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DATA ACQUISITION AND COMMUNICATION REQUIREMENTS FOR ADVANCED MONITORING, CONTROL AND PROTECTION

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This paper concentrates on the requirements for data acquisition and communication within and among substations as well as the communication requirements between substations and control centers. The requirements are discussed in the context of some advanced monitoring, control and protection techniques developed recently using digital signal processing, expert systems and neural networks in combination with system-wide synchronized data sampling. The new techniques are aimed at an overall improvement of the power system control.

Keywords: Monitoring – Control – Protection – Data Acquisition – Communication – Intelligent Technique –Substation – Power System

1. INTRODUCTION

Introduction of microprocessor technology and digital communications to the field of power system monitoring, control and protection has resulted in a great variety of device and system designs. Integration of all of these solutions in a given application environment has become a major design, engineering and development issue in recent years. Study of the requirements for this integration has surfaced as one of the key steps in trying to find some general control and communication architectures that may accommodate several different implementations of the application functions.

This paper explores the implementation requirements for several new application functions recently proposed by the author. These functions range from automated monitoring of the substation equipment and the overall power system to improved control and protection.

2. NEW APPLICATIONS

2.1. Power System Monitoring

Recent advances in the power system monitoring area reported by this author are related to development of new fault analysis techniques using expert system and neural net technologies [1-3].

2.1.1. Automated Fault Analysis in Substations

The specific application discussed as an example of the new developments in the monitoring area is the automated fault analysis.

Recently, a PC based solution was developed for automated analysis of operation of protection relays as well as related communication channels and switching equipment [1,2]. This solution is implemented using a hybrid approach where both advanced signal processing and expert system techniques are utilized. A block diagram of the solution is given in Figure 1.

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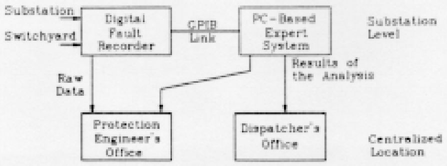

Figure 1. Substation Automated Fault Analysis

The front end data acquisition system is a Digital Fault Recorder (DFR) that provides samples from all analog waveforms and contact (status) signals in the substation. The required data sampling rates are in excess of 1kHz and samples have to be taken synchronously on all of the input channels.

Specific signal processing and expert system techniques are implemented to make detailed conclusions about correct/incorrect operation of protection relays, blocking/unblocking communication channels and circuit breaker operation and timing [1]. The decision process is based on a short data window, in the order of one power frequency cycle and below. This process is based on utilization of the temporal relationship between various phases of the analog signals as well as related contacts. This analysis is performed each time when the DFR is triggered by a disturbance.

The result of the analysis is obtained at the PC in the substation and transmitted as an abbreviated message to the protection engineers and dispatchers. The message contains a detailed description of the sequence of operation of the substation equipment with an indication if the sequence is executed correctly or not. This message is very brief and only takes a couple of bytes versus several kbytes of raw data that is otherwise transmitted by DFRs.

This system has been in operation for over two years at the STP substation in South Texas. The monitoring of operation of this system is performed by Houston Lighting & Power Company and reported results indicate satisfactory performance. Future enhancements of this system are being considered utilizing neural net techniques in place of the signal processing techniques presently used [3].

2.1.2. Hierarchical System Fault Analysis

The substation system described in the previous section performs automated analysis of the events "seen" by the substation where the system is installed. A hierarchical solution for the overall power system analysis can be envisioned as given in Figure 2.

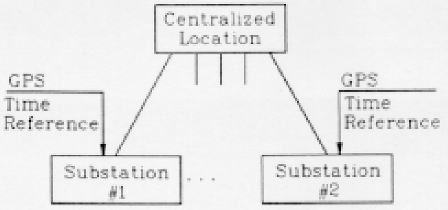

Figure 2. Hierarchical Fault Analysis

The idea is to perform two level analysis. One level is the fault analysis at the substation performed as described earlier. The second level is the analysis performed at the centralized location where all individual results from the substations are combined. The analysis at the second level is greatly enhanced if all the data in the substation is synchronously sampled. An absolute time reference would provide an easy combining, at the centralized point, of the events analysis performed at the substation. A Global Positioning System (GPS) of satellites can be used to provide an absolute time reference for the required synchronization.

