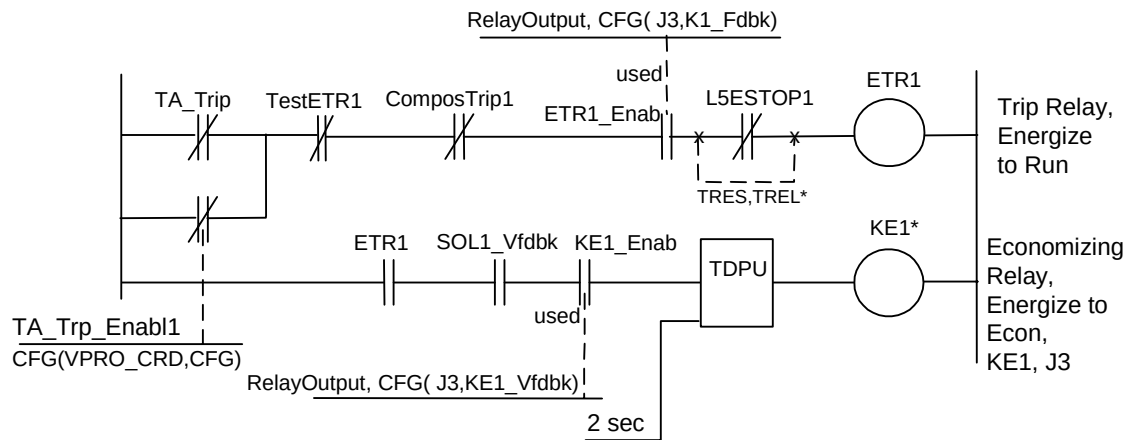
VPRO Protection Logic - Trip Anticipation



VPRO Protection Logic - Trip Logic

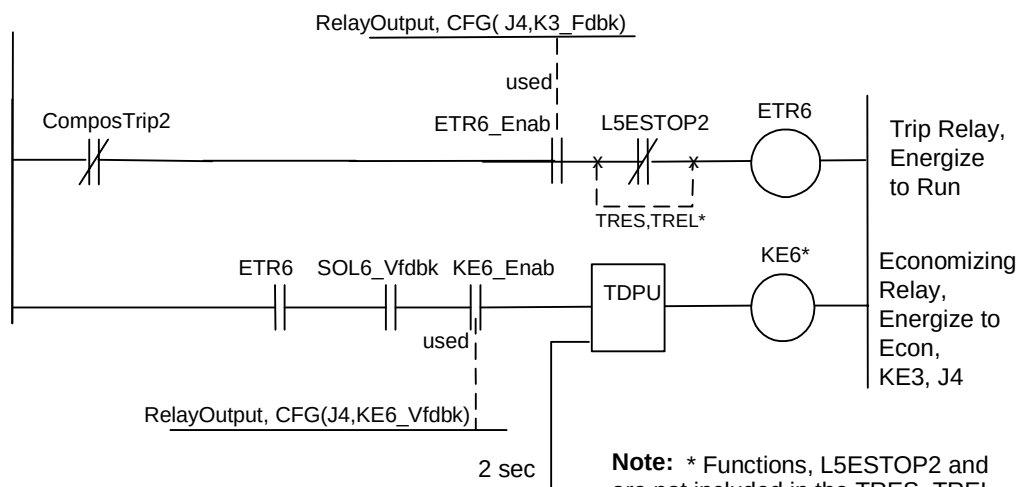
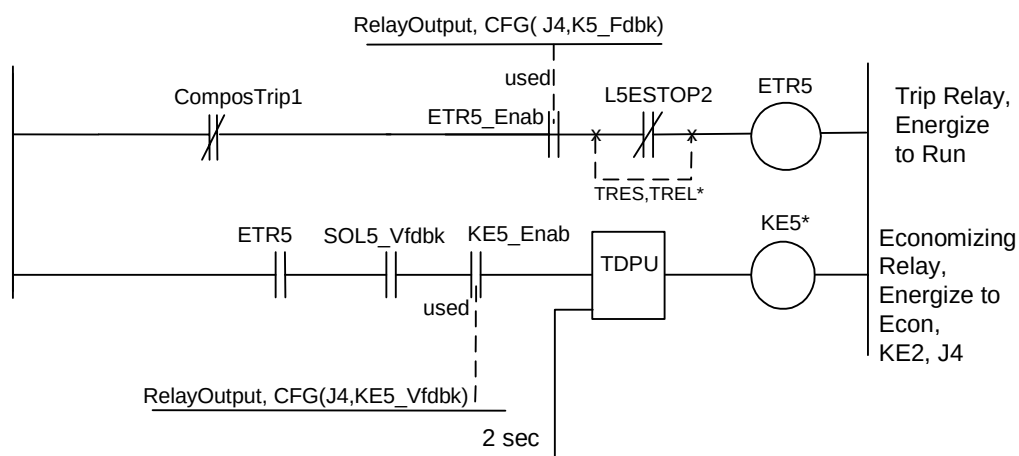
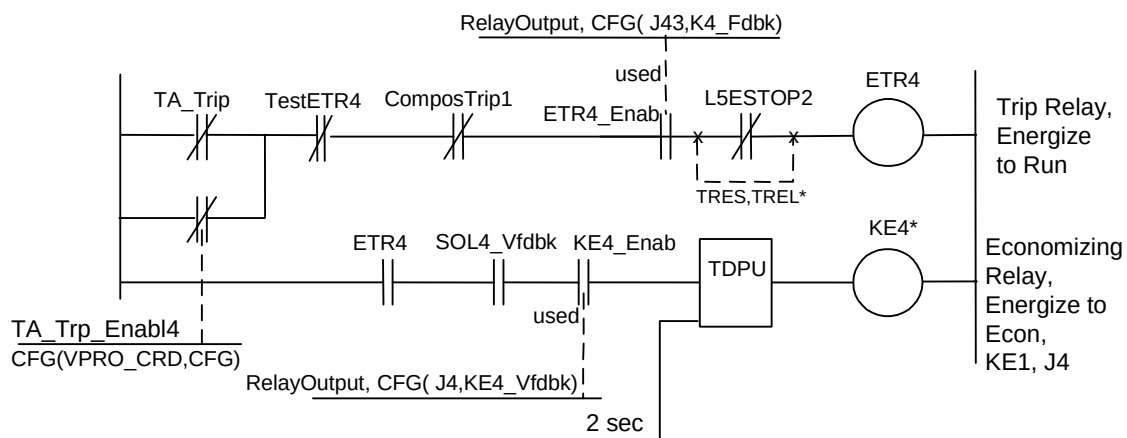


VPRO Protection Logic - Trip Logic (continued)



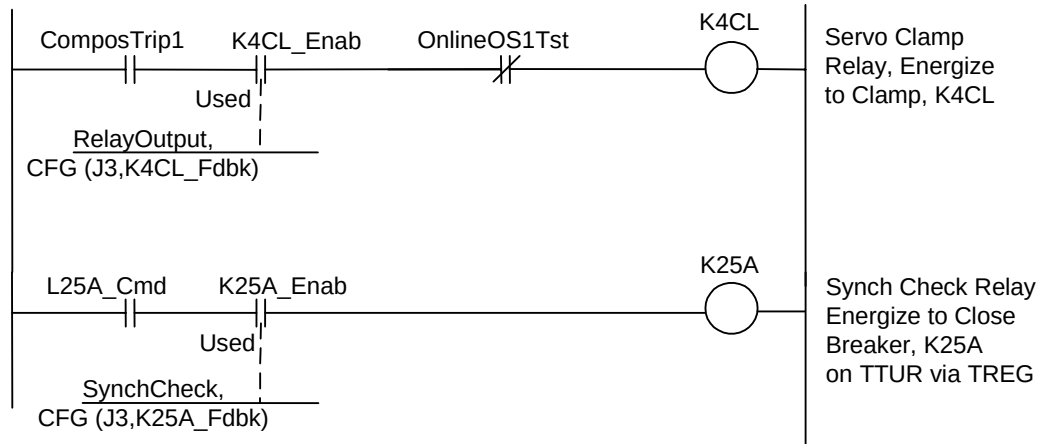
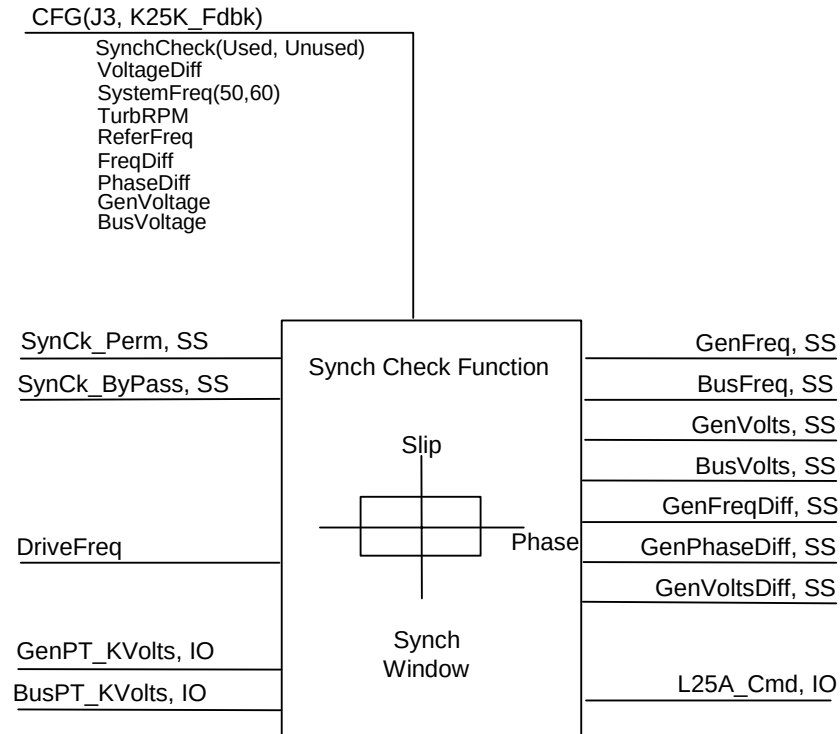
Note: * Functions, L5ESTOP1 & KE_x are not included in the TRES, TREL TB applications. They are included only in the TREG applications.

