IMPLEMENTATION FRAMEWORK FOR AN EXPERT SYSTEM FOR GENERATOR MONITORING

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U S A

Abstract - This paper describes an implementation framework for an intelligent generator monitoring system. This solution is based on high performance front-end data acquisition system and real-time processing of electrical signals and contacts from related protective relays, circuit breakers, and switches. Based on this data, the system performs continuous monitoring of the electrical part of the generator and informs operators of any deviations from the normal operating conditions. The monitoring involves automated comparison and evaluation of several input quantities according to the rules defined by the experts. The system is implemented using a PC interfaced to an advanced digital fault recorder.

Keywords: Generator, Expert system, Digital fault recorder, Monitoring, Control, Protective relaying

I. INTRODUCTION

Automated monitoring of large generators is a well established practice in the industry. Several computer systems are employed today in a control room to monitor various parts of the generator such as boiler controls, turning and cooling gear, as well as control and protection of the electrical part.

Introduction of advanced data acquisition systems and intelligent techniques have prompted development of new monitoring systems that provide improved performance with a reduced overall cost [1-3]. Those developments have been primarily related to the specific applications such as monitoring of the electrical parts of the generator.

This paper describes a new application of an intelligent system for automated monitoring of the electrical part of a generator. The main advantage of this application over the existing ones is the improvement in the data acquisition and related processing of the data.

The idea for such a system came from development of a similar system aimed at automated monitoring and analysis of the faults in the high voltage substations [4]. This system is also based on the high performance data acquisition front-end using digital fault recorders and an advanced data processing using an expert system [5]. The substation system has been installed in the field and its performance has been monitored for over two years. The experiences from this development and the basic application concept have been incorporated in the generator monitoring expert system design described in this paper.

The prototype of the generator expert system is completed and its functionality tested using analog and digital signals generated using Multi-Amp Pulsar test system. The field installation of the prototype is scheduled for December 1995.

The first section of the paper gives a discussion of the main reasons for introducing such a design. The next section describes the application requirements for a selected generating plant. The last section give details of the hardware and software framework for the implementation. Conclusions and list of references are given at the end.

II. MOTIVATION FOR THE NEW DESIGN

A close analysis of the existing computerized monitoring systems for the electrical part of the generator has revealed the following:

- The input data sensors and selected sampling rate can only provide periodic update of the system conditions. This is realized using averaged values of the analog inputs which may not be sufficient to account for some important transient and fast dynamic changes
- The monitoring philosophy is to alarm all the individual deviations of the input quantities. This may produce a large number of alarms for a given event that may be difficult to interpret in the case of some unusual or complex operating conditions
- The type and number of sensors and measuring instruments as well as related wiring and instrument transformers, are selected to fit individual measuring tasks. This does not provide for any intelligent comparison or redundant checks among all the measured quantities that are naturally correlated by the laws of the electrical circuits.
- There are digital fault recorder installed at generating plants at some utilities, but their function is only to record data once they are triggered and no intelligent processing or analysis is performed.

As a result of this analysis, it was realized that an advanced data acquisition and processing system consisting of a digital fault recorder and a PC can offer several major benefits when compared to the existing solutions:

- The input data can be obtained by using synchronized sampling of currents, voltages, and contact states. This provides enhanced resolution and temporal relation for the input quantities that enables monitoring of fast transients and dynamic changes of the generator electrical system
- An intelligent processing of alarms can be performed. This may eliminate the need to report the individual alarms by automatically correlating the alarms and providing one comprehensive resulting statement about the prevailing generator operating condition

- All the input data is gathered in a common data base that is updated in real time. This enables consistent processing of input quantities, where intelligent correlations may be established, thus providing additional redundancy and logic checks for improved monitoring
- High speed processing and reporting of transient and fast dynamic changes can be performed. This provides real time reporting to the operator.

Based on the mentioned observations, it was concluded that the new monitoring system will benefit different groups of personnel responsible for the various aspects of the generator system operation.

The following are the major benefits identified for the specific groups of personnel:

- The operators will have a dedicated high performance system capable of making intelligent conclusions about the operating state based on variety of system measurements and conditions. This may simplify the operator tasks while improving overall quality of the operations
- The engineering and design staff will have a system capable of recording system conditions and operations with increased accuracy and selectivity. This may provide useful information needed for the on-going analysis of the generator operating performance and improvements in the engineering design practices
- The protection engineers will have access to analyzed data, that have not been available earlier, describing abnormal operations and conditions on the generator. This may improve their capability to troubleshoot various operations of protective relaying systems and to better understand impact of the protective relaying operation on the generator

III. APPLICATION REQUIREMENTS

The following design criteria was established in order to cover wide range of generating stations:

- provide continuous sampling and monitoring of input data
- provide synchronized data sampling that automatically aligns all monitored electrical quantities in time
- provide redundant checks and indication to determine if sensor readings are erroneous
- provide historical data and trends for most important electrical quantities
- check that all readings are within expected limits
- check trends to determine if continuation of the present mode of operation will take the generator unit outside the allowable range for the electrical quantities
- provide displays of measurements for the present operating state
- provide alarm limits that can be variable, i.e., recalculated for each specific operating level
- provide "early warning" of operating problems
- provide concise and condensed measurement and event information to aid the operators in making decisions
- provide digital synchroscope and monitoring of the synchronizing procedure to help operator synchronize the generator with the system
- provide storage of historical data and recovery capability using data compression techniques
- provide modular design allowing easy adaptability and expandability for future use on other generator units

Several expert systems for generator monitoring and diagnosis are reported in the literature [1-3]. Data acquisition in all of these systems is done through different sensors and transducers, hence the sampling frequencies are low (several samples per minute). Also, the number of different inputs is large, because they utilize both electrical quantities and mechanical quantities.

GENerator monitoring EXpert system (GENEX) described in this paper, provides on-line monitoring of most of the electrical parameters, protective relays and circuit breakers for a generator unit in one of the HL&P's fossil-fired steam plants. Figure 1 shows the one line diagram of the generation plant. The location and type of the GENEX input signals are also shown. Table 1 presents types of analog and digital quantities that are measured or monitored by GENEX.

TABLE 1
ANALOG AND DIGITAL SIGNALS USED BY GENEX

Analog quantities
generator output currents
generator exciter field current
generator terminal voltages
generator neutral current
generator neutral voltage
voltage from the main transformer primary
voltage from the auxiliary buses
generator exciter field voltage
voltage from the system buses
turbine speed
Digital quantities
relay contacts (e.g., generator lockout relay, differential relay, loss of excitation relay, etc.)
control switches (e.g., synchronizing switch, control switch, etc.)
circuit breakers (e.g., generator breaker, auxiliary transformer breaker, etc.)
main transformer disconnect switch

IV. IMPLEMENTATION FRAMEWORK AND GENEX FUNCTIONS

Figure 2 shows the GENEX block diagram. Digital fault recorder (DFR) serves as a data acquisition front-end, to the

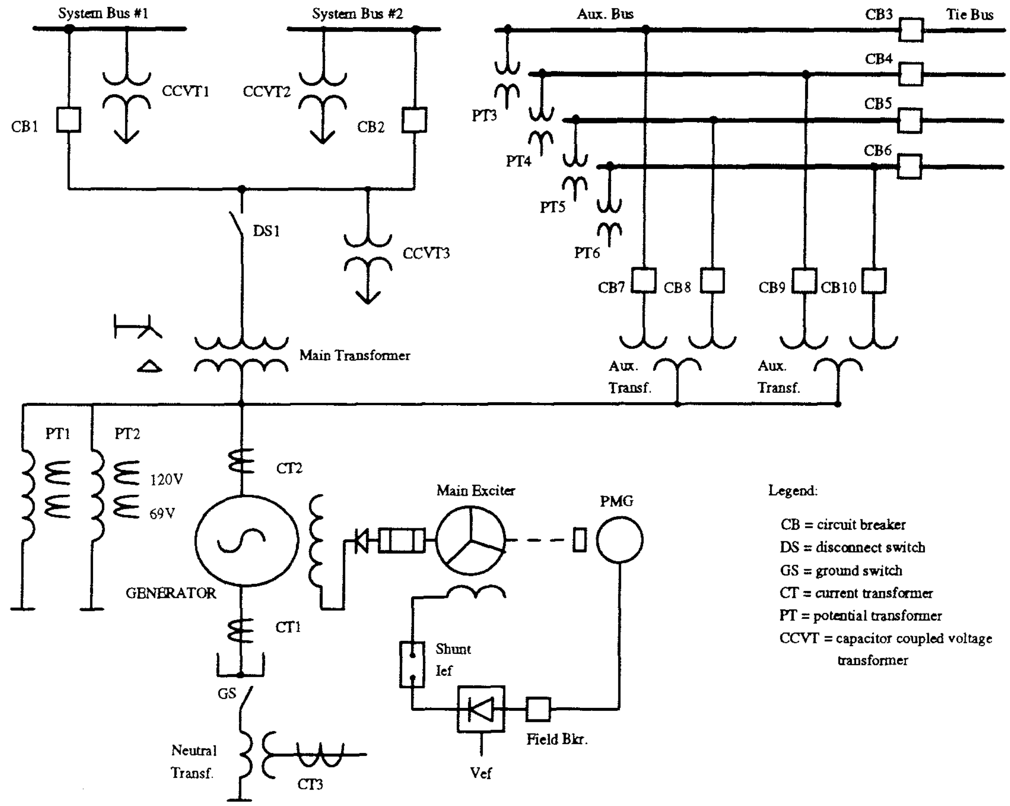

Figure 1. One line diagram of the power plant

providing continuous data flow toward the expert system PC. At the same time, DFR maintains its basic function of recording the events according to the internal triggers and storing those events on the local hard drive inside the recorder. These stored events are available remotely per request over a dial-up line, using master station software provided by the DFR manufacturer.