2.2. Power Flow and Stability Control

An important measurement in most of the control approaches is the phase (angle) difference between tow nodes (buses) in a power system. If data sampling at the two nodes is synchronized, a new technique for direct measurement of the difference can be developed [4].

2.2.1. Phase (Angle) Difference Measurement

If the samples of the waveforms at the two ends of a line are defined as:

$$X_n = X\cos(\delta_n + \psi)$$

$$Y_n = Y\cos(\delta_n + \phi) \quad ; \quad \delta = 2\pi\frac{f_s}{f}$$

where the two signals are pure sinusoids of the same frequency f, then the phase angle difference can be calculated as [7]:

$$\psi - \phi = \sin^{-1}\left\{\frac{BFH_1XY(n)}{\sqrt{QFH_2X(n)\cdot QFH_3Y(n)}}\right\}$$

where values $BFHXY$ and $QFHX$ are defined as:

$$BFHXY = \propto(\delta)\frac{X}{2}\cos(\psi - \phi) + \beta(\delta)\frac{XY}{2}\sin(\psi - \phi)$$

$$QFHX = \propto(\delta)\cdot\frac{X^2}{2}$$

and values $\propto(\delta)$ and $\beta(\delta)$ as:

$$\propto(\delta) = \sum_{x=0}^{N-1}\sum_{m=0}^{N-1} h_{km}\cos(m-k)\delta$$

$$\beta(\delta) = \sum_{x=0}^{N-1}\sum_{m=0}^{N-1} h_{km}\sin(m-k)\delta$$

Weights h_{km} belong to weight matrices H_1, H_2 and H_3 that have the sums of their anti-diagonals equal to zero. They also satisfy two additional conditions:

$$\propto_1(\delta) = 0 \qquad \beta_1^2 = \propto(\delta)\cdot\propto_3(\delta)$$

Any three matrices satisfying the above conditions may be used for the calculation of the phase shift.

One requirement to observe is that the samples X_n and Y_n taken at the two ends of the line have to be taken simultaneously, and then transmitted to a common point where the calculation of the phase difference is performed.

2.2.2. Architecture for Power Flow and Stability Control

Based on the above mentioned requirements, the architecture is shown in Figure 3.

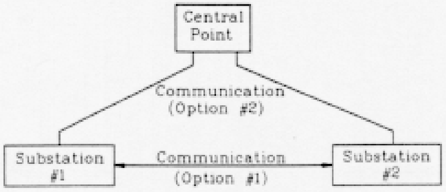

Figure 3. Power Flow and Stability Control Architecture

From Figure 3, it can be observed that there are two options in meeting the communication requirements for the measurement of the phase angle difference. One option is to communicate data between adjacent substations for the purpose of determining the out–of–step conditions or a power flow exceeding predefined limits. The other option is to communicate all the phase angle differences to a central point where all the measurements are compared to a reference bus angle. This information may be further used to determine stability and/or power flow conditions for the entire system.

2.3. New Protective Relaying Approaches for Transmission Lines

The area of protective relaying of transmission lines can also benefit from utilization of either synchronized sampling or intelligent system techniques.

2.3.1. High Speed Fault Location and Classification

Recent developments in high speed fault location, reported by the author, demonstrated a very robust technique that can be used for fault analysis as well as protective relaying [5,6].

In either case, the data acquisition and communication set–up shown in Figure 4 is required. As can be observed, the samples have to be taken synchronously and communicated to the other end.

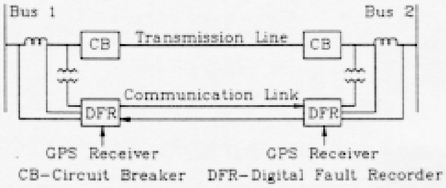

Figure 4. Data Acquisition for New Fault Location Scheme

Again, the synchronization through the GPS receiver may be required.

