SPEEDTRONIC™ MARK V STEAM TURBINE CONTROL SYSTEM

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INTRODUCTION

The SPEEDTRONIC Mark V is the latest version of GE's long series of highly reliable electro-hydraulic control (EHC) systems for steam turbines. Its heritage consists of a long list of successful control systems, including the first EHC Mark I steam turbine control built in the 1960s, and the SPEEDTRONIC Mark I-IV gas turbine control. The Mark V continues to combine the best turbine and generator design engineering with the latest electronic controls engineering to provide a modern, yet experienced controls package (Figure 1).

The Mark V is the third generation of triple-redundant microprocessor-based turbine controls that originated in 1982, with the Mark IV[1] and was followed in 1987, with the DCM[2]. GE has an installed base of over 1,000 running triple-redundant, steam and gas turbine control systems. The Mark V family of turbine controls for the 1990s, offers a common control architecture for small, medium, and large steam turbines, turbine-generator monitoring systems, generator excitation systems, and gas turbine controls.

Some of the features are:

- *Common Architecture, Maintenance, and Spare Parts* between steam turbine, gas turbine, and other controls
- Very flexible, PC-based operator interface with *Color Monitor* and *Logging Printer* with alarm log, event log, historical trip log, etc.
- *Common operator training and controls* for steam and gas turbines in combined-cycle STAG™ plants
- *Full Turbine-Generator Monitoring* for all sizes of turbines can be included
- *High Resolution Time Tags* including 1 ms time tags of contact inputs
- New *Communication Links* to plant controls
- *Distributed Multiprocessor Control* in each controller for maximum processing capability
- *Enhanced Diagnostics* that can isolate a fault to the card level in any of the triple-redundant controllers
- *On-Line Repair* of the triple-redundant controllers
- Standard built-in *Synchronizing Check Protection*
- Fully *Digital Valve Positioning* to provide a more linear response of the steam turbine
- *Direct Interface to Turbine Devices,* including proximity monitoring equipment
- *Compact Packaging* in half the cabinet size of the previous control system

CONTROL SYSTEM HISTORY

From their introduction in the late 1800s, steam turbines were governed by mechanical hydraulic control (MHC) systems. Speed was controlled by a flyweight governor of James Watt heritage, signals were transmitted by levers and links or hydraulic pressure signals, and motive power to control steam valves was provided by low-pressure

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Figure 1. **SPEEDTRONIC™ Mark V steam turbine control cabinet**

hydraulics. Refined to the utmost, this technology was used through the mid-1960s, to control such sophisticated units as double-extraction industrial turbines, large double-reheat fossil units, and the first nuclear units incorporating pressure controls for BWRs. The complexity of these later controls clearly showed that a new technology was needed.

ANALOG CONTROLS

GE introduced the electro-hydraulic control (EHC) system for steam turbines in the 1960s. The first medium-size unit went into service in 1961, and the first large reheat unit in 1968. The proportional controls used analog circuitry with dual redundancy for speed control and single channel for other controls. The logic and protective system was implemented with relays.

The original Mark I system consisted of discrete component analog circuitry. In the 1970s, these circuits were modernized to take advantage of integrated circuitry (IC) technology as well as solid state logic circuits for some of the protection and logic. This resulted in the EHC Mark II, which had many IC components and a new cabinet arrangement, while the subsequent Mark III, used only on small- and medium-sized turbines, employed ICs throughout and also included electronic speed sensing and microprocessors for automation.

A major improvement for both medium and large steam turbine controls was a reduction in component count with a resultant increase in reliability. The EHC Mark II version for large steam turbines, in addition to integrated circuits, also introduced triple-redundant protection systems for the functions that can cause a turbine trip, resulting in further improvement in running reliability by virtually eliminating spurious forced outages.

The associated high-pressure hydraulic system, using 1600 psig (110 bar) fire-resistant fluid, has undergone gradual improvement through the years. The basic technology is still in use for the new electro- hydraulic controls.

The history of analog controls, as well as the new digital controls, is summarized in Table 1.

The reliability of EHC systems developed according to a classic learning curve shown in Figure 2. The step change in reliability realized with the EHC Mark II is attributed to two factors: the superior reliability of integrated electronics and the introduction of triple-redundant protection logic described above.

DIGITAL CONTROLS

While GE steam turbines were being shipped with these EHC systems through the mid-1980s, in the early 1980s, GE's Gas Turbine Division introduced the very successful triple-redundant digital control system – the SPEEDTRONIC Mark IV. The first triple-redundant steam turbine control system for utility turbines, the DCM system, was

Table 1
PROGRESS OF STEAM TURBINE ELECTRONIC CONTROLS

System	EHC MK I	ECH MK II	EHC MK III*	DCM/MK III+	ST MK V
Introduced	1961	1970	1980	1986	1991
Total Shipped (Approx.)	190	290	120	27/44	55
Control	Discrete Solid State	Integrated Circuits & Discrete	Intregrated Circuits & Micro-processors	TMR Micro-Processors/single	
Protection	Relays	Relays	Relays	TMR Micro-Processors/single	
Display	Analog Meters & Lights	Digital Meters & Lights	Digital Meters & Lights	Color CRT	
Operator Inputs		Pushbuttons and Dials		Touch Panel	Cursor or Touch
Fault Tolerance	Dual Redundant Speed Control	Dual Redundant Speed Control	Single Channel Control & Protection	TMR (2/3 Voting) with Sift (Software Implemented Fault Tolerance)/Single	
Sequencing/ Automation	N.A.	N.A.	Limited Micro-Processor	Micro-processors	

