NEW TECHNOLOGIES FOR EFFECTIVE MONITORING, CONTROL AND PROTECTION

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SUMMARY

The main theme of this paper is how to use the new technologies to utilize utility assets to the maximum by improving monitoring, control and protection. The technologies discussed are: implementation of advanced utility communication infrastructure; application of synchronized sampling for data acquisition and related measurements; use of digital substation instrumentation and equipment designs; use of advanced microcontrollers and control devices; utilization of intelligent techniques such as expert systems, neural nets and fuzzy logic; development of new sensors for measurement of electrical and non-electrical quantities. After the technologies are introduced, several applications using these technologies are presented. Improved substation monitoring related to accurate fault location and automated analysis of operation of the protective relays and related equipment is discussed first. The new decentralized control approach based on local measurement is also introduced. Each of the applications offers overall improvements achieved by increasing the system availability, reliability and capacity.

INTRODUCTION

The utility industry is well into deregulation and increased competition. This leads to a need to operate the utility assets more efficiently and reliably with reduced budgets and staff. One possible way of meeting this goal is to introduce advanced technology for improved assessment and control of the operating conditions as well as to implement automation for quicker operator responses and fewer required staff. How precisely the technology and automation relate to increased efficiency and reliability under a constraint of reduced budgets and staff is a rather complex question. The answers to this question may be quite different depending on the given utility history and development, as well as its existing assets and operating practices.

This paper is concentrating on a rather important issue of how the improved monitoring, control and protection can increase efficiency and reliability of operation. The paper summarizes experiences gained in this area at Texas A&M University through a variety of research projects that may be in one of the following stages: completed, on-going, or just proposed. The first part of the paper provides an overview of the technologies for improvements in the monitoring, control and protection. The second part of the paper discusses advanced monitoring and protection solutions while the advanced control solutions are presented next. Conclusions and references are given at the end.

NEW TECHNOLOGIES

A variety of technologies may be used to improve monitoring, control and protection. This paper concentrates on very specific group of technologies that are believed to be a core of new monitoring, control and protection paradigm. The technologies with brief description of the features and expected benefits are summarized in Table I.

Table I. Summary of the Major Technologies and Expected Benefits

FEATURE	EXPECTED BENEFITS
DIGITAL SUBSTATION MONITORING, CONTROL AND PROTECTION SYSTEMS	
Extensive substation data base	Better monitoring for control and maintenance
Substation wide coordinated protective relaying	More dependable and secure relaying schemes using adaptive features
Automation of substation switching sequences	More efficient execution of operator actions during emergency and restoration
ADVANCED INTRASTATION, INTERSTATION AND SYSTEM WIDE COMMUNICATION SYSTEMS	
Elaborate intrastation and interstation data exchange	Ability to exchange data between adjacent substations for improved monitoring and protection
Advanced system-wide data exchange	Ability to implement decentralized strategies for more responsive emergency control
SYNCHRONIZED SAMPLING AND WIDE AREA MEASUREMENT SYSTEMS (WAMS)	
Data acquisition synchronized with GPS receivers	Implementation of precise measurement of fault location, phase angles and transmission line parameters
WAMS system implementation	Monitoring of load characteristics, detection of unstable modes, and measurement of system states
ADVANCED MIROCONTROLLERS AND CONTROL DEVICES	
Inexpensive controller chips with integrated A/D, Comm. interfaces and multiple I/O	High speed local processing of control algorithms and initiation of control actions
SMES, Braking Resistors, FACTs and SVCs	Ability to inject or extract energy as well as to control load flows and voltage stability quickly
INTELLIGENT SYSTEMS	
Expert systems capable of handling large rule-base	Intelligent alarm processing and fault diagnosis
Neural nets capable of parallel processing	High speed pattern recognition for detection of faults and system instabilities
Fuzzy logic capable of dealing with imprecise data	Ability to formulate fuzzy controls for handling difficult control situations
ADVANCED SENSORS	
Optical CTs and PTs for wide-band, wide dynamic range, accurate measurements	Utilitization of highly accurate measurements for monitoring and control and development of new relaying principles based on non-fundamental frequencies
Measurement of temperature, gas content, electrical discharges, status of contacts	Improved monitoring capability for maintenance purposes for power transformers, circuit breakers, bushings, etc.

NEW APPROACHES FOR MONITORING AND PROTECTION

The new concepts in this area are based on improved data acquisition capabilities. In particular, the ability to acquire signals of voltages and currents from CTs and PTs as well as contact status from breakers and switches across the system with GPS synchronization is of interest. Such data can be obtained by retrofitting the existing equipment. Further discussion is concentrating on several new developments presently under way at Texas A&M University[1].

