IMPROVED GENERATOR TEMPERATURE MONITORING
FOR HYDROELECTRIC POWERPLANTS

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ABSTRACT - The problem of monitoring the temperatures of hydroelectric generators and pumps has existed since the first machines were built. The past methods of collecting, archiving, and analyzing these data have been primarily manual processes with humans taking recordings on paper from analog meters. The operator would determine if the temperatures were out of range as he collected the data. Variations included automated data collection with output on paper for operator analysis and storage. This paper describes a fully automated temperature monitoring system which collects, archives, and analyzes the data for the operator, as well as generates any report defined by the operator.

KEY WORDS - automated temperature monitoring, computer automation, data archival and retrieval

INTRODUCTION

The monitoring of equipment temperatures associated with hydroelectric generation facilities has been done for as long as the Bureau of Reclamation has been operating these facilities. The monitoring process has many problems such as how to collect, store, analyze, and report the data to others. The Bureau of Reclamation has implemented many solutions to this problem over the years with limited success. This paper presents Reclamation's latest approach in solving these problems, which will correct the deficiencies of previous systems and provide a better solution to the basic problem. The equipment is for the Lower Colorado Dams Project Office located at Hoover Dam near Boulder City, Nevada. Although the development was done for this project, the approach will work at any hydroelectric facility.

BACKGROUND

The past methods of collecting the temperature data at Hoover Powerplant included recording the readings manually onto data forms from analog meters and producing hard copy

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output from several small data collection units. These methods are very labor intensive and result in large amounts of paper being stored. In addition, the data were archived on an irregular basis due to the difficulties involved. In spite of this, the past 50 years has resulted in six galleries of the dam being filled with boxes stacked six feet tall and several hundred feet long against both walls.

Recently, the operating personnel at Hoover Powerplant needed to analyze some archived data for a warranty-related issue on a bearing of an upgraded unit. They needed to extract the bearing's temperature data for a 6-month period from the paper stored in the dam's galleries. They needed this bearing's temperatures versus time on a simple line graph for the manufacturer to review. The effort took one person 2 months of work. There were many voids in the period of question due to incomplete data collection or storage retrieval problems. Thus, the result was not as useful as it should have been and was very expensive.

An analysis of the problem was undertaken in an effort to devise a system that would solve the powerplant's temperature monitoring problem. Many possible solutions were evaluated, including the use of different types of hardware at various costs and amounts of labor to install, maintain, and use. Several of the solutions were fully automated approaches but required that all types and amounts of data be defined at system conception with very little future flexibility or expandability. Some of them required considerable operator training or were difficult to maintain. The best solution is described in the remainder of this paper.

DESIGN CONSIDERATIONS

The design requirements were:

1. Fully automated data collection of all channels
2. Fully automated data archival of all channels
3. Fully automated data limit checking
4. Fully automated data retrieval of any channel(s)
5. Data archival medium which is physically small
6. Data archival and retrieval for at least 30 years
7. Fully flexible display and report formats
8. Operator definable display and report formats
9. Low maintenance and minimal down time
10. Commercially available hardware for longevity
11. User-friendly operational interface
12. Modular design to ease maintenance

These resulted in a completely automated temperature monitoring system for hydroelectric synchronous machines. The system is very modular, which aids in the maintenance and configuration flexibility. All hardware is commercial

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off-the-shelf equipment, and the software is commercially available from the contractor. Thus, the system will completely meet the needs at Hoover as well as many other hydroelectric facilities.

HARDWARE CONFIGURATION

The system hardware was assembled from several commercial sources. The heart of the system is three 386-based personal computers operating in a peer-to-peer star-type local area network. Figure 1 shows that the computers consist of two dedicated data archival nodes labeled Nevada and Arizona which are the names of the two powerhouses at Hoover Dam. The third computer is the

Figure 1 - General configuration of the Star-type LAN personal computers

operator interface node where all of the data are displayed and the reports are generated. A printer is attached to this node for hard copy output. An RS-232C dial-up modem is connected to the operator's node so that the remote console in Denver can monitor and make modifications to the system as needed. The two data collection nodes have the same man-machine interface as the operator's node so that the maintenance and programming personnel can perform their functions without interfering with the operator's work.