*Used only for small and medium size steam turbines
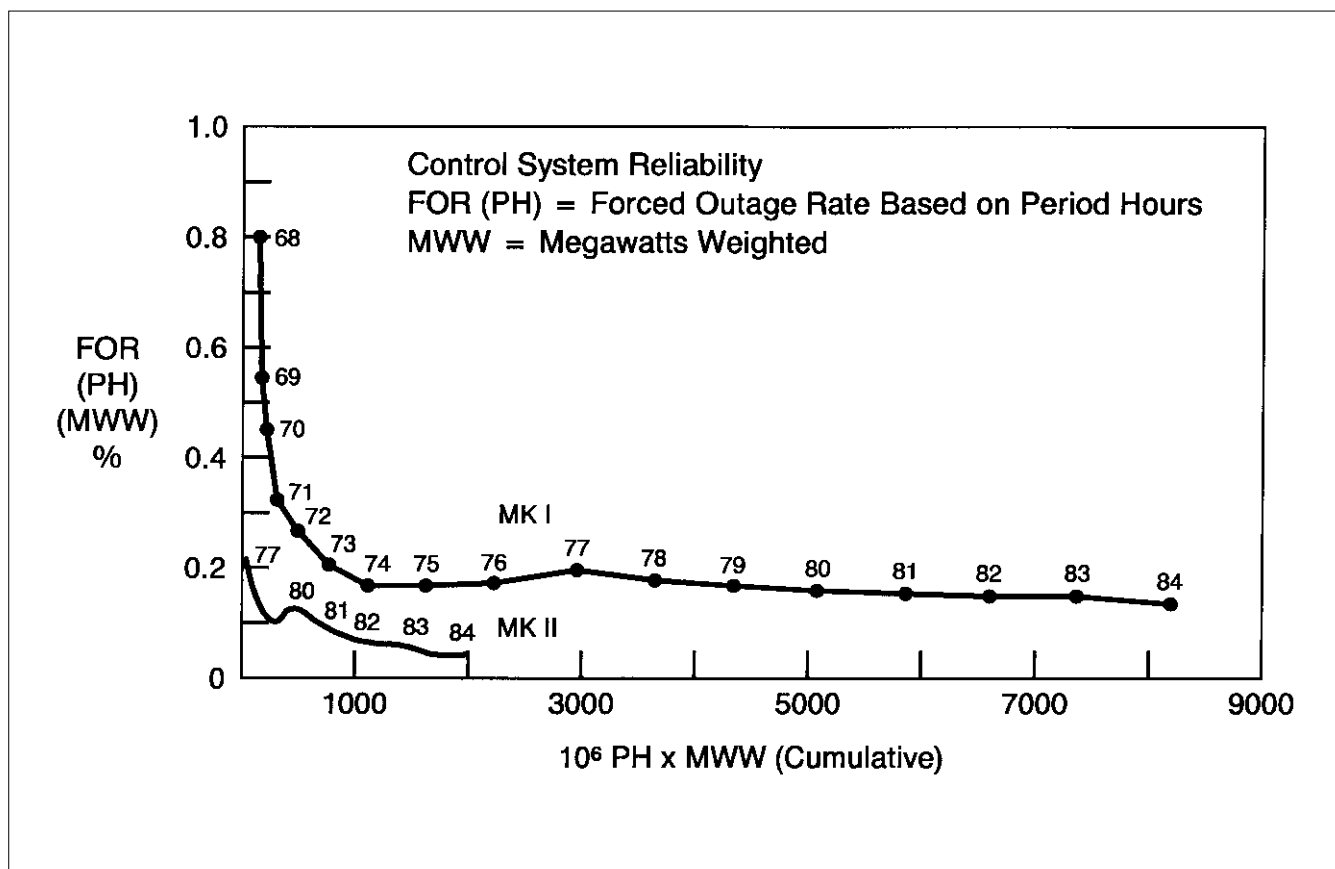
Figure 2. Control system reliability, PH is forced outage rate based on period hours; MWW is megawatt weighted

shipped in 1987, building on gas turbine experience, including the use of many of its electronics modules, and developing it further with Software Implemented Fault Tolerance (SIFT). A companion single-channel system, the Mark III Plus, aimed at the smaller industrial units, was first shipped in 1988.

Some of the benefits from the new digital systems are flexibility and greater precision of of the benefits from the new digital systems are flexibility and greater precision of controls because functions are determined by software rather than hardware, CRT operator interface, data link interface to plant level control systems, and online repair capability for triple-redundant systems, providing further improvement in reliability.

The new SPEEDTRONIC Mark V Steam Turbine Control System is developed from this long evolution of electronic steam turbine controls. It is available in both triple-redundant Mark V TMR and single-channel Mark V Simplex control systems, the only difference being the two additional controllers in the TMR design.

STEAM TURBINE UNIT CONTROLS

The main functions of a modern steam turbine control system are:
- Speed and acceleration control during start-up
- Initialization of generator excitation
- Synchronization and application of load in response to local or area generation dispatch commands
- Pressure control of various forms: inlet, extraction, back pressure, etc.
- Unloading and securing of the turbine
- Sequencing of the above functions under constraint of thermal stress
- Overspeed protection during load rejection and emergencies
- Protection against serious hazards, e.g., loss of lube oil pressure, high exhaust temperature, high bearing vibration
- Testing of steam valves and other important protective functions

Additional control and monitoring functions are also required in most applications, such as:
- Monitoring and supervision of a large num-

ber of pressures, temperatures, etc., to provide guidance and alarms for operators

- Start-up and monitoring of turbine-generator auxiliaries such as lube oil, hydraulic, and steam seal systems
- Display, alarm, and recording of the above functions and data
- Diagnosis of turbine or generator problems
- Health check and diagnostics of the electronic system itself

It is characteristic of the first group of functions that they must be performed with high control bandwidth, or with very high reliability, or both, to ensure long-term reliable operation and service of the turbine. It is for these reasons that GE has, from the very beginning of turbine technology, designed and provided the controls and protection for its units, starting with the MHC systems a century ago and continuing with the new SPEEDTRONIC Mark V control system.

For the new all-digital systems, GE has defined the first group of functions as a "Turbine Unit Control System." These functions, together with the input and output devices (I/O) required, are included in all control systems which are an integral part of steam turbines supplied by GE.

A characteristic of the unit control system is that all essential turbine control and protection functions are included to allow a unit to operate safely even if other supporting systems should fail. Another characteristic is that the "control point" interface (i.e., the interface between the turbine and the control system) remains in GE's scope, while interface to plant controls can be made at "data point" level, which does not include critical and rapidly varying commands and feedback signals, and therefore, is a more suitable point of interface to possible non-GE controls. Yet another characteristic of unit control functions is that they must be performed either continuously or very frequently to provide satisfactory control. Data sampling and processing of control algorithms up to ten times per second are used for many unit control functions.

The second group of functions can be performed less frequently (i.e., every few seconds or more), and turbine operation may be continued, in most cases, during short-term interruptions in the monitoring functions as long as the "unit control" is performing correctly.

The second group of functions includes most of what used to be called "TSI," for Turbine Supervisory Instrumentation, which we now pre-

Table 2
STEAM TURBINE CONTROL PHILOSOPHY

1. Clear separation between control and protection shall be provided.
2. Controls comply with IEEE 122 standard. (e.g., can reject rated load without causing a turbine trip.)
3. A protection system backup is provided for all control functions.
4. A double set of steam valves is provided for all major admissions; one set for controls and one set for protection.
5. Protection (trips) are classified according to criticality: vital to have conceptual redundancy and for triple redundant systems.
6. Controls use two out of three redundancy from sensor to actuator for all vital and important functions.
7. A single failure in the controls will not cause a shutdown. It will cause a diagnostic alarm, and it is repairable on-line.

fer to call TGM, for Turbine Generator Monitoring. The TGM functions can be included in the Mark V systems, or they may be integrated into the plant control system. For small- and medium-sized units, the TGM functions can be incorporated without significant extra hardware, and for large units, additional cabinets are needed. These cabinets can be mounted either at the turbine and generator or in an equipment room, and they can interface with a common Mark V operator interface.

