

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 electrohydraulic 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 IV¹ and was followed in

1987, with the DCM². 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



RDC26449-2-11

Figure 1. SPEEDTRONIC™ Mark V steam turbine control cabinet

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

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.

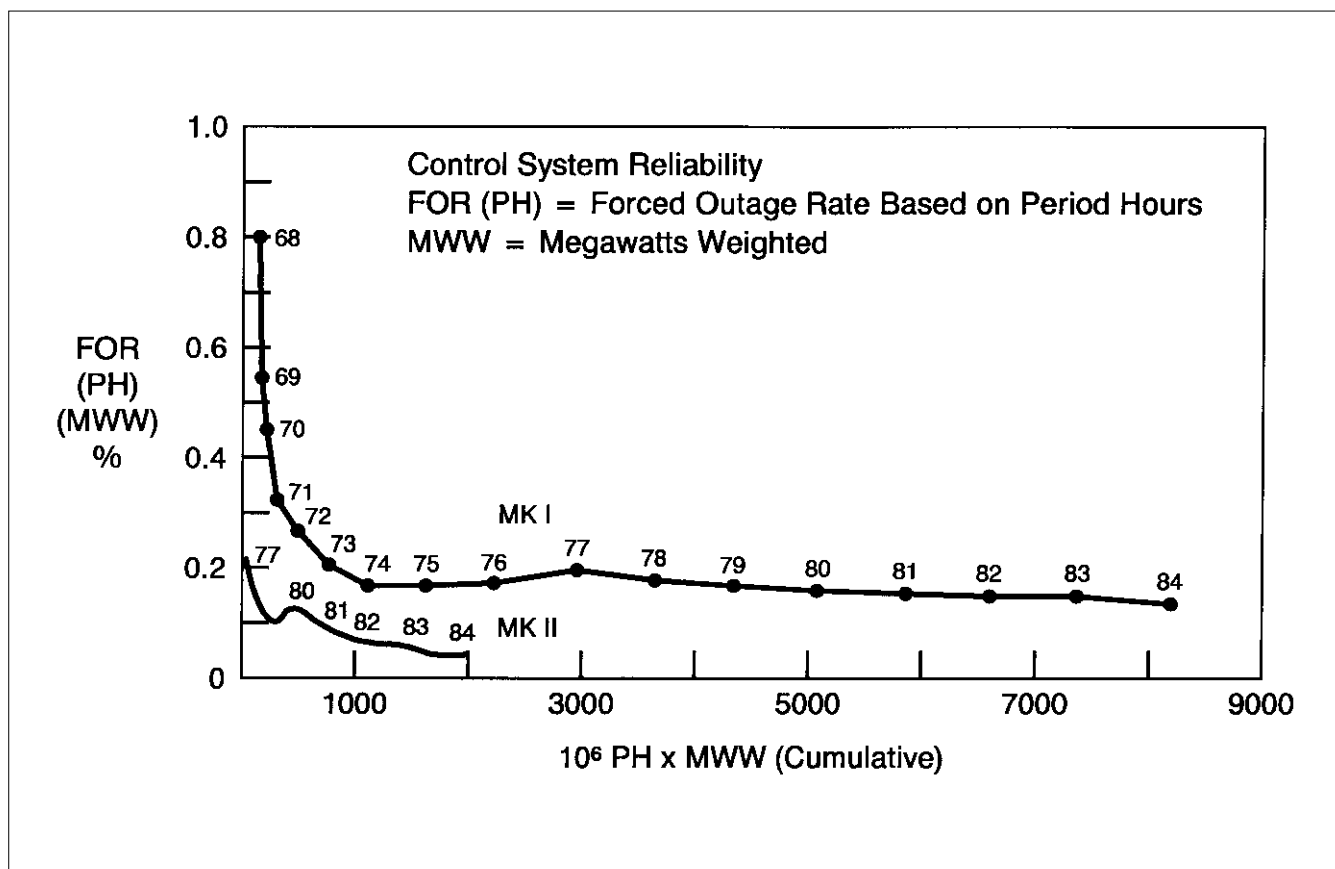
DIGITAL CONTROLS

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 Introduced	EHC MK I 1961	EHC MK II 1970	EHC MK III* 1980	DCM/MK III+ 1986	ST MK V 1991
Total Shipped (Approx.)	190	290	120	27/44	55
Control	Discrete Solid State	Integrated Circuits & Discrete	Integrated 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



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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 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 on-line 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 lock-out 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.