2.3.2. High Speed Fault Detection and Classification Using Neural Nets

Some of the recent laboratory experiments, carried out by the author utilizing neural nets, indicate the possibility of high speed fault detection and classification that is very selective and robust. This technique can be used, as mentioned earlier, for the automated fault analysis or for the protective relaying function [7].

The use of neural nets also requires sampling synchronization among all the channels on a given transmission line since the neural net algorithm recognizes the phase relations between analog waveforms. In addition, the use of the neural net for protective relaying scheme requires data from both ends of the lines, and this data needs to be synchronized as well.

3. NEW REQUIREMENTS

3.1. Data Acquisition Requirements

This set of requirements is primarily relevant for selection and/or design of the front end data acquisition system needed in the substation monitoring, control and protection equipment.

3.1.1. High Sampling Rate

Typical sampling rates for some of the new microprocessor based applications are given in Table I.

Table I. Sampling Rates for New Applications

Application	Sampling Rate (kHz)	Location
Supervisory Control & Data Acquisition Remote Terminal Unit	.25	Substation
Line Protection	.5	Transmission Line
Digital Fault Recording	1	Substation
Fault Location	5	Transmission Line

As can be observed from Table I, the required sampling rates at the front end are quite demanding. This places quite stringent requirements on both the speed of computation that the field devices have to provide as well as the communication speed in the case that this data has to be exchanged between various devices.

3.1.2. Short Computation Data Window

A close study of the applications reported in this paper reveals that all the applications are based on communications that require a data window of only several data sample points. This data window rarely exceeds one fundamental frequency cycle worth of sampled data. Understanding of this computational requirement is important for two reasons:

- Firstly, if data is to be combined between various devices in the substation, it is important to recognize that the decisions have to be made with a short time interval. In other words, if the data window for the decision making is short, the time allowed for combining the data also has to be fairly short or otherwise the benefit of the fast decision making would be lost.
- Secondly, if data is to be combined between various devices in different substations, then obviously the problem is even more complex. The fast decision of a given algorithm may severely be improved if the communication delays required to combine the data are much longer than the time needed by the algorithms to make the decision.

3.1.3. Synchronized Sampling

This data acquisition may be the one that is least understood, and hence, under estimated regarding its importance and complexity.

It is well known that individual digital devices in a substation need to have data sampling on their inputs synchronized in order for the digital algorithms that work on the waveforms from a given bay to provide correct results. This synchronization is straight forward and is typically implemented using either an external time reference or a phase lock loop solution.

The data sampling synchronization requirement at the level of a substation is somewhat less understood since very few applications available today have a need for such synchronization. However, some of the emerging new applications, such as automated fault analysis, do require that all the sampled data in a substation is taken synchronously. Once this is understood, then it is not difficult to explain one of the main misconceptions related to the use of data acquired by advanced digital relays. These relays do acquire a large amount of data that is stored in their memory. Availability of this data may suggest that almost any analysis of faults can easily be performed based on this data. Unfortunately, if these relays are sampling data individually, without a synchronization between the relays, the data may not be as useful. In fact, for many new all digital substation applications, it may be useless.

Finally, the least understood data sampling requirement is the synchronization among various devices located in different substations. It is obvious why this is the case since there are very few applications available today that will require such synchronization. The new applications reported in this paper clearly indicate that such a need will exist in the future. One of the most promising techniques is to use GPS time reference signal that is transmitted to each device through a low cost GPS receiver located in each substation.

3.2. Communication Requirements

This section discusses only the communication requirements that are peculiar to the applications reported in this paper. As will be seen, these requirements are quite unique and not found in today's applications.

3.2.1. Intra-Station Communications

The special intra-station communication requirements are only related to the overall substation fault analysis applications. The individual device applications, such as relaying and phase angle measurement, do not have such needs.

When substation fault analysis is considered, the communication requirements are heavily dependent on the front end equipment used for data acquisition. If a Digital Fault Recorder (DFR) is used as the front end, then obviously the entire substation data is acquired with one instrument. In that case, all the data is collected in a common substation database. The only communication requirement that is left is the high speed parallel link needed to transfer the data from the DFR to an outside PC that may be used to perform the analysis. If the fault analysis software is located at the DFR, then this communication requirement is not needed.