The philosophy applied to steam turbine control systems has developed over time, and it is summarized in Table 2.

A block diagram of the protective system of the Mark V is shown in Figure 3. The left-hand side shows the various trip inputs entering through redundant paths. At the extreme right is the output to the emergency trip system (ETS), a hydraulic pressure signal, which will cause rapid closure of all steam admission valves when depressurized. The critical inputs to the ETS can be tested on-line, one at a time, with the help of the lockout valves located immediately to the left of the final output to the ETS. This diagram shows the standard offering with an all-electronic overspeed trip. Optionally, a system with a mechanical overspeed governor can be supplied.
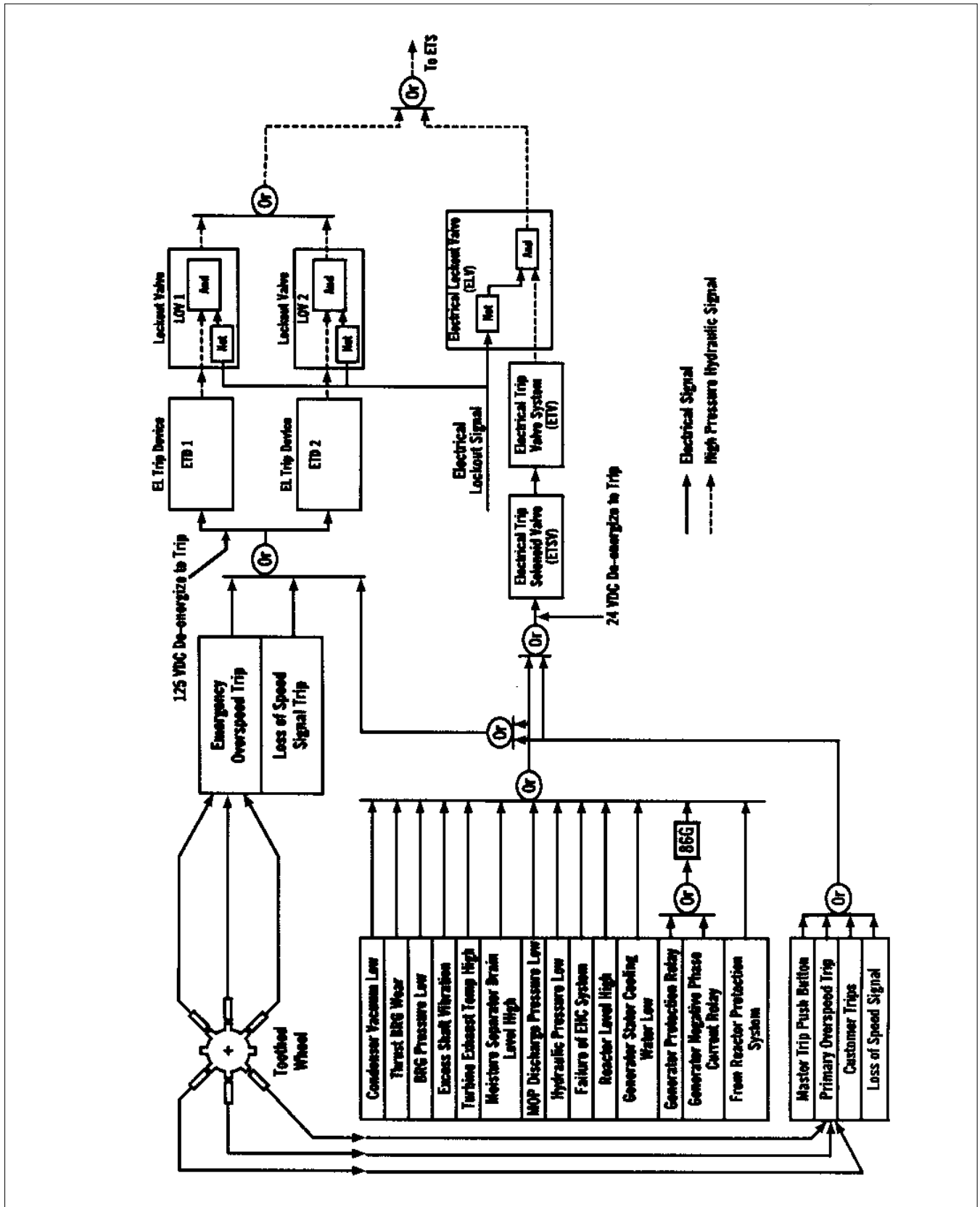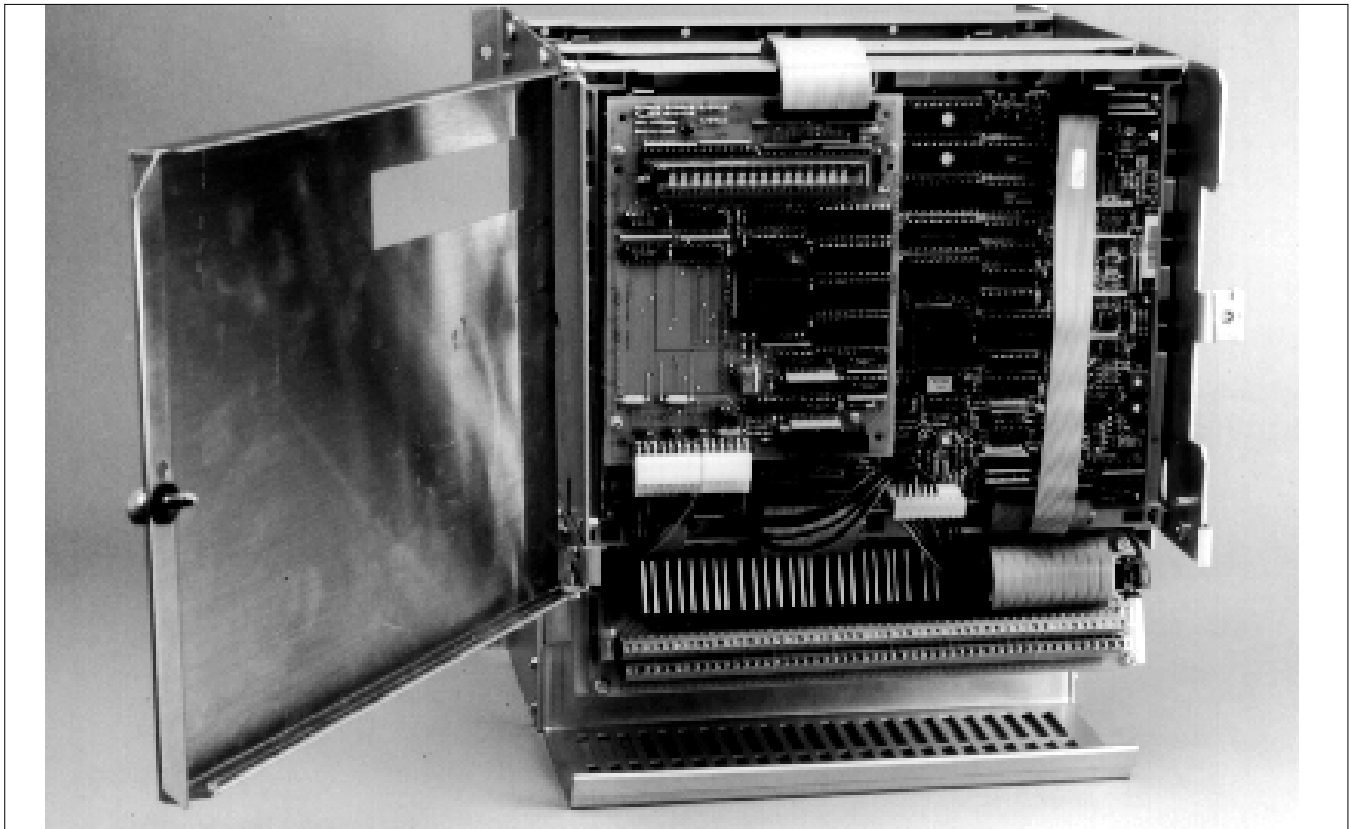
Figure 3. Turbine protection system