VPRO Protection Logic - ETR 1, 2, and 3



Note: * Functions, L5ESTOP2 and are not included in the TRES, TREL TB applications. They are included only in the TREG applications.

VPRO Protection Logic - ETR 4, 5, and 6



VPRO Protection Logic - Servo Clamp

Inputs	
TPRO, J5 Speeds, PR	PulseRate1
	PulseRate2
	PulseRate3

TREG, J3 ESTOP1	KESTOP1_Fdbk
Trip Interlocks	Contact1
	Contact2
	Contact3
	Contact4
	Contact5
	Contact6
	Contact7
Voltage to solenoid, feedback	Sol1_Vfdbk
	Sol2_Vfdbk
	Sol3_Vfdbk
Trip Relay feedback	K1_Fdbk*
	K2_Fdbk*
	K3_Fdbk*
Econ Relay feedback	KE1_Fdbk
	KE2_Fdbk
	KE3_Fdbk
Clamp Relay feedback	K4CL_Fdbk
Synch Check Relay feedback	K25A_Fdbk

TREG, J4	KESTOP2_Fdbk
ESTOP2	Sol4_Vfdbk
Voltage to solenoid, feedback	Sol5_Vfdbk
	Sol6_Vfdbk
	K4_Fdbk*
Trip Relay feedback	K5_Fdbk
	K6_Fdbk
	KE4_Fdbk
Econ Relay feedback	KE5_Fdbk
	KE6_Fdbk
	KE6_Fdbk

Inputs	
TPRO, J6	GenPT_KVolts
Gen Volts	BusPT_KVolts
Bus Volts	TC1*
Thermocouples	TC2*
	TC3*
	ColdJunction
Analog Inputs	AnalogIn1
	AnalogIn2
	AnalogIn3

Outputs:	
ETR1	TREG, J3
ETR2	Relays KX1, KY1, KZ1
ETR3	Relays KX2, KY2, KZ2
KE1	Relays KX3, KY3, KZ3
KE2	Relay KE1
KE3	Relay KE2
K4CL	Relay KE3
K25A	Relay K4CL
	Relay K25A

ETR4	TREG, J4
ETR5	Relays KX1, KY1, KZ1
ETR6	Relays KX2, KY2, KZ2
KE4	Relays KX3, KY3, KZ3
KE5	Relay KE4
KE6	Relay KE5
	Relay KE6

***Note:** Each signal appears three times in the CSDB; declared Simplex.

VPRO Protection Logic - Hardware I/O Definition

Inputs	Signal Space
PulseRate1	TPRO,J5
PulseRate2	Speeds, RPM
PulseRate3	
KESTOP1_Fdbk	TREG, J3
Contact1	ESTOP1
Contact2	Contacts
Contact3	
Contact4	
Contact5	
Contact6	
Contact7	
Sol1_Vfdbk	Voltage to solenoid, feedback
Sol2_Vfdbk	
Sol3_Vfdbk	
*K1_Fdbk	Trip Relay feedback
*K2_Fdbk	
*K3_Fdbk	
KE1_Fdbk	Econ Relay feedback
KE2_Fdbk	
KE3_Fdbk	
K4CL_Fdbk	Clamp Relay feedback
K25A_Fdbk	Synch Check Relay feedback
KESTOP2_Fdbk	TREG, J4
Sol4_Vfdbk	ESTOP2
Sol5_Vfdbk	Voltage to solenoid, feedback
Sol6_Vfdbk	
*K4_Fdbk	Trip Relay feedback
K5_Fdbk	
K6_Fdbk	
KE4_Fdbk	Econ Relay feedback
KE5_Fdbk	
KE6_Fdbk	
GenPT_KVolts	TPRO,J6
BusPT_KVolts	Gen Volts
	Bus Volts
*TC1	Thermocouples
*TC2	
*TC3	
ColdJunction	
AnalogIn1	Analog Inputs
AnalogIn2	
AnalogIn3	

Inputs	Signal Space	Outputs:
PR1_Zero	Zero Speed	SynCk_Perm
PR2_Zero		SynCk_ByPass
PR3_Zero		Cross_Trip
OS1_SP_CfgErr	Config Alarm	OnLineOS1Tst
OS2_SP_CfgErr		OnLineOS1X
OS3_SP_CfgErr		OnLineOS2Tst
ComposTrip1	Composite Trips	OnLineOS3Tst
ComposTrip2		OffLineOS1Tst
ComposTrip3		OffLineOS2Tst
L5CFG1_Trip	Config Trip	OffLineOS3Tst
L5CFG2_Trip		TrpAntcptTst
L5CFG3_Trip		LockRotorByp
OS1_Trip	Overspd Trips	HPZeroSpdByp
OS2_Trip		PTR1
OS3_Trip		PTR2
Dec1_Trip	Dec Trips	PTR3
Dec2_Trip		PTR4
Dec3_Trip		PTR5
Acc1_Trip	Accel Trips	PTR6
Acc2_Trip		OS1_Setpoint
Acc3_Trip		OS2_Setpoint
LPShaftLock	LP Shaft Locked	OS3_Setpoint
TA_Trip	Trip	OS1_TATrpSP
TA_StptLoss	TA Antic	CPD
OT_Trip	Ovrtemp Trip	TestETR1
L5ESTOP1	ESTOPs	TestETR2
L5ESTOP2		TestETR3
L5Cont1_Trip	Contact Trips	TestETR4
L5Cont2_Trip		CJBackup
L5Cont3_Trip		L86MR
L5Cont4_Trip		PR_Max_Rst
L5Cont5_Trip		DriveFreq
L5Cont6_Trip		
L5Cont7_Trip		
mA1_Trip	Misc Trips	
mA2_Trip		
mA3_Trip	Relay Test	
L25A_Cmd	Synch Check	
GenFreq		
BusFreq		
GenVolts	Cold Junction Backup	
BusVolts		
GenFreqDiff	VCM (Mstr) Reset	
GenPhaseDiff		
GenVoltsDiff	Max speed Reset	
PR1_Accel	Accel	
PR2_Accel		
PR3_Accel	Gen Center Freq	
PR1_Max		
PR2_Max	Max Speed since the last Zero	
PR3_Max		

***Note:** Each signal appears three times in the CSDB; declared Simplex

VPRO Protection Logic - Signal Space

Inputs	Signal Space
Cont1_TrEnab	Configuration
Cont2_TrEnab	
Cont3_TrEnab	Status
Cont4_TrEnab	
Cont5_TrEnab	
Cont6_TrEnab	
Cont7_TrEnab	
Acc1_TrEnab	
Acc2_TrEnab	
Acc3_TrEnab	
OT_TrEnab	
GT_1Shaft	
GT_2Shaft	
LM_2Shaft	
LM_3Shaft	
LargeSteam	
MediumSteam	
SmallSteam	
Stag_GT_1Sh	
Stag_GT_2Sh	
ETR1_Enab	
ETR2_Enab	
ETR3_Enab	
ETR4_Enab	
ETR5_Enab	
ETR6_Enab	
KE1_Enab	
KE2_Enab	
KE3_Enab	
KE4_Enab	
KE5_Enab	
KE6_Enab	
K4CL_Enab	
K25A_Enab	

VPRO Protection Logic - Signal Space (continued)

Power Load Unbalance

The Power Load Unbalance (PLU) option is used on large steam turbines to protect the machine from overspeed under load rejection. The PLU function looks for an unbalance between mechanical and electrical power. Its purpose is to initiate Control Valve (CV) and Intercept Valve (IV) fast closing actions under load rejection conditions where rapid acceleration could lead to an overspeed event. Valve actuation does not occur under stable fault conditions that are self-clearing (such as grid faults).