Automation of Disturbance Analysis Using DFR Systems

The latest trends in this area are to perform the entire analysis related to detection of events, their classification and characterization using only automation software with minimal intervention of the operators. One such system developed recently utilizing Digital Fault Recorders (DFRs) is shown in Figure 1.

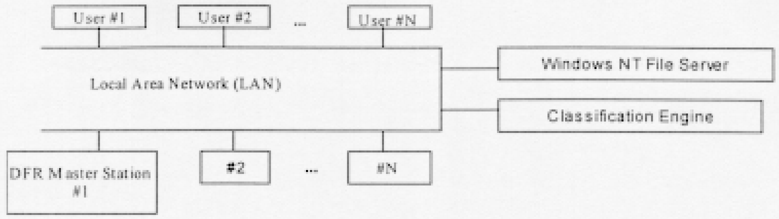


Figure 1. Automation Analysis of Disturbances Using DFR.

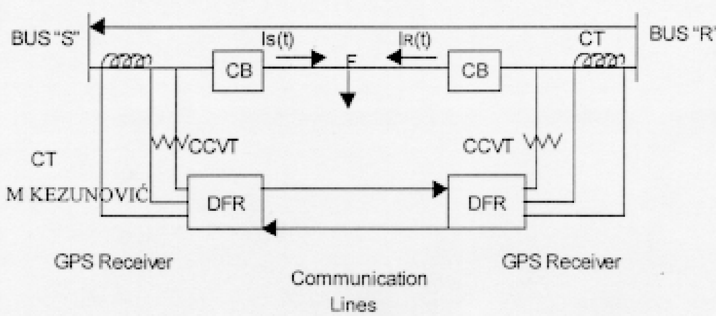
This system is implemented using an expert system shell and enables automated detection and classification of faults as well as identification of relay misoperations, slow breaker operations, breaker failures, restrikes, ferroresonance, and failure of communication channels for protective relaying[2].

The major benefits of this solution are high precision and resolution of the collected data, high speed of data processing and system-wide monitoring. Combined, all of the mentioned features enable a very precise analysis of disturbances to be performed within few seconds allowing system operators to react in real-time.

High Accuracy Fault Location

Another recent development utilizes synchronized sampling technology to implement new fault location techniques based on use of samples of voltages and currents from the ends of the transmission lines[3]. The data from the ends are exchanged via communication links and the final decision is made at a centralized location. The basic outline of the system is given in Figure 2.

The benefits of this system are not only the high accuracy but its robustness. The system is capable of determining the fault location accurately under very difficult fault and operating conditions such as: time-varying fault resistance, mutual coupling, switching in



the system affecting equivalent source impedances. In addition, the system is capable of classifying faults for the purposes of single-pole autoreclosing.

DFR-Based System with Combined Fault Location and Event Analysis

A logical extension of the two mentioned developments is to merge them into one. This combined solution can be achieved by retrofitting the existing DFRs, with capabilities for synchronized sampling using GPS receivers. In that case both the disturbance analysis and accurate fault location can be combined to provide rather powerful fault analysis.

Further extension of this concept would be to perform continuous monitoring of disturbances and hence to carry out the analysis not only to the faults but also to other disturbances such as power quality events. Some of the events associated with faults, such as voltage dips, frequency change, and switching equipment operation can be analyzed from the data file whose capturing was triggered by the fault disturbance. However, to perform analysis of the events that occur during "normal" system operations such as harmonics, flickers, switching transients and other distortions of the fundamental signal, it is necessary to maintain a continuous data acquisition. This requires further retrofitting of the DFR system to allow for continuous stream of input data[4]. The analysis is then implemented using real-time processing. Each of the disturbances will trigger an appropriate algorithm that may be implemented using variety of signal processing and intelligent system techniques[4]. An example of such a system for analysis of power quality events is shown in Figure 3[5].

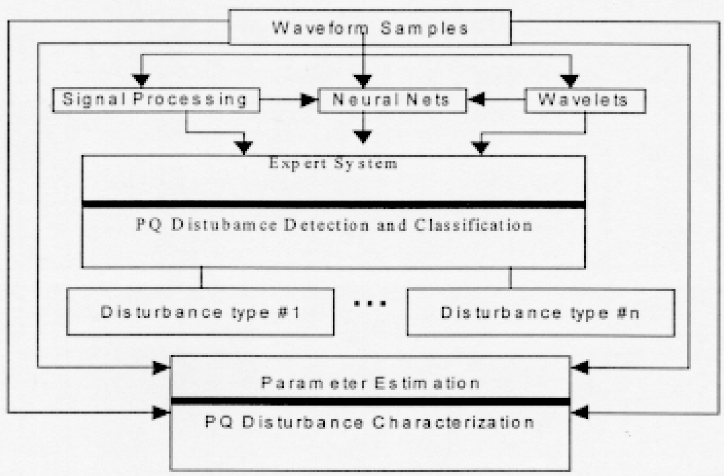


Figure 3. Automated Analysis of Power Quality Events

Future Substation Monitoring, Control and Protection Systems

Finally, the concepts implemented using the DFR-based systems can be expanded if a full blown digital substation monitoring, control and protection system is available.