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Figure 4. Mark V controller module

SPEEDTRONIC MARK V CONTROL CONFIGURATION

Figure 5 shows the configuration for the SPEEDTRONIC Mark V triple modular redundant (TMR) control system for a medium to large steam turbine with redundant operator interfaces. The core of this system is the three identical controllers called <R>, <S>, and <T>. All critical control algorithms, protective functions, and sequencing are performed by these processors. In so doing, they also acquire the data needed and generate outputs to the turbine. Protective outputs are routed through the <P> module consisting of triple redundant processors <X>, <Y>, and <Z>, which also provide independent protection for certain critical functions such as overspeed.

The three control processors, <R>, <S>, and <T>, acquire data from the triple-redundant sensors as well as from dual or single sensors. A generic complement of sensors is described in Table 3. The actual number of sensors will depend on turbine type. All critical sensors for continuous controls, as well as protection, are triple-redundant. Other sensors are dual or single devices fanned out to all three control processors. The extremely high reliability achieved by TMR control systems is due in considerable measure to the use of triple sensors for all critical parameters, as it was first demonstrated with the triple-redundant protection system of the EHC Mark II.

MARK V ELECTRONICS

All of the microprocessor-based controls have a modular design for ease of maintenance. Each module or controller contains up to five cards, including a power supply. Multiple processors reside in each controller which distribute the processing for maximum performance. Individual processors are dedicated to specific I/O assignments, application software, communications, etc., and the processing is performed in a real-time, multi-tasking operating system. Communication between the controller's five cards is accomplished with ribbon cables and gas-tight connectors. This eliminates the traditional computer backplane. Communication between individual controllers is performed on high-speed Arcnet links.

Figure 4 shows the standard microprocessor module.

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Table 3
**DIGITAL CONTROLS REDUNDANCY**

Analog	Use	Digital	Use
2/3		2/3	
Speed pickups	Control	Low bearing oil pressure	Trip
EOS pickups	and/or	Low shaft pump pressure	Trip
Main steam pressure	trip	Low vacuum, each hood	Trip
Hot or cold reheat pressure		Low hydraulic fluid pressure	Trip
Thrust bearing wear	Trip		
LVDT CV #1-4 IV #1/2	Control	Exhaust thermostat each hood	Trip
		L-1 thermostat (for units w/bypass)	Trip
HP 1st stage temperature	Alarm/trip		
HP last stage temperature	Alarm/trip		
2/2		2/2	
Thrust bearing wear	Trip	Low ETS pressure	Cross trip
(or 2/3 if practical)		Low lube oil level (option)	Trip
1/2		1/2	
Differential expansion	Aut. Turb. Start (ATS)	None	
All ATS temperatures & press	ATS		
Bearing oil temperature			
1/1		1/1	
Eccentricity	Preroll check	Numerous contacts fanned out to R, S, & T	
Bearing vibration	Trip	for testing and plant interface.	
Shell expansion	Monitor/alarm		
CT and PT's (3)	Control/PLU/ load hold		
Bearing oil pressure		Numerous contact inputs to C for alarm,	
SS header pressure & temp	Preroll	monitoring, and ATS checks and holds.	
Hydr. fluid pressure & temp	check		
First stage pressure	Control		
Line frequency	Control	Customer trips.	
H2 pressure	ATS load		
Generator field I & V	hold		
H2 cooler inlet temp	Preroll check		
H2 cooler outlet temp	Load hold		
SCW outlet temp	Load hold		
L-1 temp	Monitor/alarm		
Unit load demand	Coord. cont. input		

PRIMARY CONTROLLERS
<R><S><T>

The three controllers <R>, <S>, and <T>, shown in Figure 5, are physically separate and independent modules that contain all control and protection hardware and software. A failure in any of the three controllers is automatically diagnosed to the card level and displayed as an alarm message. Maintenance personnel can power down the appropriate controller and replace the defective card while the turbine is on-line. Redundant sensors are used in control and trip protection systems