Valve action occurs when the difference between turbine power and generator load is typically 40% of rated load or greater, the difference has been sustained for at least 10 milliseconds and the load is lost at a rate equivalent to going from 22.5% rated load to zero in approximately 6 ms (a PLU rate threshold of 37.5 Per Unit Current/Second).

The 40% PLU level setting is standard. If it becomes necessary to deviate from this setting for a specific unit, the fact will be noted by the unit-specific documentation. The PLU unbalance threshold, (PLU_Unbal), may be adjusted from the toolbox.

Turbine mechanical power is derived from a milliamp reheat steam pressure signal. The mechanical power signal source is configurable as follows:

- The mid value of the first three mA inputs (circuits 1, 2, 3)
- The max value of the first two mA inputs (circuits 1, 2)
- A single transducer, circuit 1
- A single transducer, circuit 2
- A signal from signal space, where Mechanical Power is calculated in the controller, in percent

The generator load is assumed to be proportional to the sum of the 3-phase currents, thereby discriminating between load rejection and power line faults. This discrimination would not be possible if a true MW signal was used.

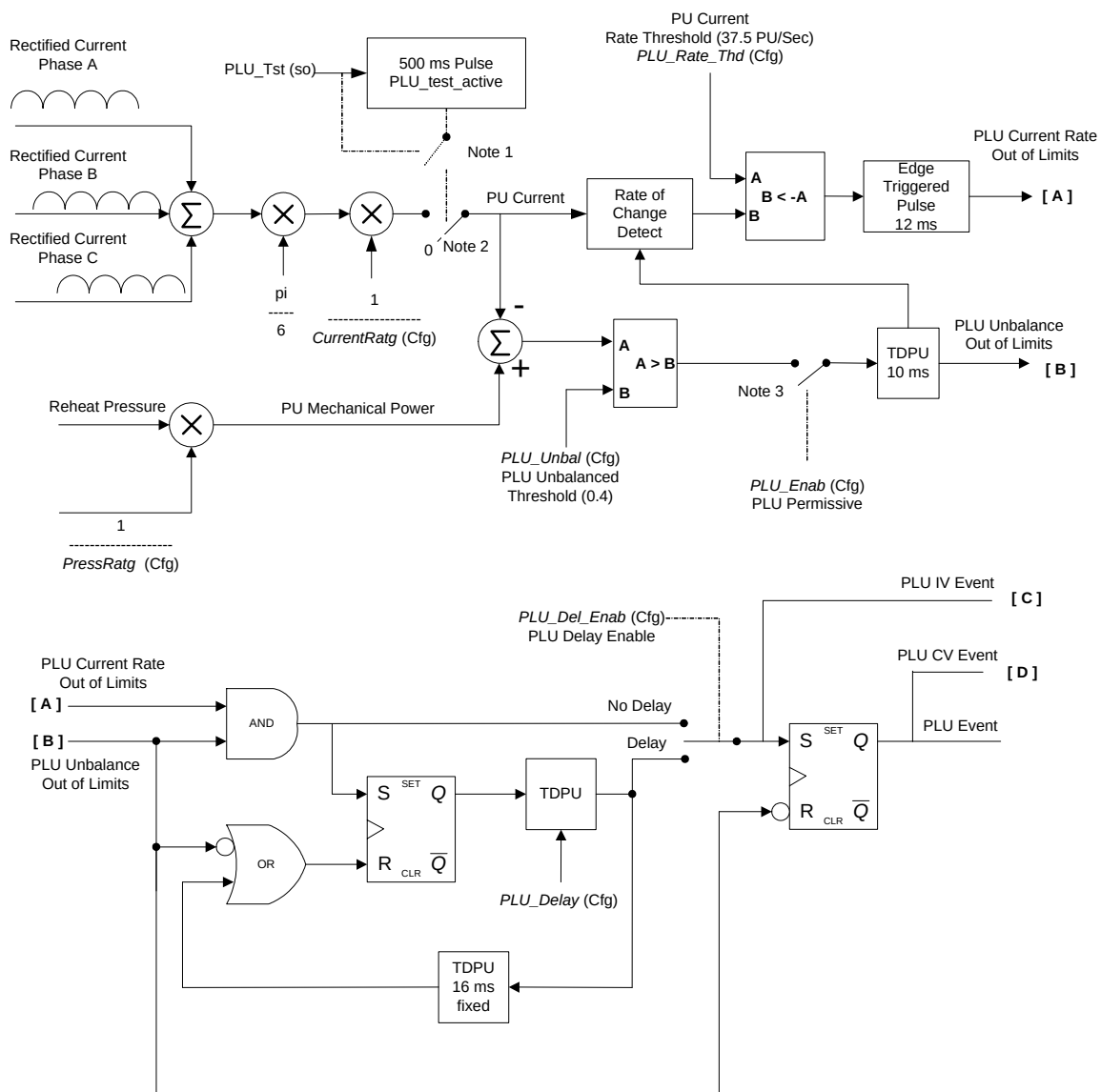
The PLU signal actuates the CV and IV fast closing solenoids and resets the Load Reference signal to the no-load value (and performs some auxiliary functions).



Caution

The PLU function is an important part of the overspeed protective system. Do not disable during turbine operation.

The three current signals from the station current transformers are reduced by three auxiliary transformers on TGEN. These signals are summed in the controller and compare to the power pressure signal from the reheat pressure sensor. The signals are qualified (normalized) according to the Current Rating and Press Rating configuration parameters. This comparison yields a qualified unbalance measure of the PLU, as shown by signal B in the following figure. The output of the total generator current is also fed into the current rate amplifier. This comparison provides a measure of the rate of change of the generator current, signal A. The current rate level may be adjusted through the PLU rate threshold function (PLU_Rate). This value must be set at 37.5 (PU/Sec).



Notes: (1) Closed when PLU_tst (so) is enabled
 (2) Force to 0 when PLU_test_active
 (3) Closed when PLU_Enab (cfg) is enabled