Each of the two data archival nodes contains an eight-port RS-232C intelligent communications controller for connection to four data collection front-end units as shown in Figures 2 and 3. In Figure 2 the Nevada Powerhouse data archival node communicates with two local

data collection front-ends for the eight Nevada side generators and over two direct-connect modem microwave channels to data collection front-ends at Parker and Headgate Rock Powerplants for the four generators and three machines at these locations, respectively. In Figure 3 the Arizona Powerhouse data archival node communicates with two local data collection front-ends for the nine Arizona side generators and one local maintenance unit. This node also communicates over a direct-connect modem microwave channel to a data

Figure 2 - General configuration of the Nevada side data collection

collection front-end at Davis Powerplant for the five generators at this location. When the two data archival nodes receive data from their four associated data collector front-end units, each node checks its data for up to four alarm limit settings and stores the data onto the 135-megabyte hard disk drive. The data from the other archival node are also stored on each hard disk so that both nodes contain the same data for redundancy. On a programmable basis, the data are archived to the 135-megabyte DC-600 tape drive unit on each of the two

archival nodes. The 135-megabyte tape drive on the operator's node is for recovering old data that are on tapes in cold storage.

As Figures 2 and 3 show, the eight data collectors communicate over a twisted-pair RS-422 cable to the data scanners in a daisy chain configuration. Each of the 30 data scanners has a unique address and only responds to commands from the data collector it is connected to. The data scanners are connected directly to the resistance

Figure 3 - General configuration of the Arizona side data collection

temperature devices (RTD's) and transducers of each hydroelectric generation unit. They convert the analog signals to digital form with programmable resolutions of 16, 14, or 12 bits. The data scanners are configured to scan 80 channels of RTD analog inputs and 20 channels of transducer inputs, i.e., ± 1 milliamperes or 4- to 20-milliamperes current loops or ± 10 volts. The data collectors convert the raw digital scanner data to engineering units such as degrees centigrade or megawatts before sending the data to the data archival computer nodes. These data collectors are intelligent front-ends with considerable programming flexibility such as scan rates and types of engineering unit conversion. The data

scanners have a wide range of input and output cards that can be used to connect them to external analog and digital signals.

In Figure 3 the last data collector and data scanner are not connected to a real generator but are configured for maintenance purposes. This hardware is programmed to test the data collection front-ends and data scanners for defective hardware. If a problem is detected by the system in one of the other data collectors or scanners, the maintenance personnel replace the suspect hardware with the spare hardware. Then in the maintenance shop where the maintenance data collector and scanner are located, they can test the suspect hardware to determine which board(s) needs to be sent back to the manufacturer for repair.

The computer nodes have similar on-line diagnostic tools and tests to aid the maintenance personnel in the rapid repair of the complete system. The objective is to quickly replace the bad component so the system can be returned to full service with minimal or no data loss.

SOFTWARE CONFIGURATION

The software running on the three 386-based personal computers is a commercially available package. The package was customized to meet the needs of the Hoover Temperature Monitoring System specifically and the general needs of other Bureau of Reclamation facilities. The software is based on a proprietary multitasking, multiuser operating system with integral networking software. A unique feature of the software is that the operators, programmers, and maintenance personnel use an extremely user-friendly menu-driven interface to the software.

The software interface allows the programmer to configure the data collectors and data scanners attached to the associated node in the network. This programming includes the numbers and types of channels to be scanned and collected, as well as the four limit values and their associated alarm messages. The data archival features and tape backup intervals are also programmable. There is channel override capability to correct the data in case of an input signal failure. There is configuration control of the computer's communications ports and tape drives.

The operations and maintenance personnel have access to all the data collected by the system on any node. The data point or channel has a unique alphanumeric name associated with it in the database. These names were picked by the programmer during configuration of the system to be English-style descriptions of the data points. This makes the data extremely user-friendly, and it is easy to remember what the physical quantity is. With these data point names or tags, the operator or maintenance person can define a virtually unlimited number of display and report formats. The displays are on the VGA-style monitors in 16 colors with black and white screen dumps to the attached printer. The reports are numerical in nature with output to the screen or the printer.