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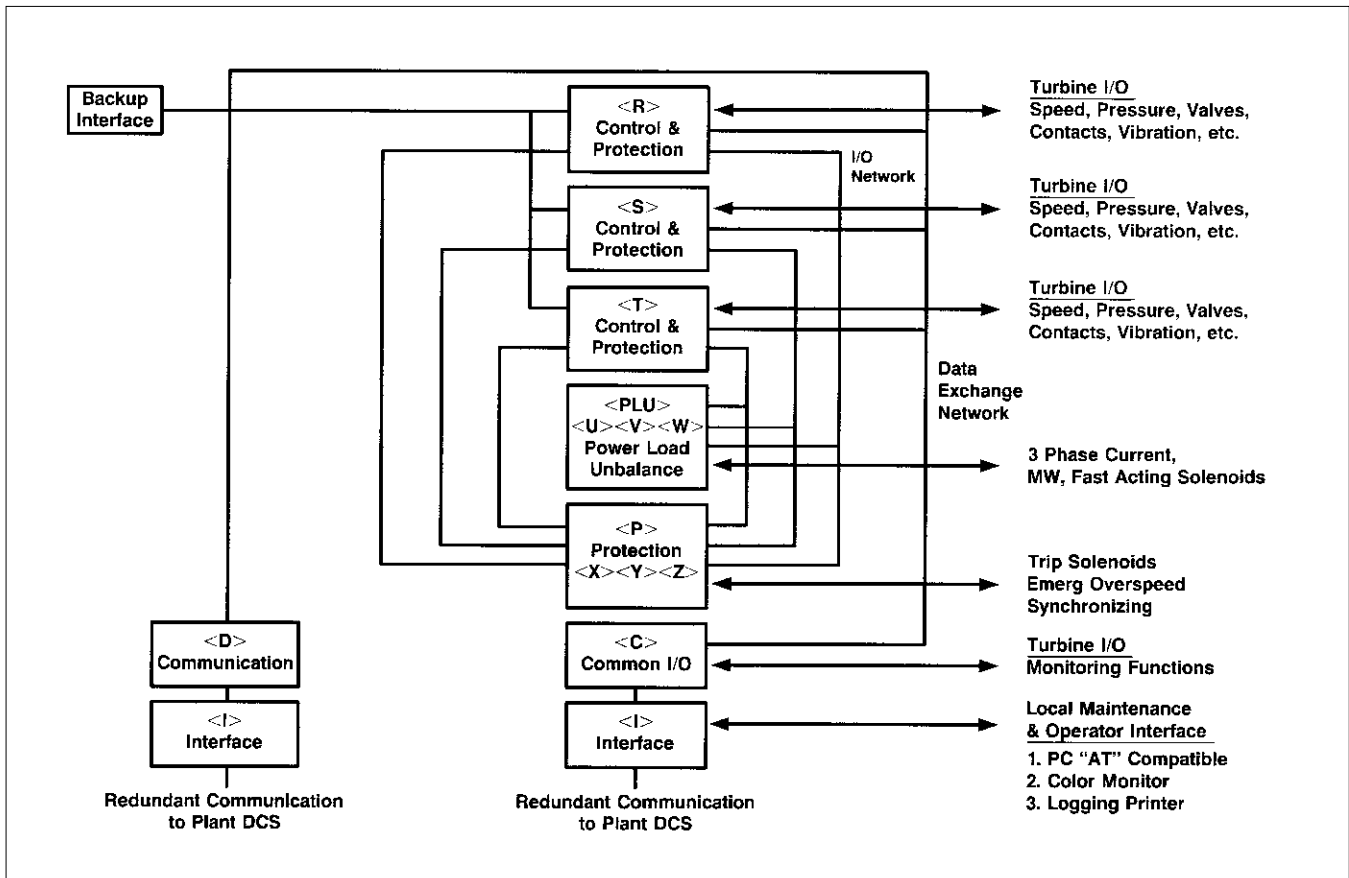
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Figure 5.   TMR system with redundant communications

to provide a "total system" fault-tolerant design. As a result, diagnostics are able to distinguish between redundant sensor failures and electronics failures.

Three basic forms of voting are used in the control. Figure 6 shows how the first form of voting, the software implemented fault tolerance (SIFT), works. At the beginning of each computing time frame, each controller independently reads its sensors and exchanges this data with the data from the other two controllers. The median value of each analog input is calculated in each controller and then used as the resultant control parameter for that controller. Diagnostic algorithms monitor a predefined deadband for each analog input to each controller, and if one of the analog inputs deviates from this deadband, a diagnostic alarm is initiated to advise maintenance personnel.

Contact inputs are voted in a similar manner. Each contact input connects to a single terminal point and is parallel wired to three contact input cards in the voted contact input module. Each card optically isolates the 125 V dc input, and then a dedicated 80196 processor in each card time stamps the input to within 1 ms resolution. These signals are then transmitted to the <R>, <S>, and

<T> controllers for voting and execution of the application software. This technique eliminates any single point failure in the software voting system. Redundant contact inputs for certain functions such as low lube oil pressure are connected to three separate terminal points and then individually voted. With this SIFT technique, multiple failures of contact or analog inputs can be accepted by the control system without causing an erroneous analog or trip command from any of the three controllers as long as the failures are not from the same circuit.
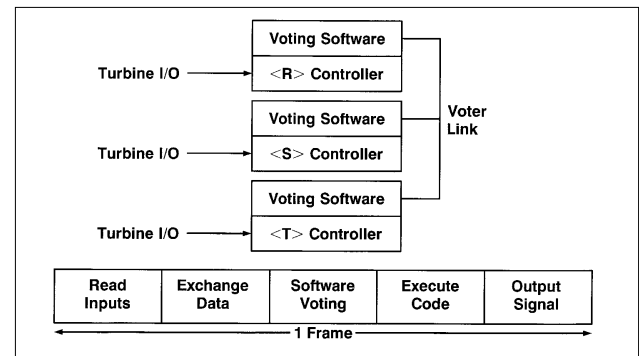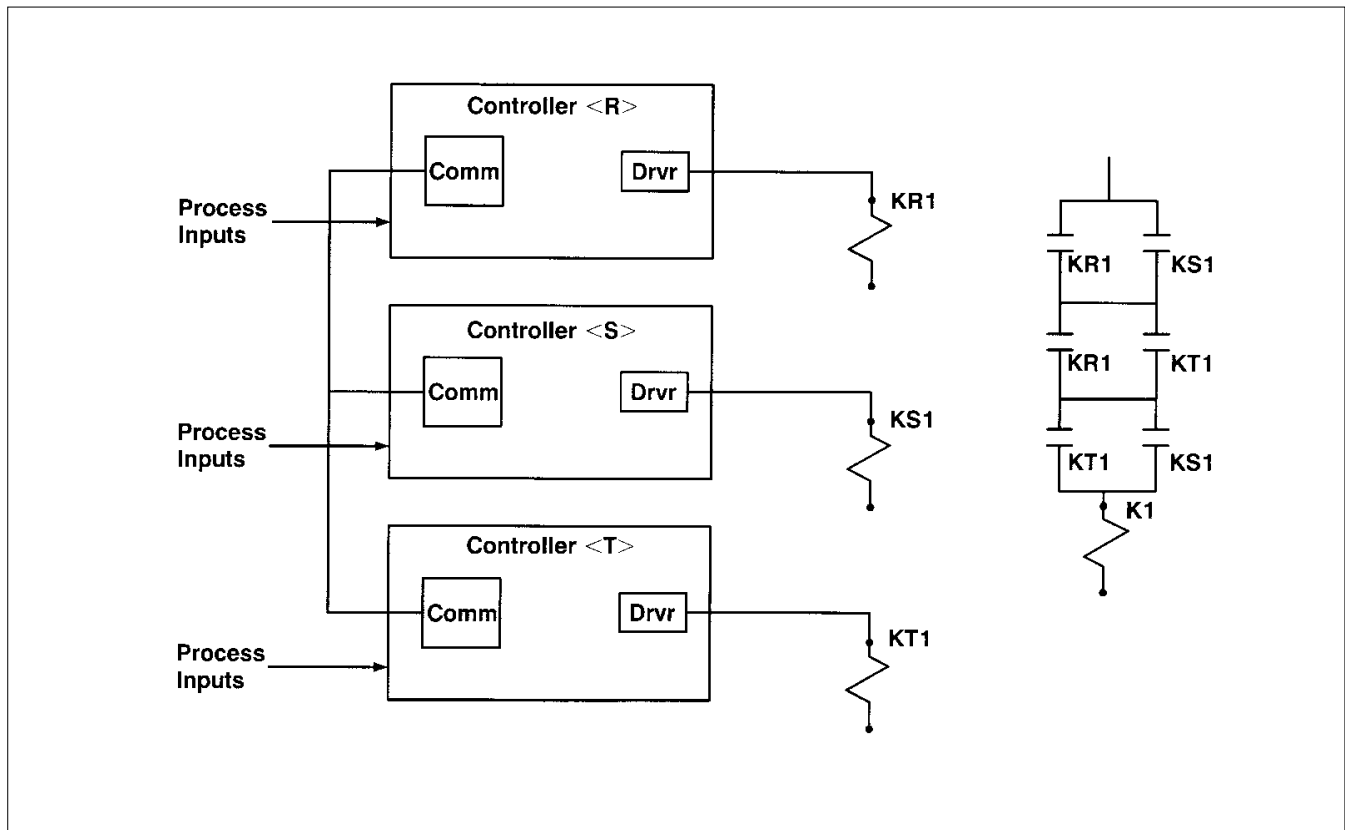