A variety of digital substation systems designs are available today. However, they still may have to be upgraded to provide for synchronized sampling and high speed communications[6]. In any case, the required upgrades are not too demanding and will become a standard solution in the near future.

The benefits of digital substation systems are multiple. In the monitoring area, these systems have access to a very detailed data from variety of substation equipment. With introduction of new sensors and related monitoring technologies, there is even more data available. The substation systems have very powerful computing capabilities which will enable elaborate monitoring and diagnostics processing to be carried out locally at the substation. As a result, very precise maintenance data base can be developed locally and related control center processing may be reduced.

The benefits in the relaying area are also rather profound. New relaying functions as well as improved existing functions can be implemented. The new relaying applications may be introduced for transmission line relaying where both synchronized sampling and neural nets are used for improved selectivity and dependability[7] . Power transformer protection may be enhanced by using fuzzy logic to deal with imprecise data during CT saturation and in rush conditions. Bus bar protection may be implemented using high speed pattern recognition techniques capable of making decision before the CT saturation occurs. Finally, a variety of adaptive relaying principles can be implemented to enhance the existing functions.

NEW CONTROL APPROACHES

To utilize the advanced technology, the controls need to be organized in such a way that one can effectively decide on the most appropriate controls for a particular event, either for preventive control or emergency control. The needed measurements as feedback inputs to activate the centralized controls for all events may not be realistic due to geographically dispersed nature of power systems. It is well known that it takes time to collect and synchronize all the measurement data. Accordingly, the distributed control law that utilizes local measurements with some coordination among local controls may be the natural way to go about solving this problem.

New Distributed Control Approaches

The Hierarchical Aggregation and Decomposition (HAD) approach that utilizes "think-globally-but-act locally" concept and fundamental power system properties has been developed to pinpoint the effective controls, to select the needed feedback measurements, and to coordinate local controls to be able to achieve a global goal[8] . To describe the HAD approach, we further divide it into the Textured Decomposition (TD) method and Hierarchical Aggregation and Disaggregation (HAD) method[9,10].

The TD method uses nonlinear sensitivity concept to organize controls and the controlled states so that one can pinpoint the effective controls through troubled states[9]. The sensitivity is a nonlinear function of loading. To localize the control effects, the system is decomposed into groups. Inside each group, active controls, inactive control and corresponding buses are defined. Active control can influence the states of the buses in the group. Inactive controls can influence the states outside the group. For local problems in a group, we can focus on using the active controls in the group to solve the problem to localize the solution. The approach can also deal with global problems that involve many groups. By temporarily freezing the inactive controls, we can compute and apply active controls from disjoint groups concurrently without worrying about the overlapping effects. All the effective controls will be considered by going through the levels of computations and control actions. At each level, the groups are disjoint from each other. The overlapping effects of effective inactive controls are considered from level to level.

The HAD method uses aggregation concept to simplify the overall system model by aggregating details into cruder, smaller dimension, models for fast crude decisions[10]. The decision is then refined by incorporating more pertinent detailed information into the decision process. As shown under some conditions, the decision can be a true optimal one for the whole system. This can be used for emergency situation, when the response time is a hard constraint; we can start from the crudest but fastest solution to remedy the crisis. If the time allows, we can continue elaborating the solution until the time runs out. We can organize the models into a hierarchical structure; from the simplest to the most detailed one. At one hierarchical level, the system may still be large; then we can use the TD to localize the computations and controls. The combined approach becomes our HAD approach. The approach can be combined with off-line planning for fast online operations.

The HAD approach can be applied to both monitoring, security assessment, preventive control and emergency control actions. The approach can be incorporated into the following implementation.