The real-time displays can take the form of trends, strip charts, vertical bar graphs, horizontal bar graphs, panel meters, dial meters, X-Y plots, or tabular numerical screens. Real-time means that as the data are received

from the data collectors during a scan, they are displayed on the screen in the appropriate form. The trends are a plot of point tag data on the vertical or y-axis versus time on the horizontal or x-axis, while the strip charts reverse the axes so that time is on the vertical or y-axis. As time progresses, the trends scroll to the left and the strip charts scroll down the screen. The X-Y plots look like the trends except the point tags are plotted against each other instead of against time. This is very useful to obtain the relationship of one input signal versus another as time progresses. The bar graphs, panel meters, dial meters, and tabular screens simulate their namesake discrete devices on the computer monitor.

The trend, strip chart, and X-Y plot displays can also be used to display archived data for any time period in the past. If the data are on the hard disk, they will be displayed as soon as the screen is called up. If the data are too old to still be on the hard disk, they will need to be restored from the DC-600 tapes in cold storage to the operator's node hard disk. Then these data can be displayed like any other historical data point tag.

Any of the screen displays can be dumped to the printer for hard copy in black and white format. In addition, the software has report generation capability using a real-time or historical spreadsheet module. This is a standard spreadsheet program where the data for a cell can come from the keyboard, the incoming data from the latest scan, or from data that were stored from past scans. The spreadsheet has format capabilities and the standard mathematical functions performed on the cells. This means that the data collected and archived by the system can be manipulated, analyzed, and reported in any way the user may desire.

The software has a status screen that is called up by a hotkey sequence. The status screen shows the latest system messages and what data collection units are active. It indicates the status of the archival process, which is called "polls" by the software. Each poll generates one archive file each day of the data point tags programmed for that poll number.

The software requires that alarms generated from the programmed limit settings be acknowledged by the operator on a special screen called up by a function key. The alarms create messages on the status screen, start an audible beep from the computer, and log the alarm on the alarm acknowledgment screen. The operator must access this screen to acknowledge the alarm. The operator acknowledgments are stored in a file which includes the operator's initials and time of day for future reference.

In addition to the alarm acknowledgments being filed, the software files the system messages and data alarms with time tags. The data point tags are alarmed when they exceed a limit and when they return to normal or come out of alarm. The limits can be high or low, of any value and configuration, with four being the maximum number possible. Thus, the software keeps complete records of all activities and status of the system for operation and maintenance tracking.

Additional features of the software include MS-DOS execution capabilities, transfer of data files to MS-DOS-compatible file format, and user security features. The MS-DOS execution capabilities exist on the operator's node so that database, spreadsheet, and network programs can be

used by the operator on the same node. This saves space in the control room by not needing multiple computers on the operator's desk to do the necessary tasks of managing the powerplant. Since the software can transfer the data to an MS-DOS-type file format, the data can be analyzed and manipulated by any of the familiar MS-DOS application programs. The best feature from the system manager's point of view is the user security features of the software. All of the menu items can have priorities assigned to them, and all of the users can have priority access levels assigned to them. Thus, when a user logs onto the system, he only sees and can access the menu items that are below his priority access level. This prevents an untrained user from accessing something that he does not understand and may not use correctly. In other words, operators do not have access to the programming features used by the programmers, and programmers do not have access to the system administrator's menu items.

DATA CONFIGURATION

The data channels or point tags being collected by the system consist of the following for each generator at Hoover, Davis, Parker, and Headgate Rock Powerplants.

- o 4 thrust-bearing RTD's
- o 2 upper guide-bearing RTD's
- o 2 lower guide-bearing RTD's
- o 3 turbine guide-bearing RTD's
- o 27 stator RTD's
- o 8 air housing cooler RTD's
- o 1 air housing ambient RTD
- o 6 transformer RTD's
- o 6 transducer analog signals
 - megawatts
 - megavars
 - terminal voltage
 - stator current
 - field voltage
 - field current

There are eight Nevada Powerhouse (N1 through N8) and nine Arizona Powerhouse (A1 through A9) generators at Hoover. There are four generators (P1 through P4) at Parker and five generators (D1 through D5) at Davis. There will be three synchronous machines at Headgate Rock when the modifications are completed. This means that the system is collecting about 60 channels from each of 29 machines plus a maintenance unit, which results in about 1,800 channels worth of data during each scan.