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Figure 6. Software implemented fault tolerance (SIFT)

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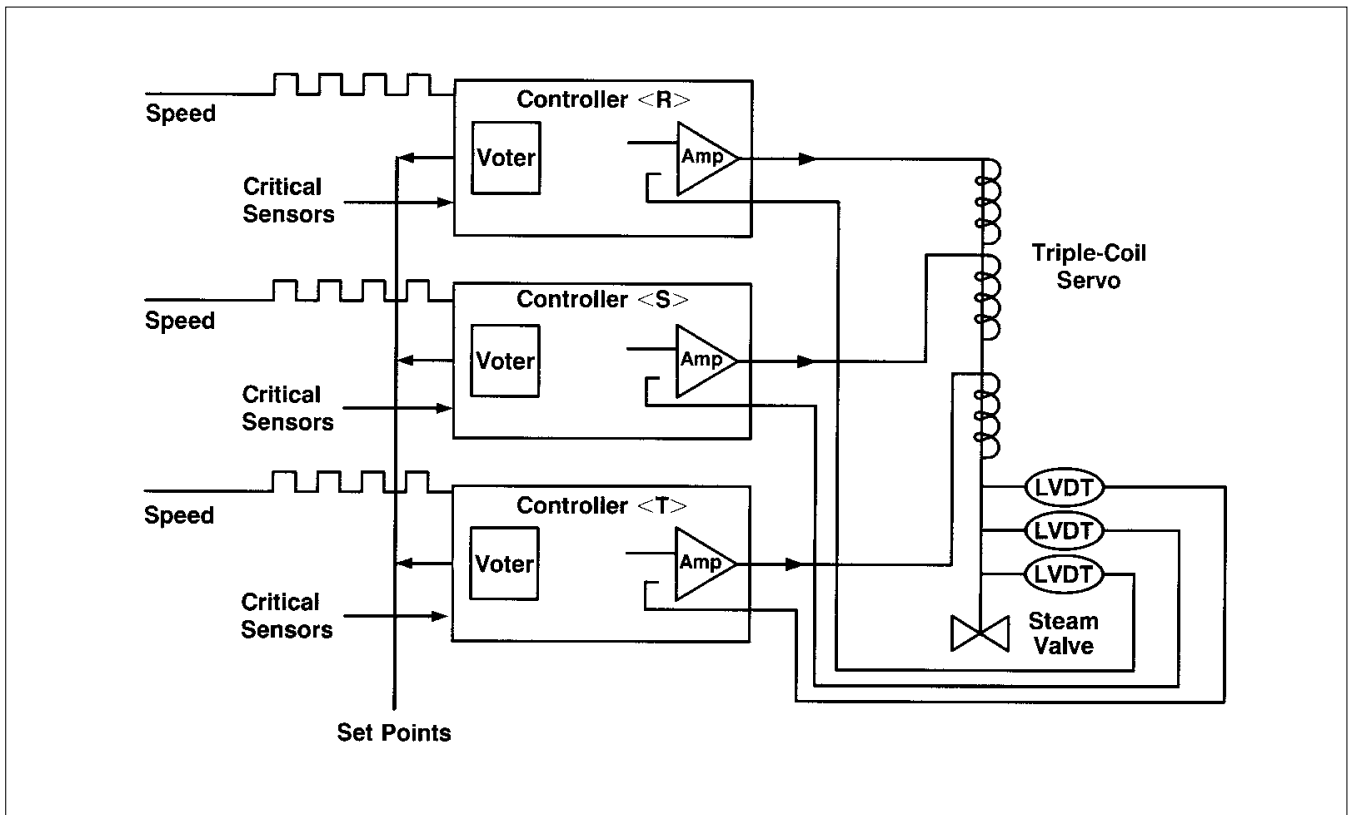
Figure 7. Hardware voting of analog outputs

Figure 8. Hardware voting of logic outputs

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A second form of voting is hardware voting of analog outputs. As illustrated in Figure 7, three coil servo valves on the steam valve actuators are separately driven from each controller, and the position feedback is provided by three LVDRs. The normal position of each steam valve is the average of the three commands from <R>, <S>, and <T>, respectively. The resultant averaging circuit has sufficient gain to override a gross failure of any controller, such as a controller output being driven to saturation. Diagnostics monitor the servo coil currents and the D/A converters in addition to the LVDRs.

The third form of voting for the trip solenoids is discussed under OVERSPEED.

OVERSPEED

The <P> protective controller contains three independent cards <X>, <Y>, and <Z> with their own processors and power supplies. This separate set of triple-redundant electronics with its associated three separate speed pickups replaces the mechanical overspeed governor. <R>, <S>, and <T> use the first three pickups for speed control and the primary overspeed protection, while <X>, <Y>, and <Z> monitor the second set of three pickups for emergency overspeed protection (Figure 3).

In addition, the <X>, <Y>, and <Z> cards contain separate relay drivers and magnetic relays that perform a final contact vote prior to driving the turbine trip solenoids. Diagnostics monitor the status of the output ports, relay drivers, and relays to initiate maintenance alarms if a failure occurs. Standard on-line and off-line primary and emergency overspeed trip tests are built in to facilitate testing all hardware and software. Figure 8 illustrates hardware logic voting of an output from each of three controllers.