A Proposed Implementation of a Hierarchy of the Tuning and Structural Control

The envisioned monitoring system will have two layers:

- Layer 1: This layer represents the intelligent monitoring and control actions at the substation level. Typically, it takes at least one cycle to detect the occurrence of a fault and several more cycles to characterize, locate and clear it. In the case where a state of the art fault locator (based on synchronized sampling of close-in and remote-end signals) is used, the faulted line can be identified reliably and fast within a single cycle. Thus, current relaying practice of "blind" auto-reclosing of one or several lines can be readily avoided. In addition, due to the insignificant likelihood of multiple simultaneous fault occurrences, tripping of various lines within close electrical proximity of the faulted line can be prevented by fast communication infrastructure between neighboring substations. An intelligent monitoring system will also be capable of predicting the likely sequence of line trippings and reclosings based on the current and historical values of local system parameters. This information will be continuously telemetered to a central coordinating entity so that system wide control actions can be based on these future predictions of structural changes. The HAD approach can be used for such a coordination.
- Layer 2: This layer will be composed of local controllers with an ability to communicate with system wide distributed controllers at various substations. Each controller will be responsible for the local stabilizing and viabilizing actions. However it will also possess the necessary intelligence to alter local decisions based on the structural and analog information at the remote transmission line terminals to eliminate unnecessary control actions. In the scenario of the loss of load in an area, controllers at the terminal buses of the weak tie-lines in the connecting areas will take stabilizing actions in order to avoid break-up of the areas. While such actions are being taken, these controllers will continue to receive updated and predicted structural and analog information about the sequence of events taking place in the area where the event has occurred. Current practice not only lacks controllers for such local action (controls are centrally coordinated and decided upon), but also relies fully on the after-the-fact information as far as the structural changes (such as line trippings and reclosings) are concerned. In our proposed paradigm, anticipated sequence of events will be taken into account by the local controllers. As an example, if a sequence of line trippings as unnecessary or even counter productive, then this will be communicated to the relevant relay for possible blocking. Such interactions can be evaluated through our HAD approach.

CONCLUSIONS

Based on the issues discussed in this paper, the following conclusions can be made:

- The use of advanced technologies may lead to development of new and improved monitoring, control and protection strategies.
- The improvements in the monitoring and protection area are possible due to availability of additional data and synchronization of measurements.
- The improvements in the control area are possible due to the improvements in the monitoring and protection as well as to the use of new decentralized control concept being combined with the new digital substation system features.

M KEZUNOVIĆ

- Better monitoring, control and protection will increase the ability to maintain system availability, reliability and capacity in new operating conditions imposed by deregulation.

REFERENCES

[1] M. Kezunović, I. Rikalo, C.W. Fromen, D.R. Sevcik, S.M. McKenna, D. Hamai, W.M. Carpenter, S.L. Goiffon, "Automated Fault Analysis Using Intelligent Techniques and Synchronized Sampling," 1998 CIGRÉ General Session, Paris, France, September 1998.

[2] M. Kezunović, I. Rikalo, B. Vesović, S. Goiffon, M. Carpenter, "The Next Generation System for Automated DFR File Classification," Fault and Disturbance Analysis Conference, Georgia Tech, May 1998.

[3] M. Kezunović, B. Peruničić, "Automated Transmission Line Fault Analysis Using Synchronized Sampling at Two Ends," IEEE Transactions on Power Systems, Vol. 11, No. 1, February 1996.

[4] M. Kezunović, I. Rikalo, B. Peruničić, M. Mallini, "Automated Power Quality Assessment Using DFR Data," Precise Measurements in Power Systems and Fault Disturbance Analysis Conference, Arlington, November 1996.

[5] M. Kezunović, A. Abur, "Advanced Tools and Methodologies for Power Quality Assessment," European Conference Power Quality 97, Nurenberg, Germany, June 1997.

[6] M. Kezunović, "Future Requirements for Digital Substations Control and Protection Systems," SEE Conference, Paris, March 1997.

[7] M. Kezunović, I. Rikalo, "Detect and Classify Transmission Line Faults Using Neural Nets," IEEE Computer Applications in Power, Vol. 9, No. 4, pp. 42-47, October 1996.

[8] G. Huang, J. Zaborszky, et al., "On Line Stabilization of the large HV-AC-DC Power System by Observation Decoupled Reference as a System-Wide Target," IEEE Trans. on Power Apparatus and Systems, pp. 788-797, April 1994.

[9] G. Huang, J. Zaborszky, et al., "A Textured Model for Computationally Efficient Reactive Power Control and Management," IEEE Trans. on Power Apparatus and Systems, pp. 109-121, July 1985.

[10] G. Huang and s. Zhu, "A New HAD Algorithm for Optimal Routing of Hierarchically Structured Data Networks," IEEE Trans. on Parallel and Distributed Systems, Vol. 7, No. 9, pp. 939-953, September 1996.