However, in the case that digital protection relays are used as the front end, then a fast local area network (LAN) may be needed to get the data samples from each relay into a common data base.

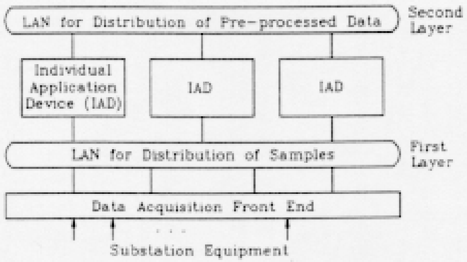

Figure 5. Intra-Station Communication Architecture for Future Applications

An ideal intra-station communication architecture that would fit almost all of the future applications is shown in Figure 5.

The architecture shown in Figure 5 may only be applicable if all-digital equipment is installed in a substation.

3.2.2. Inter-Station Communication

New requirements for inter-station communications are related to the new phase angle measurement and protective relaying applications. These requirements ask for bandwidth and reliability needed to transfer raw data samples between substations. Since data samples may be acquired in a substation at several kHz sampling rate, and a given application may need a one cycle data window, it can be seen that this communication requirement becomes quite stringent. This may have to be continuously sustained since the application would need the new data all the time to be able to promptly react when a disturbance occurs.

3.2.3. Hierarchical Control and Communication Architecture

One additional layer of communication is required in the fault analysis and phase angle measurement applications to bring data to the central point for processing it at the overall power system level. This communication link needs to support extremely fast burst communications. Very short messages, of up to several bytes in length, would have to be transmitted on demand when certain substation processing results are available. It is important to note that this communication requirement is not related to continuous transmission of data samples taken at a substation.

The communication architecture needed to support this hierarchical control implementation is shown in Figure 6.

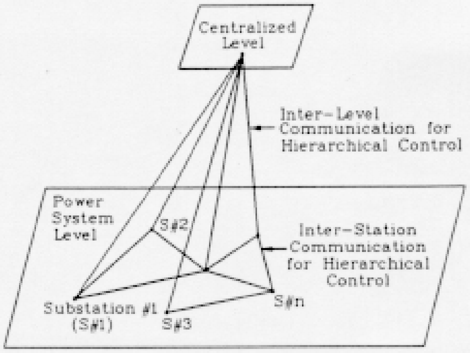

Figure 6. Communication Architecture

It should also be noted that each node (substation), at the power system level, may have to support the intra–station communication as shown in Figure 5.

CONCLUSIONS

Based on the discussion given in the paper, the following can be concluded regarding future data acquisition and communication requirements:

- Synchronized sampling with high sampling rates for the entire substation may be used.
- Sampling synchronization among substations may be required
- High speed data communications for intra–station and inter–station continuous data transfers may be needed
- High speed burst communications between the power system level and the centralized level may be necessary

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RESUME

Le présent rapport traite de la saisie de données et des exigences de communication introduites par les nouvelles applications de surveillance, de commande et de protection. Plusieurs applications inédites, récemment introduites par l'auteur, sont analysées du point de vue de ces nouvelles exigences. Ces nouvelles applications sont liées à l'analyse automatisée des défauts utilisant des systèmes experts, aux mesures des déphasages faisant appel à un échantillonnage synchronisé ainsi qu'à de nouvelles approches relatives au relayage de protection utilisant l'échantillonnage synchronisé et les réseaux neuronaux.

Les résultats de cette analyse indiquent que de nouvelles exigences concernant la saisie de données peuvent être définies dans les domaines suivants : fréquence d'échantillonnage élevée, fenêtre étroite pour données de calcul et échantillonnage synchronisé. Les nouvelles exigences de communication peuvent être reconnues comme étant les suivantes : communications à l'intérieur des postes, communications entre postes ainsi que commande hiérarchique et architecture de communication. Chacune de ces nouvelles exigences est traitée et illustrée à l'aide de quelques diagrammes fonctionnels.