SYNCHRONIZING

Automatic synchronization is performed by the <X>, <Y>, and <Z> cards in conjunction with the <R>, <S>, and <T> controllers. The controllers match speed and voltage and issue a command to close the breaker based on a predefined breaker closure time. Diagnostics monitor the actual breaker closure time and self-correct each command. Redundant sets of primary and backup phase-slip windows eliminate the need for the traditional GXS synchronizing check relay in the generator control cabinet. Another feature is the ability to synchronize manually via the Mark V operator interface instead of using the traditional synchroscope on the generator protective cabinet. Operators can choose one additional mode of operation by selecting the monitor mode, which automatically matches speed and voltage, but waits for the operator to review all pertinent data on the CRT display before issuing a breaker close command.

POWER LOAD UNBALANCE – PLU

Large steam turbine applications use another module similar to <P> which is designated <PLU> for power load unbalance. This provides power load unbalance protection and interface to the fast closing feature on control and intercept valves via three independent cards <U>, <V>, and <W>.

COMMON I/O <C>

A significant amount of I/O on turbines and generators is used only for monitoring. This non-redundant I/O is monitored by the <C> module. For example, thermocouples can be used for control and protection or just for monitoring. Thermocouples which are used for rotor stress calculations are connected directly to the <R>, <S>, and <T> controllers, while thermocouples that are used for monitoring only, e.g., the thrust bearing oil drain temperature, connect to <C>.

OPERATOR INTERFACE <I>

The interface work station <I> consists of a PC, color monitor, cursor positioning device, keyboard, and printer. It can be used as the sole operator interface or as a local maintenance work station with all operator control and monitoring coming from communication links with a plant distributed control system (DCS). Figure 9 shows the operator interface schematically.

Operators use the monitor, cursor positioning device, and keyboard. The keyboard is not necessary. However, the keyboard is convenient for accessing displays with dedicated function keys and adjusting setpoints by entering a numeric value such as 1,000 rpm rather than issuing a manual raise/lower command. Set point and logic commands require an initial selection, such as the command to engage the turning gear, which is followed by a confirming execute command. The monitor is available in various sizes and types, and it can be used for desktop mounting, packaged as a drop-in insert for a control room console, or mounted in a separate free-standing cabinet. The keyboard is primarily used
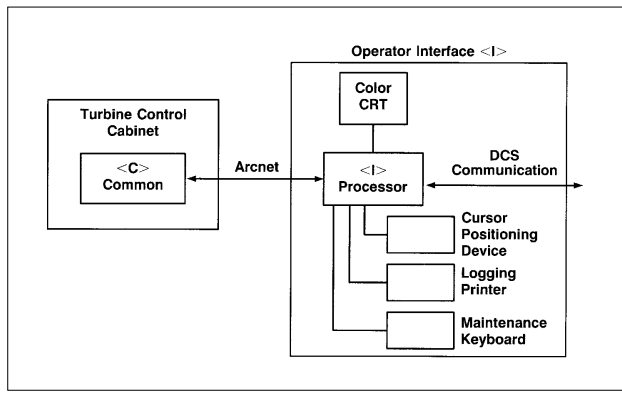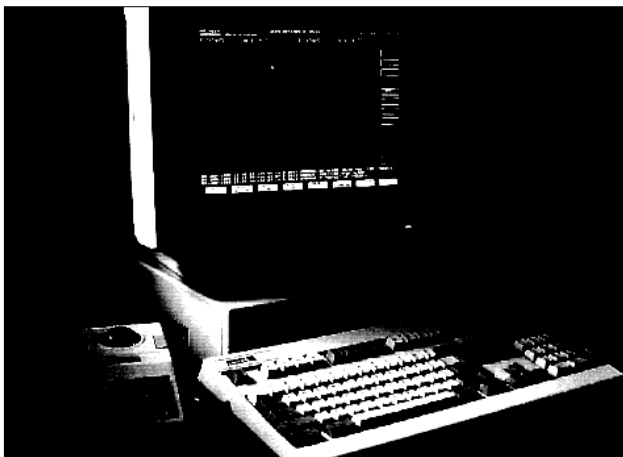
Figure 9. Mark V operator interface

for maintenance such as editing application software or alarm messages. Figure 10 shows one example of operator interface.

The standard logging printer is a 150-cps (characters per second), dot matrix printer with alarm logging, event logging, historical trip log, user defined log, and the ability to copy any screen. Each alarm and event is logged with a high-resolution time tag including contact inputs to within 1 ms. Separate alarm queues are maintained for turbine-generator system alarms and internal diagnostic alarms. A new alarm initiates an audible alarm and drives a contact output which is connected to the plant alarm bus. If a trip occurs, the historical trip log captures all key control parameters and alarm messages at the time of the trip and at several time intervals preceding the trip. This data is logged on the printer.

The <I> processor is located external to the control cabinet, and it communicates with the <C> controller via an Arcnet communication link. Eight Mark V turbine controls of any type, including gas turbines for combined-cycle applications or EX2000 generator excitation systems in any

Figure 10. Typical operator interface

combination, can be monitored by a single <I>, or multiple <I>s can be provided for redundancy. A typical application has a Mark V main turbine control, Mark V Turbine-Generator Monitoring System with historical database, and an EX2000 Generator Excitation System communicating on a local high-speed Arcnet communication link to any combination of local interface stations. Monitoring and control of this localized system from a plant DCS is facilitated via various types of communication links.

This makes it possible to include the control and monitoring of a steam turbine in the central control room supported by the DCS.

<I> is an open architecture, AT compatible PC which runs a real-time, multi-tasking operating system called IDOS. The system runs in protective mode with DOS running as one of 32 tasks under a scheduler. The PC supplied with each application is of the type 486 DX to provide a responsive interface with a screen update time within one second.
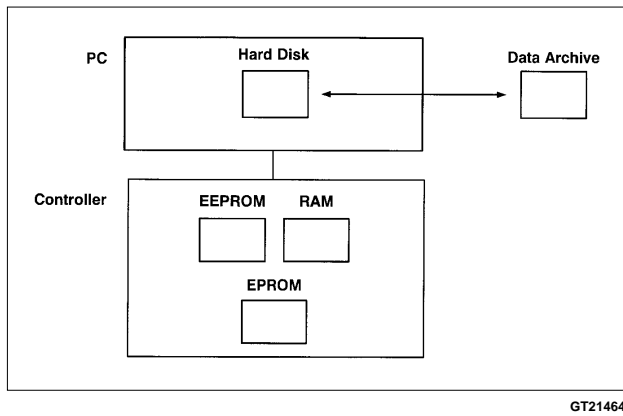
MEMORY

Memory is located in the individual controllers and in the <I> processor. Controllers have EPROM for fixed memory, RAM for volatile memory, and EEPROM for permanent storage of up-to-date application software. Changes to sequencing, I/O assignments, gains, etc. can be made from <I> and stored in the individual controller's EEPROM. Changes to control constants such as gains and offsets can be made while the turbine is on-line by entering a security code. However, changes to application software are restricted to off-line maintenance. The hard disk in <I> has a copy of all application software and display information. Alarm messages can be added and changed. Text for existing displays can be changed or new displays can be created. I/O tag names can be added or changed.