PLU Valve Actuation Logic

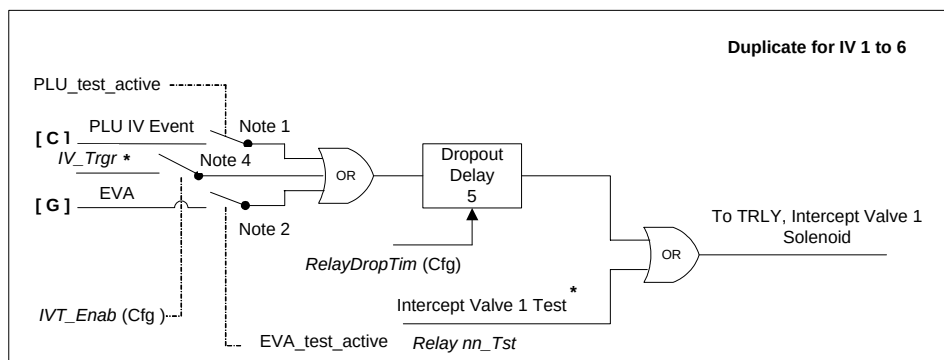
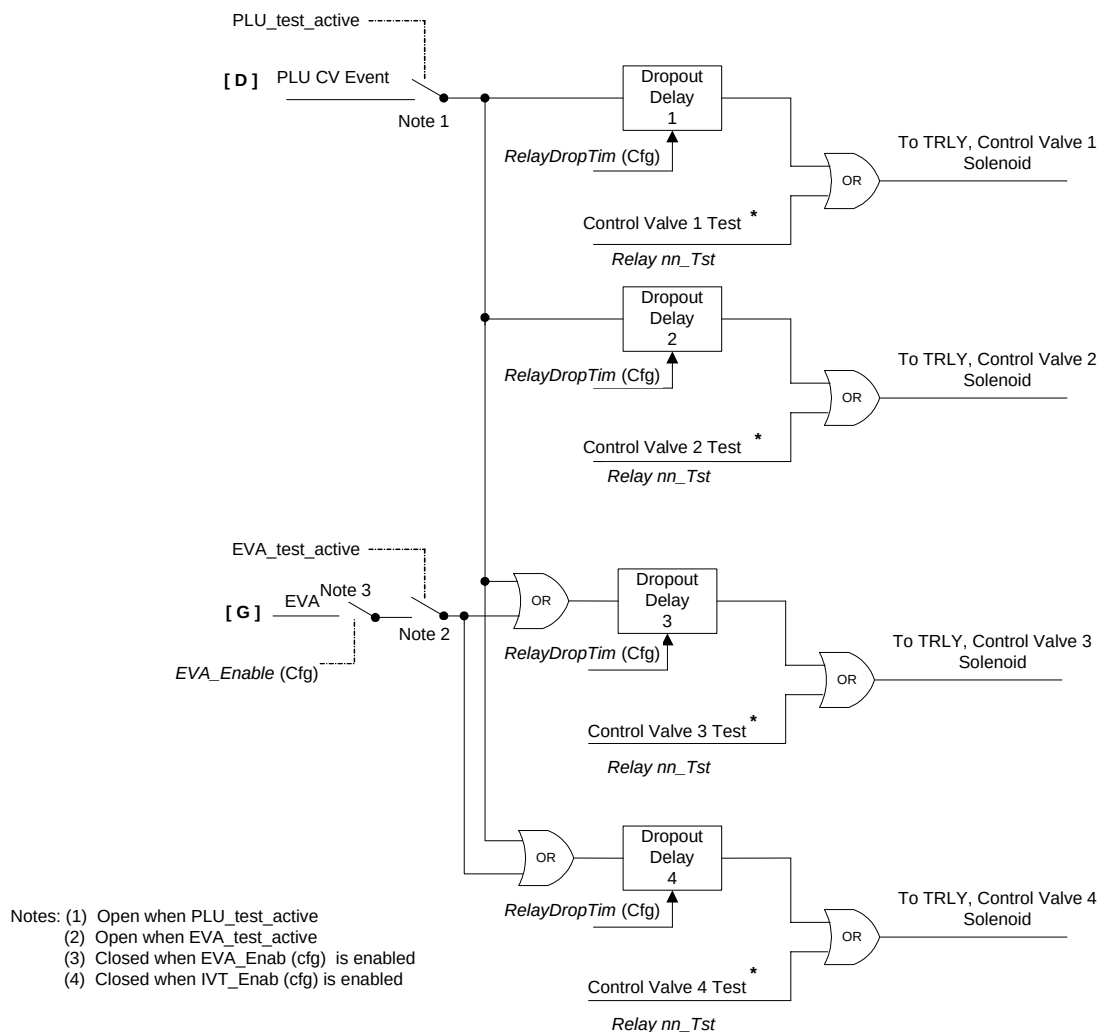
If these comparators operate simultaneously, PLU action is initiated and latched, making continuation of the PLU action dependent only on the unbalance for all functions except IV fast closing. The IVs do not lock in, but remain closed for approximately one second and then begin to re-open regardless of PLU duration.

A time-delay may be implemented for the PLU function. To initiate the delay, go to the Enable PLU response delay parameter (PLU_Del_Enab) and select Enable. The duration of the time-delay can be adjusted by altering the value of the PLU delay (PLU_Delay) parameter.

These dropout times have been arrived at based on experience, and are used to reduce the transient load on the hydraulic system.

The IVs and CVs may be operated through test signals from the controller. These signals are executed individually and are logic ORed with the above signals as shown in following figure. The IVs may also be driven by the Early Valve Actuation (EVA) and IV Trigger (IVT) functions. Each solenoid has a unique dropout time delay, refer to the following table and figure.

<i>Solenoid Drop-Out Point Delay Values</i>										
Steam Valve	IV1	IV2	IV3	IV4	IV5	IV6	CV1	CV2	CV3	CV4
Dropout Delay, seconds	1.35	1.50	1.75	1.35	1.75	1.50	1.10	2.00	3.00	4.00



Spare 7-12 Test

Spare Solenoid 7-12 Control

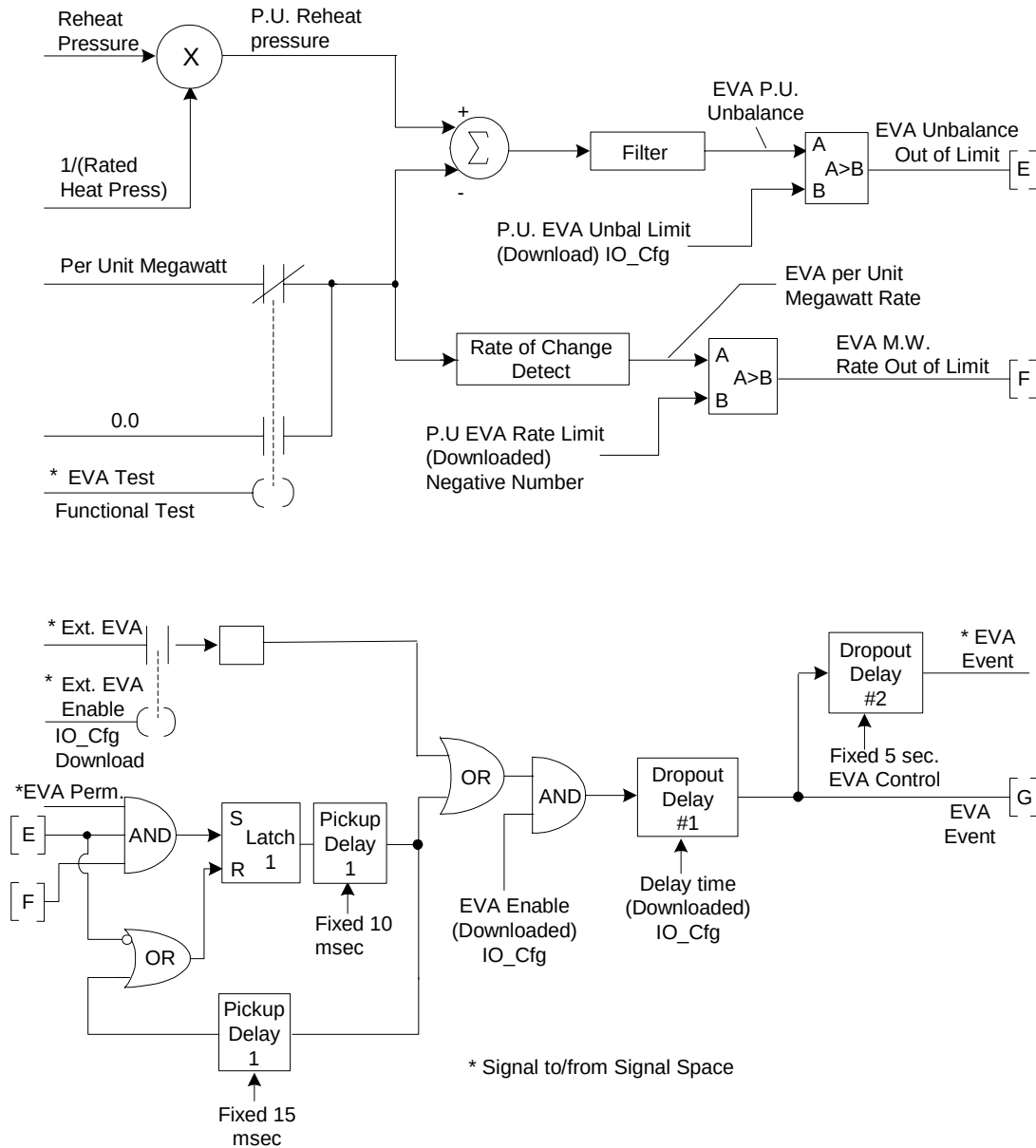
Spare Solenoid
Control Signals

*
Signal to/from System

Fast Acting Solenoid Sequencing

Early Valve Actuation

The Early Valve Actuation (EVA) system was developed for power systems where instability, such as the loss of synchronization, is a problem. When the EVA senses a fault that is not a load rejection, it causes closing of the Intercept Valves (IV) for approximately one second. This action reduces the available mechanical power to that of the already reduced electrical power, and therefore prevents too large an increase in the machine angle and the consequent loss of synchronization. See following figure for the valve actuation diagram.