The communication between DFR and PC is done via high speed parallel interface board. The DFR sampling frequency is fixed at 4800 Hz. All analog and digital channels are sampled synchronously. Data samples are transferred to the PC in blocks. Each data block contains 20 samples of every input channel. Data blocks are queued and processed by the expert system software on the fly.

Since the processing of the incoming data blocks need to be done in a real-time, expert system PC is based on a high speed Pentium microprocessor with a dedicated high speed graphics accelerator. Graphic accelerator supports real-time data displaying on a 21" monitor. All system information is presented either in a form of a plain English messages to the operator, or in the form of graphical displays that are refreshed every second (e.g., capability curve with present operating point indicated on the chart).

Digital fault recorder and expert system PC are packaged together, because the parallel link between them needs to be short, allowing high data transfer rates. Both of them are placed in the same cabinet. The monitor, keyboard and trackball are, on the other hand, placed in the control room, allowing operators easy access and visibility. Special extension cables are provided with the GENEX system so the distances between the computer and peripherals can be up to 50 ft.

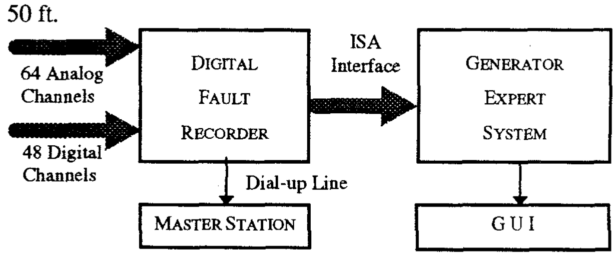

Figure 2. Generator monitoring expert system block diagram

Table 2 lists major functions embedded in GENEX. These functions are grouped based on two distinctive states of any generator unit, namely normal operating state and synchronizing state.

All of the above functions are integrated using upper level intelligence module (see Figure 3). This module is the core of the expert system, allowing correlation and combination of different independent conclusions into one global conclusion about the generator operating event.

The upper level intelligence module receives the status messages from individual application functions and performs inferencing based on the available information. Since one of the most important requirements for the expert system was real time operation, none of the commercially available expert system shells has been used because of the overhead they put on the necessary data processing. Simplified and optimized forward chaining inference engine was designed for this application.

Table 3 gives an example of a rule in the knowledge base of the upper level reasoning module. The first part of the table outlines the specific conditions that are checked for this contingency, while the second part of the table presents possible messages displayed to the operator.

The following are examples of other contingencies that can be detected by the GENEX:

- Blown fuse on potential transformers
- Open phase
- Generator lockout relay misoperation
- Loss of Boiler Feed Pump Turbine
- Loss of Primary Air Fan
- Loss of field

TABLE 2

MAJOR GENEX APPLICATION FUNCTIONS

Normal Operating State (monitoring and alarming)
voltage unbalances
current unbalances
excessive V/Hz detection
negative sequence current detection
loss of field detection
100% stator ground fault detection
generator trip analysis
generator speed
rotor subsynchronous resonance
capability curve limits and operating point
Synchronizing State (control and monitoring)
synchronizing generator to the system
synchronizing bus to the system (ring bus)
performance analysis of the synchronizing procedure

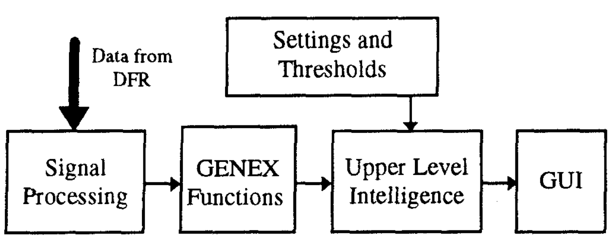

Figure 3. Software organization

Different algorithms are used in the signal processing part of the GENEX system for calculation of necessary parameters, such as MW, MVARs or frequency, on a continuous basis.

Settings and thresholds for every application function are stored in a data base, and available to each function when function call is made.

The GUI is organized in two ways. Alarms and system messages are displayed on screen in a real-time for the use by the operators. Also, the displayed messages are always logged together with several cycles of data in a time-stamped report. This report is useful for post-mortem analysis of a given generator event.