The memory system is illustrated in Figure 11.

BACKUP INTERFACE

A small backup interface is provided on the cabinet door. It uses a liquid crystal display with two lines of 40 characters per line to display key control parameters and alarms. In addition, it can be used to issue operator commands. A second backup interface can be provided for remote mounting via an RS422 connection.

An emergency stop pushbutton is located on the door. It has a latching contact, and it must be turned and pulled to reset. Loose emergency stop

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Figure 11. Mark V memory schematic

pushbuttons can be provided for remote mounting. All emergency stop pushbuttons are hard-wired in series with the trip solenoids. Diagnostics monitor the trip circuitry and initiate a separate trip in the application software.

HISTORY

Most turbine controls transmit data to a DCS which provides a historical database. Mark V systems can provide their own historical database which can store up to one month of data on-line and archive data older than one month. A single historian can provide historical trending for up to eight small units of any type including generator excitation systems.

COMMUNICATION

The open architecture of the <I> processor facilitates a wide range of communication links. The Mark V's internal Arcnet communication link is isolated from external communication links at the <I> processor. An RS232 link with Modbus protocol can be provided for general compatibility with most DCSs, and Arcnet and Ethernet communications are supported. GE's Message Service Protocol (TCP-IP) can be used on a variety of links including RS232 and Ethernet to communicate individual time tags for alarms and events and to receive the time from the DCS.

Since a single <I> can be used to communicate with one or multiple units, the communication with the DCS can support one or multiple units. Control of multiple units over a single communication link generally dictates faster communication links with more sophisticated protocols such as Ethernet with TCP-IP. Redundant communication links are available in various levels such as redundant <I>s or redundant <I>s with redundant communication modules within the Mark V.

DIRECT SENSOR INTERFACE

The Mark V I/O is designed for direct interface to turbine and generator devices such as thermocouples, RTDs, and vibration sensors. Direct monitoring of these sensors eliminates the cost and potential reliability factors associated with interposing transducers and instrumentation. In addition, all of the resultant data is visible to the operator from the Mark V interface and from the DCS via the communication link. Typical Mark V steam turbine controls provide direct interface to Proximitors* for vibration protection and axial position for thrust wear, differential expansion, and eccentricity via a reference probe and key phasor. Monitoring of shell expansion is available via an LVDT input.

POWER

Mark V steam turbine controls come with standard redundant 115/230 V ac inputs and a 125 V dc input. The electronics run on the highest bus with diagnostics monitoring the actual voltage levels of each bus, as well as any possible grounds on the 125 V dc bus, if used. An internal power distribution module fuse isolates the resultant 125 V dc and feeds it to individual power supplies located in each controller. Diagnostics monitor each internal feeder, and LEDs are located next to each fuse to provide additional maintenance assistance.
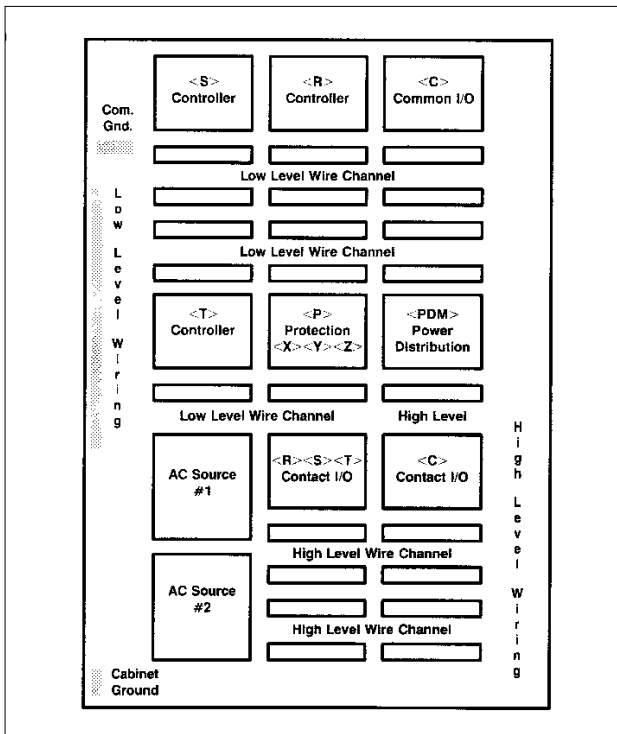
CONTROL CABINET

The control cabinet (Figure 12) carries the CSA and UL labels. It can be provided as a NEMA 1 convection-cooled enclosure for mounting in an air-conditioned room or in NEMA 12 or NEMA 4 enclosures with air purifiers or additional cooling as required. Cabinets have front access only with top and/or bottom cable entrances and have a heat dissipation of 800 watts. All electronics modules are mounted on a common base with ribbon cable connections between modules.

High level field wiring runs vertically in the right-side wire channel, and then horizontally to the contact input/output modules at the bottom of the cabinet and to the power distribution module. Low level wiring runs vertically in the left-side wire channel where the shield ground bar is located, and then horizontally to the low level terminal boards. Filters are located on circuit boards where the terminal boards are mounted to provide EMI, RFI, surge, and noise decoupling to the case.

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Figure 12. Typical cabinet layout (TMR with ac and dc power)

SUMMARY

The SPEEDTRONIC Mark V steam turbine control is the GE control system for the 1990s. It is jointly engineered by turbine control engineering based in Schenectady, New York, and electrical controls engineering based in Salem, Virginia. The resultant product reflects years of experience in providing high-performance turbine-generator sets with integrated control systems. This is exemplified by a track record of no forced outages occurring in a DCM triple-redundant control system due to the electronics or its related redundant sensors. The Mark V is designed to build on this experience and to be the platform for implementing new features resulting from projects currently underway at GE Corporate Research and Development. This will keep GE and its customers at the forefront of technology and leaders in their respective markets.

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LIST OF FIGURES

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Previous to his present position, Kure-Jensen managed several engineering units engaged in development of advanced turbine components and controls. Before joining GE, he worked for a European turbine supplier.

W. Barker

Walter Barker currently works in Turbine Controls Marketing, GE Drive Systems Sales.

He joined GE's Speed Variator Department in Erie, Pennsylvania in 1969, as a Control Systems Engineer on adjustable speed dc drives. In 1971, he transferred to GE Drive Systems in Salem, Virginia where he was a Controls Systems Engineer on Gas Turbine and Steam Turbine Controls. From 1988 until mid-1992, he was a Sales Application Engineer.

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