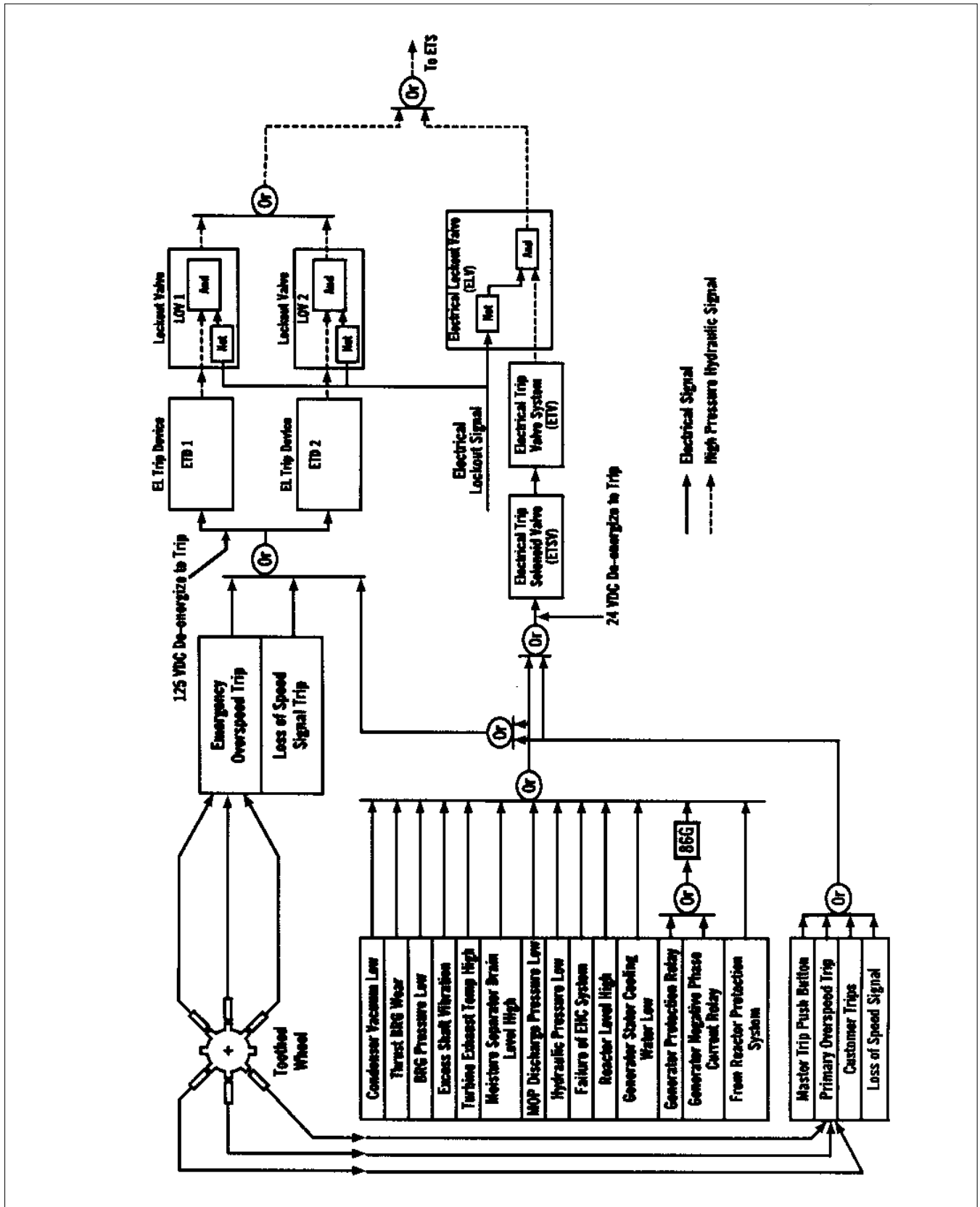
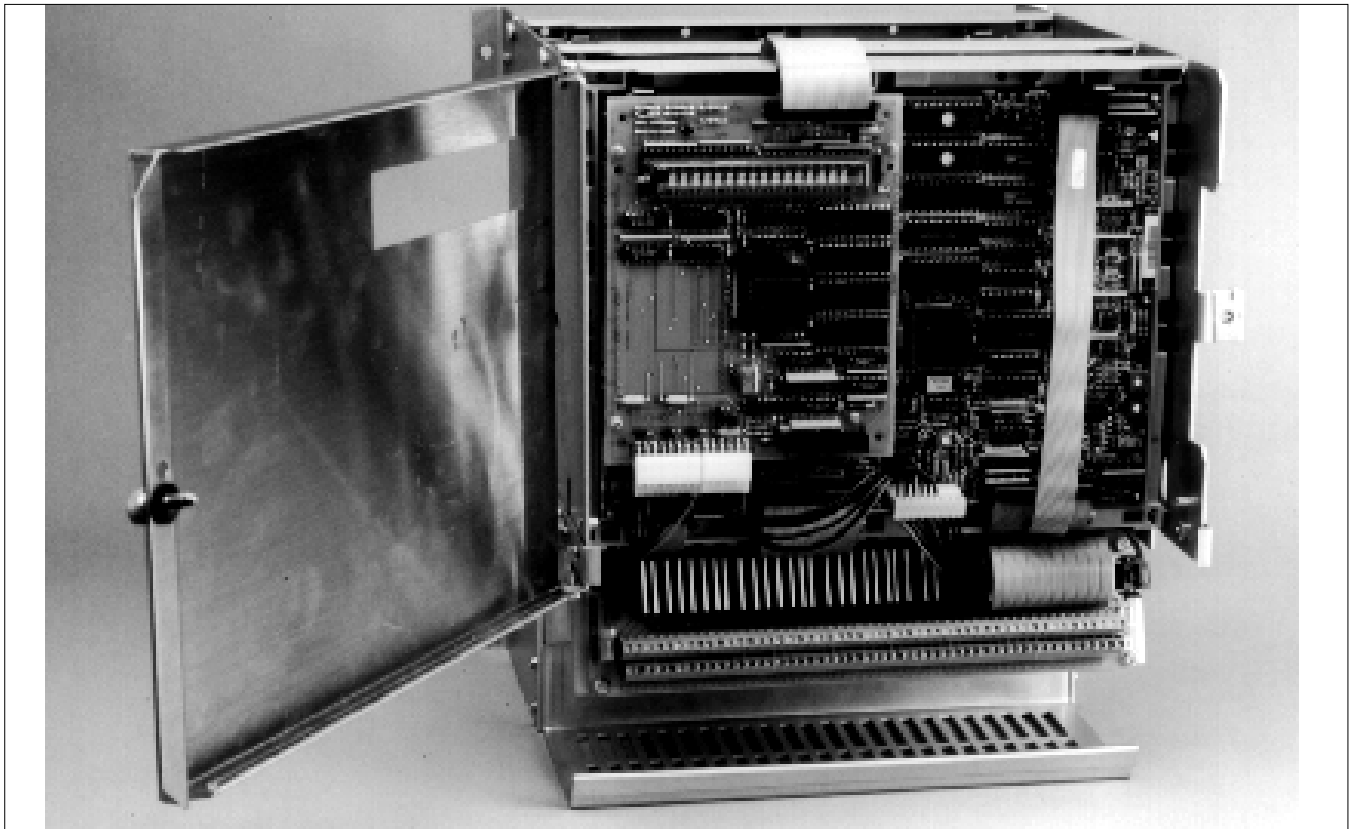


Figure 3. Turbine protection system

GT24371



CGR1219A

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.