EVA Valve Actuation Logic

Intercept Valve Trigger

The peak speed following rejection of 10% or greater rated load cannot be maintained within limits on some units by the normal speed and servo control action. Approximately 70% of turbine power is generated in the reheat and low-pressure turbine sections (the boiler re-heater volume represents a significant acceleration energy source). Fast closing of the IVs can therefore quickly reduce turbine power and peak overspeed. The action fulfills the first basic function of normal overspeed control, limiting peak speed. The Intercept Valve Trigger (IVT) signal is produced in the controller by the IVT algorithm and associated sequencing, see the previous figure, EVA Valve Actuation Logic.

Early Valve Actuation (EVA)

The EVA function may be implemented on sites where instability, such as loss of synchronization, presents a problem. EVA closes the IVs for approximately one second upon sensing a fault that is not a load rejection. This action reduces the available mechanical power, thereby inhibiting the loss of synchronization that can occur as a result of increased machine angle (unbalance between mechanical and electrical power). If the fault persists, the generator loses synchronization and the turbine is tripped by the overspeed control or out-of-step relaying.

The EVA is enabled in the toolbox by selecting Enable for the EVA_Enab parameter. The conditions for EVA action are as follows:

- The difference between mechanical power (reheat pressure) and electrical power (megawatts) exceeds the configured EVA unbalance threshold (EVA_Unbal) input value.
- Electrical power (megawatts) decreases at a rate equivalent to (or greater than) one of three rates configured for EVA megawatt rate threshold (EVA_Rate). This value is adjustable according to three settings: High, MEdium, and LOw. These settings correspond to 50, 35, and 20 ms rates respectively.

Note The megawatt signal is derived from voltage and current signals provided by customer-supplied transformers located on the generator side of the circuit breaker.

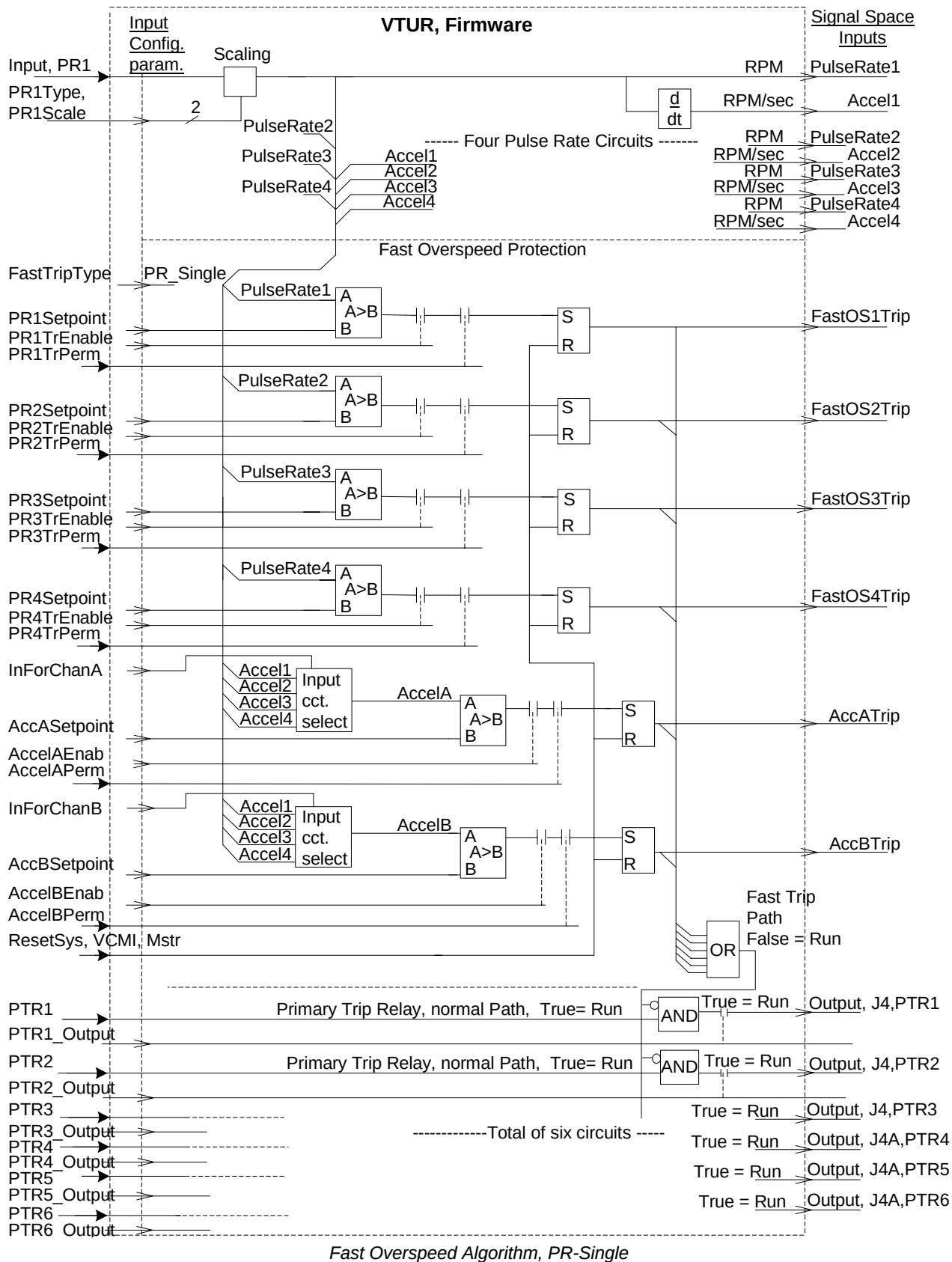
The EVA_Unbal value represents the largest fault a particular generator can sustain without losing synchronization. Although the standard setting for this constant is 70%, it may be adjusted up or down 0 to 2 per unit from the toolbox. All EVA events are annunciated.

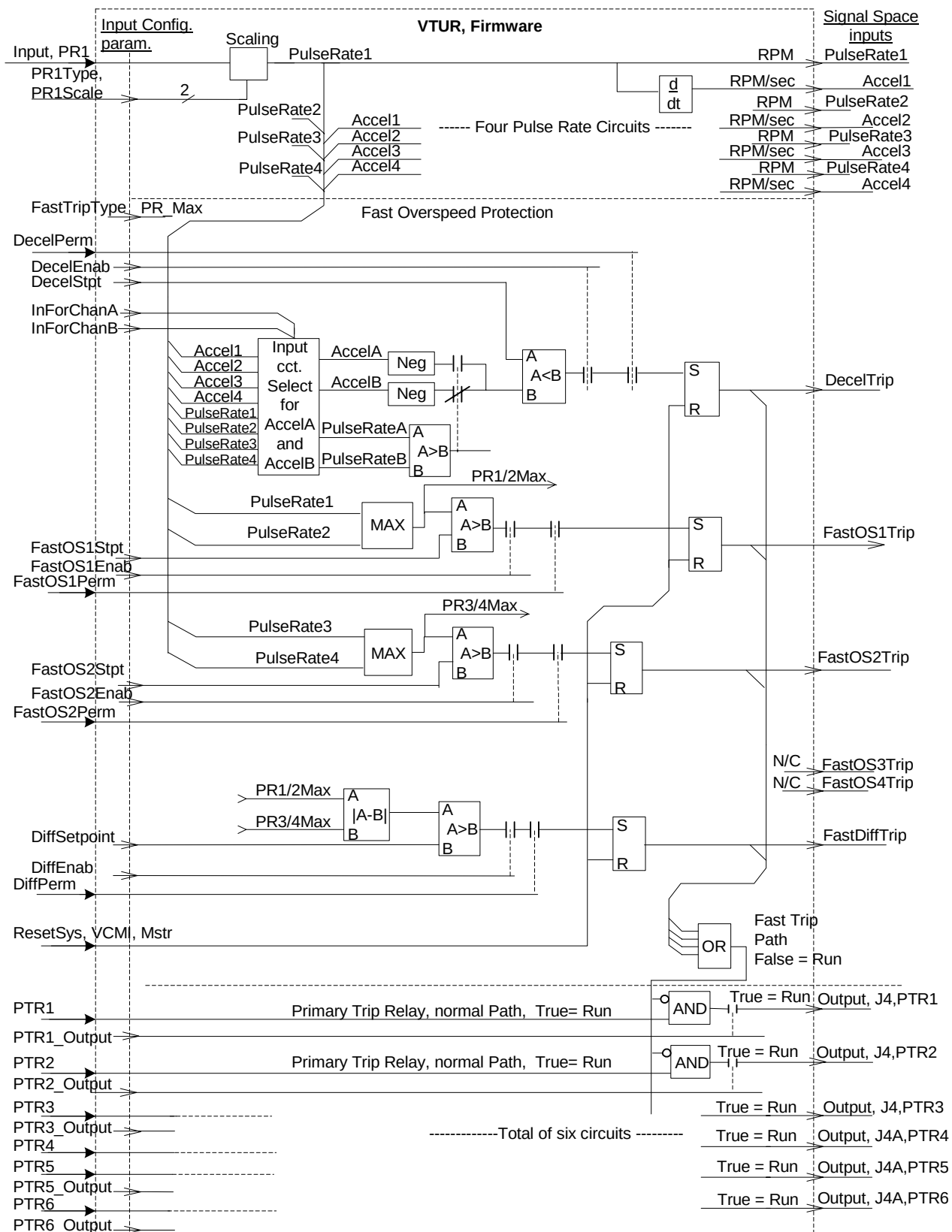
Fast Overspeed Trip in VTUR

In special cases where a faster overspeed trip system is required, the VTUR Fast Overspeed Trip algorithms may be enabled. The system employs a speed measurement algorithm using a calculation for a predetermined tooth wheel. Two overspeed algorithms are available in VTUR as follows:

- **PR_Single.** This uses two redundant VTUR boards by splitting up the two redundant PR transducers, one to each board.
- **PR_Max.** This uses one VTUR board connected to the two redundant PR transducers. PR_Max allows broken shaft and deceleration protection without the risk of a nuisance trip if one transducer is lost.

The fast trips are linked to the output trip relays with an OR-gate as shown in the following figures. VTUR computes the overspeed trip, not the controller, so the trip is very fast. The time from the overspeed input to the completed relay dropout is 30 msec or less.



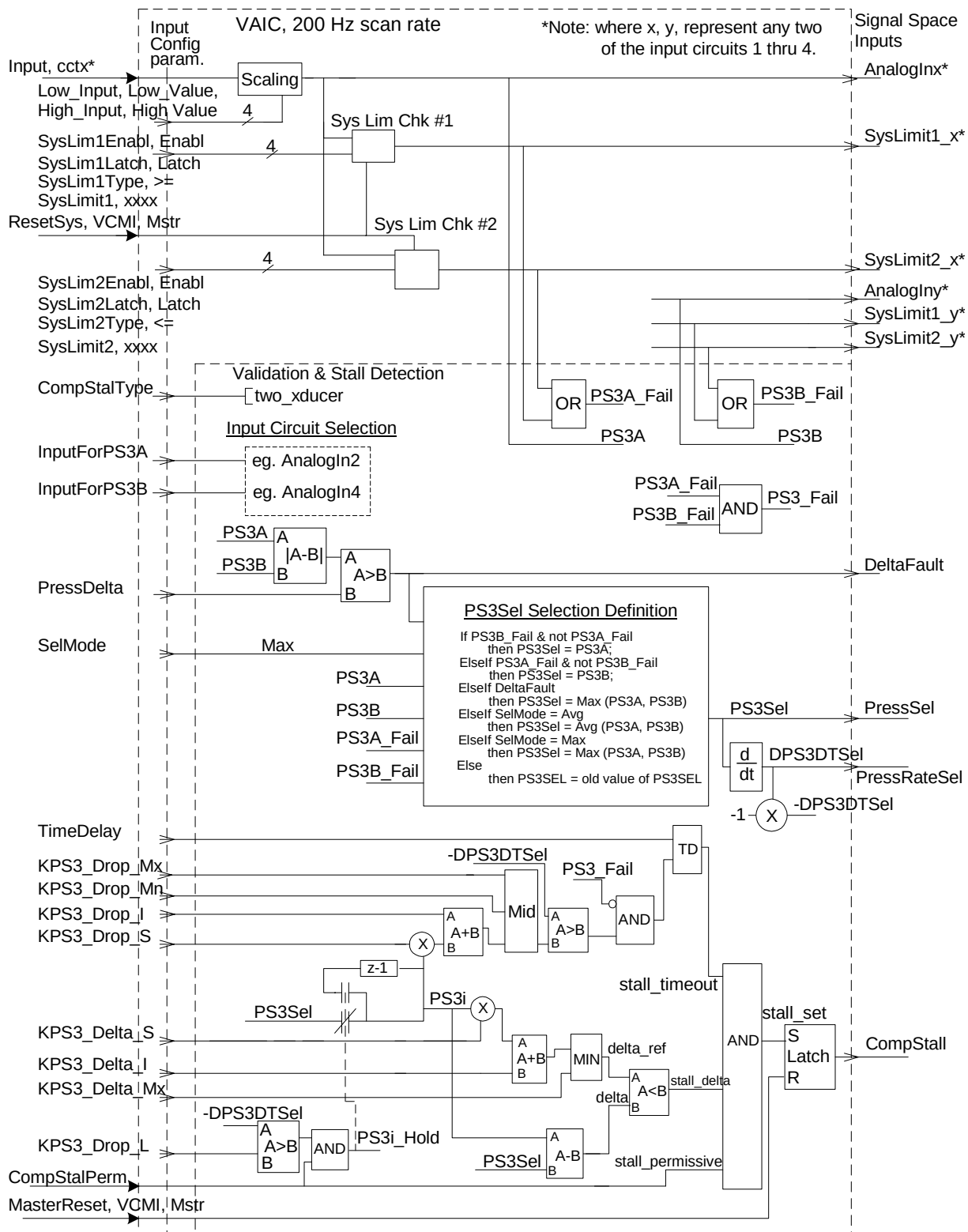


Compressor Stall Detection

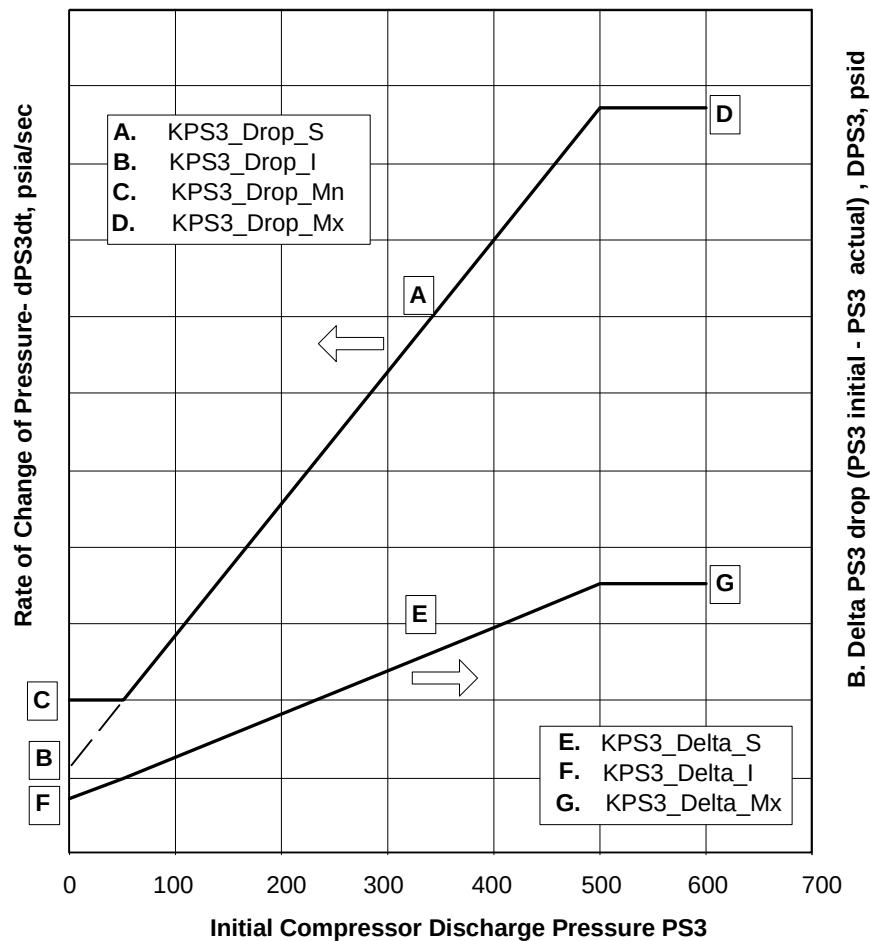
Gas turbine compressor stall detection is included with the VAIC firmware and is executed at a rate of 200 Hz. There is a choice of two stall algorithms and both use the first four analog inputs, scanned at 200 Hz. One algorithm is for small LM gas turbines and uses two pressure transducers. The other algorithm is for heavy-duty gas turbines and uses three pressure transducers, refer to the figures below.