The system is set up to scan all of the data points on a 1-minute rate for real-time display and alarm purposes. The data are archived on a 5-minute basis, which means that every fifth scan is saved for historical records. At these rates, the system saves about 5 megabytes worth of data per day to the hard disk. The 135-megabyte tape cartridge can hold about 1 month's worth of data. Thus, the historical records will consist of two DC-600 tapes per month or 24 tapes per year or 1,200 tapes in 50 years.

INSTALLATION

The installation of the complete system is presently under way at Hoover Powerplant. The computer nodes of Figure 1 went into service in August of 1989 with four generators connected to the system. Additional units at Hoover are

being added as modifications are completed on each generator. Conversion to the new system at Davis and Parker will start in the near future as manpower becomes available after the Hoover modifications wind down. The Headgate Rock units will be added as they are built and put into service. The system was developed and configured in both the hardware and software areas with this need for modular growth and expansion in mind. The data collection front-ends and unit scanners can be added to the system as they are needed with only simple programming changes being needed at the appropriate computer node. These changes do not affect the units and data already on the system but simply add the new unit and its data to the rest of the data structure.

The conversion from the old data collection methods to this system is very labor intensive. Each existing RTD and transducer signal must be re-cabled and connected to the new data scanners as well as some new RTDs and transducers needing to be added. This translates into the routing and connecting of about 60 3-conductor cables per scanner or 180 connections at each scanner plus some changes being needed at the other end in a few cases. Older powerplants like Hoover, Davis, and Parker presently or soon will need some kind of temperature monitoring upgrade as part of the plant modernization effort. This system's approach is no more labor intensive than any of the other possible solutions investigated for this project.

OPERATION

The system has been in continuous and expanding use since installation with only minor problems as expected with any new system. The hardware has had some infant mortality related failures, but the manufacturer has repaired the hardware under warranty with no difficulties. The computers were picked with care to insure ruggedness and field applicability. This care has paid off since there have been no failures under heavy use. The software has had a few bugs, but the contractor has worked hard to solve them with good success. None of the bugs have affected the basic operation of the software which has proven to be well designed and almost indestructible during power outages and operator usage.

The operations personnel are very pleased with the system and are using it on an every day basis. They have discovered many interesting facts such as the thrust bearing temperature is higher by a couple of degrees during condensing operation compared to full load operation and such as the good correlation between unit transformer and stator temperature profiles during unit load profile changes. The maintenance personnel are happy with the system due to it being relatively maintenance free and easy to calibrate and program. They like the highly modular construction and the forethought given to maintenance, expansion, and upgrade issues associated with this type of long-life fully-automated temperature monitoring system.

FUTURE UPGRADES

Although the 1,200 DC-600 magnetic tapes for the next 50 years occupies a lot less volume than the past 50 years worth of data, which occupies a large part of six galleries in the dam at Hoover, the desire is to replace the tape drives with optical disk drives. The optical disks are due within the next year from the manufacturer and have several advantages. The first is better magnetic field immunity, which is important in a hydroelectric powerplant environment. Second is better longevity with better probability of reading very old data correctly. Third, on an 800-megabyte optical disk, the system can store about 6-months worth of data or only 200 optical disks in 50 years. This is a substantial volume reduction over the tape cartridges for the same data storage and provides better data integrity.

The other upgrade is to tie this system into the master fiber-optic wide area network when the network goes into service and to provide a link to the Programmable Master Supervisory Control (PMSC) system when it is delivered in 1993. The Hoover Temperature Monitoring System is an integral part of the Lower Colorado Dams Project's Supervisory Control and Data Acquisition (SCADA) System.

CONCLUSIONS

The Hoover Temperature Monitoring System solves several problems that have plagued Reclamation's hydroelectric powerplants for many years. The system will collect all of the RTD and electrical quantities from each generator in four powerplants along the Lower Colorado River basin on a continuous basis. The data will be archived for future use and displayed in real time for operations and maintenance purposes at Hoover Powerplant. The system is a research and development effort into the use of computer automation in hydroelectric powerplants in order to cut labor and maintenance costs. In addition, the system should aid the Bureau of Reclamation in warranty-related issues when unit operating conditions are of concern or in dispute. The system is operating very well at Hoover Powerplant with good project personnel acceptance and usage.

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