TABLE 3

AN EXAMPLE OF UPPER LEVEL REASONING

Conditions
MVARs drop from (-100 to +300) to -600
loss of field relay did not trip
terminal voltage is low (90% of V_{RATED})
circuit breakers CB1 and/or CB2 are closed
disconnect switch DS1 closed
depending on the MWs, speed should increase
Messages
probable loss of field
trip the turbine
transfer auxiliary transformer to standby transformer
trip the generator breakers

Figure 4 shows the appearance of the digital synchroscope and associated measurements and messages when generator synchronizing function is active. The underlying logic first checks presynchronizing conditions, making sure that synchronizing can be done based on the present generator and outside power system status. Then, the synchroscope is displayed. Circles represent the incoming and running voltages. Larger handle represents incoming phase angle, while smaller represents running phase angle. The marker on the circle represents the optimal closing angle. This value is calculated based on the breaker closing time and the system/generator frequencies. The marker helps the operator to synchronize the generator to the system with minimal stress to the generator itself.

Once the synchronizing is completed, GENEX records system data and evaluates the success of synchronizing based on the transients induced in the process of synchronizing.

Figure 5 and Figure 6 show some of the displays when generator is up and running. The message window displays the results of the GENEX processing in real-time. Messages are generated when a function or set of correlated functions are triggered. All GENEX functions have a set of variable thresholds. These thresholds have four possible ranges that are user selectable: nominal, alert, alarm, or limit. These ranges can be either fixed, or dynamically calculated as a function of some other threshold values.

Figure 6 shows message window that has a superimposed generator real-time capability curve. Operating point is displayed in real-time. The tail represents historic values of the operating point, so the trend can be observed easily.

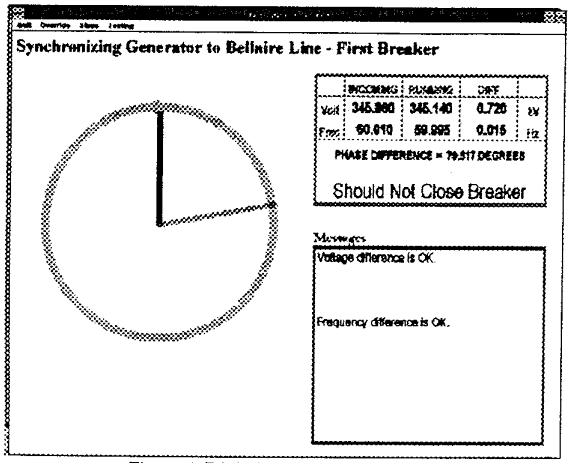

Figure 4. Digital synchroscope display

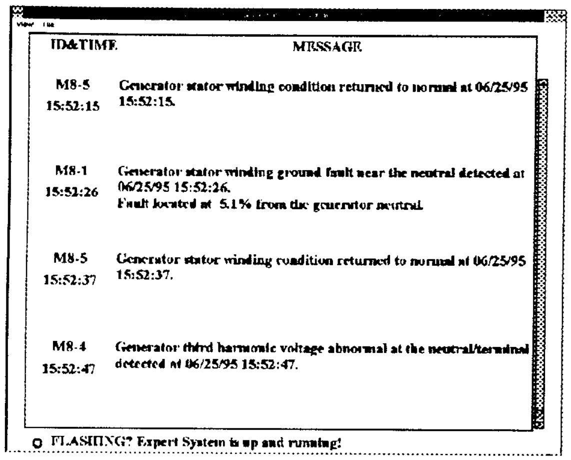

Figure 5. Message display

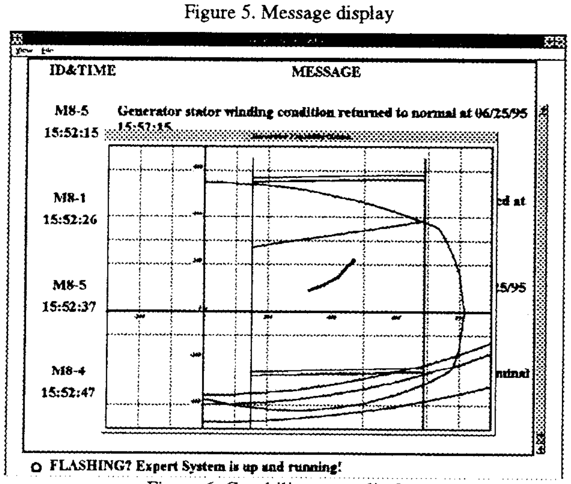

Figure 6. Capability curve display

V. CONCLUSIONS

Based on the research and development experiences gained so far, the following can be concluded:

- The existing generator monitoring systems can be enhanced if higher data sampling rate and improved processing are employed.
- The GENEX design takes advantage of the high performance data acquisition front-end provided by the DFR, and the expert system software aimed at comprehensive assessment of the generator operating status.
- The monitoring capabilities of the GENEX system may be useful for variety of utility personnel including operators, as well as design and protection engineers.

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