Real-time inputs are separated from the configured parameters for clarity. The parameter `CompStalType` selects the type of algorithm required, either two transducers or three. `PS3` is the compressor discharge pressure, and a drop in this pressure (`PS3` drop) is an indication of a possible compressor stall. In addition to the drop in pressure, the algorithm calculates the rate of change of discharge pressure, `dPS3dt`, and compares these values with configured stall parameters (`KPS3` constants). Refer to the figures below.

The compressor stall trip is initiated by VAIC, and the signal is sent to the controller where it is used to initiate a shutdown. The shutdown signal can be used to set all the fuel shut-off valves (FSOV) through the VCRC and TRLY or DRLY board.



Small (LM) Gas Turbine Compressor Stall Detection Algorithm



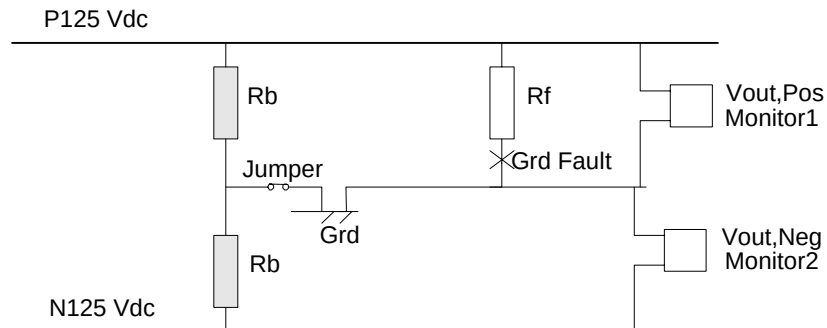
Configurable Compressor Stall Detection Parameters

The variables used by the stall detection algorithm are defined as follows:

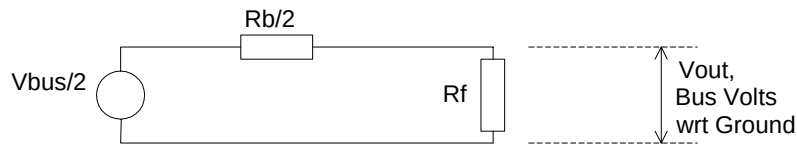
PS3	Compressor discharge pressure
PS3I	Initial PS3
KPS3_Drop_S	Slope of line for PS3I versus dPS3dt
KPS3_Drop_I	Intercept of line for PS3I versus dPS3dt
KPS3_Drop_Mn	Minimum value for PS3I versus dPS3dt
KPS3_Drop_Mx	Maximum value for PS3I versus dPS3dt
KPS3_Delta_S	Slope of line for PS3I versus Delta PS3 drop
KPS3_Delta_I	Intercept of line for PS3I versus Delta PS3 drop
KPS3_Delta_Mx	Maximum value for PS3I versus Delta PS3 drop

Ground Fault Detection Sensitivity

Ground fault detection on the floating 125 V dc power bus is based upon monitoring the voltage between the bus and the ground. The bus voltages with respect to ground are normally balanced (in magnitude), that is the positive bus to ground is equal to the negative bus to ground. The bus is forced to the balanced condition by the bridging resistors, R_b as shown in the following figure. Bus leakage (or ground fault) from one side will cause the bus voltages with respect to ground to be unbalanced. Ground fault detection is performed by the VCMI using signals from the PDM. Refer to Volume II of this System Guide.



Electrical Circuit Model



Ground Fault on Floating 125 V dc Power Bus

There is a relationship between the bridge resistors, the fault resistance, the bus voltage, and the bus to ground voltage (V_{out}) as follows:

$$V_{out} = V_{bus} * R_f / [2 * (R_f + R_b/2)]$$

Therefore the threshold sensitivity to ground fault resistance is as follows:

$$R_f = V_{out} * R_b / (V_{bus} - 2 * V_{out}).$$

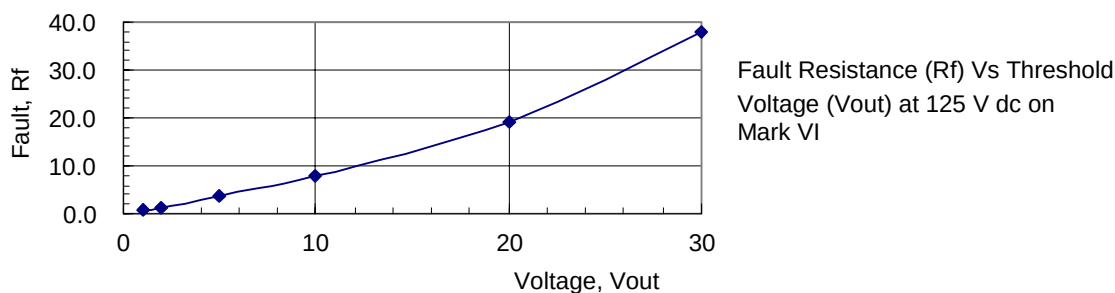
The ground fault threshold voltage is typically set at 30 V, that is $V_{out} = 30$ V. The bridging resistors are 82 K each. Therefore, from the formula above, the sensitivity of the control panel to ground faults, assuming it is on one side only, is as shown in the following figure.

Note On Mark V, the bridging resistors are 33 K each so different V_{out} values result.

Sensitivity to Ground Faults

Vbus - Bus voltage	Vout - Measured Bus to ground voltage (threshold)	Rb (Kohms) - bridge resistors (balancing)	Rf (Kohms) - fault resistor	Control System
105	30	82	55	Mark VI
125	30	82	38	Mark VI
140	30	82	31	Mark VI
105	19	82	23	Mark VI
125	19	82	18	Mark VI
140	19	82	15	Mark VI
105	10	82	10	Mark VI
125	10	82	8	Mark VI
140	10	82	7	Mark VI
105	30	33	22	Mark V
125	30	33	15	Mark V
140	30	33	12	Mark V

The results for the case of 125 V dc bus voltage with various fault resistor values is shown in the following figure.



Threshold Voltage as Function of Fault Resistance

Analysis of Results

On Mark VI, when the voltage threshold is configured to 30 V and the voltage bus is 125 V dc, the fault threshold is 38 Ω . When the voltage threshold is configured to 17 V and the voltage bus is 125 V dc, the fault threshold is 15 Ω .

The sensitivity of the ground fault detection is configurable. Balanced bus leakage decreases the sensitivity of the detector.

Notes

Glossary of Terms

application code

Software that controls the machines or processes, specific to the application.

ARCNet

Attached Resource Computer Network. A LAN communications protocol developed by Datapoint Corporation. The physical (coax and chip) and datalink (token ring and board interface) layer of a 2.5 MHz communication network which serves as the basis for DLAN+.

ASCII

American Standard for Code for Information Interchange (ASCII). An 8-bit code used for data.

Asynchronous Device Language (ADL)

An application layer protocol used for I/O communication on IONet.

attributes

Information, such as location, visibility, and type of data that sets something apart from others. In signals, an attribute can be a field within a record.

Balance of Plant (BOP)

Plant equipment other than the turbine that needs to be controlled.

Basic Input/Output System (BIOS)

Performs the controller boot-up, which includes hardware self-tests and the file system loader. The BIOS is stored in EEPROM and is not loaded from the toolbox.

baud

A unit of data transmission. Baud rate is the number of bits per second transmitted.

Bently Nevada

A manufacturer of shaft vibration monitoring equipment.

bit

Binary Digit. The smallest unit of memory used to store only one piece of information with two states, such as One/Zero or On/Off. Data requiring more than two states, such as numerical values 000 to 999, requires multiple bits (see Word).

block

Instruction blocks contain basic control functions, which are connected together during configuration to form the required machine or process control. Blocks can perform math computations, sequencing, or continuous control. The toolbox receives a description of the blocks from the block libraries.

board

Printed wiring board.

Boolean

Digital statement that expresses a condition that is either True or False. In the toolbox, it is a data type for logical signals.

Bus

An electrical path for transmitting and receiving data.

byte

A group of binary digits (bits); a measure of data flow when bytes per second.

CIMPLICITY

Operator interface software configurable for a wide variety of control applications.

COM port

Serial controller communication ports (two). COM1 is reserved for diagnostic information and the Serial Loader. COM2 is used for I/O communication.

Computer Operator Interface (COI)

Interface that consists of a set of product and application specific operator displays running on a small cabinet computer hosting Embedded Windows NT.

configure

To select specific options, either by setting the location of hardware jumpers or loading software parameters into memory.

Current Transformer (CT)

Measures current in an ac power cable.

Cyclic Redundancy Check (CRC)

Detects errors in Ethernet and other transmissions.

data server

A computer which gathers control data from input networks and makes the data available to computers on output networks.

dead band

A range of values in which the incoming signal can be altered without changing the output response.

device

A configurable component of a process control system.

DIN-rail

European standard mounting rail for electronic modules.

Distributed Control System (DCS)

Control system, usually applied to control of boilers and other process equipment.

DLAN+

GE Energy LAN protocol, using an ARCNET controller chip with modified ARCNET drivers. A communication link between exciters, drives, and controllers, featuring a maximum of 255 drops with transmissions at 2.5 MBPS.

Ethernet

LAN with a 10/100 M baud collision avoidance/collision detection system used to link one or more computers together. Basis for TCP/IP and I/O services layers that conform to the IEEE 802.3 standard, developed by Xerox, Digital, and Intel.

Ethernet Global Data (EGD)

Control network and protocol for the controller. Devices share data through EGD exchanges (pages).

EX2000 (Exciter)

Latest version of GE generator exciter control; regulates the generator field current to control the generator output voltage.

fanned input

An input to the terminal board which is connected to all three TMR I/O boards.

fault code

A message from the controller to the HMI indicating a controller warning or failure.

Finder

A subsystem of the toolbox for searching and determining the usage of a particular item in a configuration.

firmware

The set of executable software that is stored in memory chips that hold their content without electrical power, such as EEPROM.

flash

A non-volatile programmable memory device.

forcing

Setting a live signal to a particular value, regardless of the value blockware or I/O is writing to that signal.

frame rate

Basic scheduling period of the controller encompassing one complete input-compute-output cycle for the controller. It is the system-dependent scan rate.

function

The highest level of the blockware hierarchy, and the entity that corresponds to a single .tre file.

gateway

A device that connects two dissimilar LANs or connects a LAN to a wide-area network (WAN), computer, or a mainframe. A gateway can perform protocol and bandwidth conversion.

Graphic Window

A subsystem of the toolbox for viewing and setting the value of live signals.

health

A term that defines whether a signal is functioning as expected.

Heartbeat

A signal emitted at regular intervals by software to demonstrate that it is still active.

hexadecimal (hex)

Base 16 numbering system using the digits 0-9 and letters A-F to represent the decimal numbers 0-15. Two hex digits represent 1 byte.

I/O

Input/output interfaces that allow the flow of data into and out of a device.

I/O drivers

Interface the controller with input/output devices, such as sensors, solenoid valves, and drives, using a choice of communication networks.

I/O mapping

Method for moving I/O points from one network type to another without needing an interposing application task.

initialize

To set values (addresses, counters, registers, and such) to a beginning value prior to the rest of processing.

Innovation Series Controller

A process and logic controller used for several types of GE industrial control systems.

insert

Adding an item either below or next to another item in a configuration, as it is viewed in the hierarchy of the Outline View of the toolbox.

instance

Update an item with a new definition.

IONet

The Mark VI I/O Ethernet communication network (controlled by the VCMI's)

IP Address

The address assigned to a device on an Ethernet communication network.

logical

A statement of a true sense, such as a Boolean.

macro

A group of instruction blocks (and other macros) used to perform part of an application program. Macros can be saved and reused.

Mark VI Turbine Controller

A controller hosted in one or more VME racks that perform turbine-specific speed control, logic, and sequencing.

median

The middle value of three values; the median selector picks the value most likely to be closest to correct.

Modbus

A serial communication protocol developed by Modicon for use between PLCs and other computers.

module

A collection of tasks that have a defined scheduling period in the controller.

non-volatile

The memory specially designed to store information even when the power is off.

online

Online mode provides full CPU communications, allowing data to be both read and written. It is the state of the toolbox when it is communicating with the system for which it holds the configuration. Also, a download mode where the device is not stopped and then restarted.

pcode

A binary set of records created by the toolbox, which contain the controller application configuration code for a device. Pcode is stored in RAM and Flash memory.

period

The time between execution scans for a Module or Task. Also a property of a Module that is the base period of all of the Tasks in the Module.

pin

Block, macro, or module parameter that creates a signal used to make interconnections.

Plant Data Highway (PDH)

Ethernet communication network between the HMI Servers and the HMI Viewers and workstations

Potential Transformer (PT)

Measures voltage in a power cable.

Power Distribution Module (PDM)

The PDM distributes 125 V dc and 115 V ac to the VME racks and I/O terminal boards.

Power Load Unbalance (PLU)

Detects a load rejection condition which can cause overspeed.

product code (runtime)

Software stored in the controller's Flash memory that converts application code (pcode) to executable code.

PROFIBUS

An open fieldbus communication standard defined in international standard EN 50 170 and is supported in simplex Mark VI systems.

Programmable Logic Controller (PLC)

Designed for discrete (logic) control of machinery. It also computes math (analog) function and performs regulatory control.

Proximitors

Bently Nevada's proximity probes used for sensing shaft vibration.

QNX

A real time operating system used in the controller.

realtime

Immediate response, referring to process control and embedded control systems that must respond instantly to changing conditions.

reboot

To restart the controller or toolbox.

Redundant Power Supply Module (RPSM)

IS2020RPSM Redundant Power Supply Module for VME racks that mounts on the side of the control rack instead of the power supply. The two power supplies that feed the RPSM are mounted remotely.

register page

A form of shared memory that is updated over a network. Register pages can be created and instanced in the controller and posted to the SDB.

Relay Ladder Diagram (RLD)

A ladder diagram that represents a relay circuit. Power is considered to flow from the left rail through contacts to the coil connected at the right.

resources

Also known as groups. Resources are systems (devices, machines, or work stations where work is performed) or areas where several tasks are carried out. Resource configuration plays an important role in the CIMPLICITY system by routing alarms to specific users and filtering the data users receive.

runtime

See product code.

runtime errors

Controller problems indicated on the front cabinet by coded flashing LEDs, and also in the Log View of the toolbox.

sampling rate

The rate at which process signal samples are obtained, measured in samples/second.

Sequence of Events (SOE)

A high-speed record of contact closures taken during a plant upset to allow detailed analysis of the event.

Serial Loader

Connects the controller to the toolbox computer using the RS-232C COM ports. The Serial Loader initializes the controller flash file system and sets its TCP/IP address to allow it to communicate with the toolbox over the Ethernet.

server

A computer which gathers data over the Ethernet from plant devices, and makes the data available to computer-based operator interfaces known as viewers.

signal

The basic unit for variable information in the controller.

simplex

Operation that requires only one set of control and I/O, and generally uses only one channel. The entire Mark VI control system can operate in simplex mode, or individual VME boards in an otherwise TMR system can operate in simplex mode.

simulation

Running a system without all of the configured I/O devices by modeling the behavior of the machine and the devices in software.

Software Implemented Fault Tolerance (SIFT)

A technique for voting the three incoming I/O data sets to find and inhibit errors. Note that Mark VI also uses output hardware voting.

stall detection

Detection of stall condition in a gas turbine compressor.

static starter

This runs the generator as a motor to bring a gas turbine up to starting speed.

Status_S

GE proprietary communications protocol that provides a way of commanding and presenting the necessary control, configuration, and feedback data for a device. The protocol over DLAN+ is Status_S. It can send directed, group, or broadcast messages.

Status_S pages

Devices share data through Status_S pages. They make the addresses of the points on the pages known to other devices through the system database.

symbols

Created by the toolbox and stored in the controller, the symbol table contains signal names and descriptions for diagnostic messages.

task

A group of blocks and macros scheduled for execution by the user.

TCP/IP

Communication protocols developed to inter-network dissimilar systems. It is a de facto UNIX standard, but is supported on almost all systems. TCP controls data transfer and IP provides the routing for functions, such as file transfer and e-mail.

time slice

Division of the total module scheduling period. There are eight slices per single execution period. These slices provide a means for scheduling modules and tasks to begin execution at different times.

toolbox

A Windows-based software package used to configure the Mark VI controllers, also exciters and drives.

trend

A time-based plot to show the history of values, similar to a recorder, available in the Turbine Historian and the toolbox.

Triple Module Redundancy (TMR)

An operation that uses three identical sets of control and I/O (channels R, S, and T) and votes the results.

Unit Data Highway (UDH)

Connects the Mark VI controllers, static starter control system, excitation control system, PLCs, and other GE provided equipment to the HMI Servers.

validate

Makes certain that toolbox items or devices do not contain errors, and verifies that the configuration is ready to be built into pcode.

Windows NT

Advanced 32-bit operating system from Microsoft for 386-based computers and above.

word

A unit of information composed of characters, bits, or bytes, that is treated as an entity and can be stored in one location. Also, a measurement of memory length, usually 4, 8, or 16-bits long.

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