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DISTRIBUTION OF ARCHITECTURE AND ALLOCATION OF FUNCTIONS IN AN INTEGRATED MICROPROCESSOR-BASED SUBSTATION CONTROL AND PROTECTION SYSTEM

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Abstract. This paper is concerned with two critical problems which are appearing during a design procedure of an Integrated Microprocessor-Based Control and Protection System to be applied in H.V. Electric Power Substations. Those problems are related to strategies for selection of distributed architecture and allocation of functions for the computer system beeing designed. Topics discussed in this paper are: Functional characteristics of Electric Power Substation, Functional organization of an Integrated System, Distribution of computer system architecture, Allocation of functions to elements of a distributed microprocessor-based computer system. Five different approaches for distribution of architecture and allocation of functions are proposed as a result of the analysis. A brief discussion of advantages and disadvantages for each of the approaches is outlined having in mind real time digital control application enviroment related to control and protection of Electric Power Substations.

Keywords. Power system control; Computer control; Integrated substation control and protection; Multiprocessing systems; Computer architecture; Microprocessors; Hierarchical systems.

INTRODUCTION

Application of microprocessors in Electric Power Substations was initiated in the mid-seventies. A number of microprocessor-based devices are developed and tested so far in various research organizations, companies, and universities in Europe, U.S.A., Canada, Japan, Australia, India and elswere (Kezunović, 1981a).

The concept of Integrated Control and Protection Systems for Electric Power Substations was approached in the late-seventies. Microprocessor-Based Integrated Control and Protection Systems are beeing developed in the U.S.A. under EPRI/Westinghouse and EPRI/G.E. research projects (EPRI Workshop, 1979) as well as at the American Electric Power Service Corporation (Phadke, Horowitz, 1979). Similar systems are beeing designed in Europe at the LABORELEC Institute in Belgium (Miegroet and others, 1981) and at the Electricite de France Research Laboratories in Clamart (Pavard and others, 1981). A proposal is also published by the University of Calgary in Canada (Malik, Hope, 1981). The only commercially available Integrated System can be purchased from Mitsubishi Company of Japan (Sugiyama and others, 1982).

Design of an Integrated Microprocessor-Based Control and Protection System represents quite a complex problem and requires a system approach design methodology (Kezunović, 1981b). A detailed analysis of functional requirements reveals several design criteria which are pretty much inherent in most of the real time digital control applications. This application enviroment requires specific solutions related to computer system architecture (Kezunović, 1982) and hardware, software and communications (Kezunović, 1981c).

This paper is concerned with two critical problems which are appearing during a design procedure of an Integrated Microprocessor-Based Control and Protection System. Those problems are related to strategies for selection of distributed architectures and allocation of functions for the computer system beeing designed.

FUNCTIONAL CHARACTERISTICS

The first step of a design procedure for the Integrated System is to analize characteristics of the control and protection functions in a substation. Having in mind a microprocessor system, the following functions are briefly discussed:

- protection functions,
- control functions,
- data acquisition functions,
- operator interface functions,
- computer system functions.

The most relevant issues such as function time response, I/O characteristics and operational requirements are considered for each of the functions listed.

Protection Functions

In this group of functions are included protection of transmission lines, transformers, buses and some auxiliary functions.

Time response. Protection functions have the most stringent requirements for time response comparing to other functions. For most digital relaying algorithms in use today it is common that the sampling rate for input data is in order of 12 to 16 samples per cycle of the power signal. It is also a common requirement that the fastest time for protection algorithm to react to a fault condition should be 1/4 to 1/2 of the power signal cycle. Therefore, it is needed that two conditions for time response are satisfied: each iteration of the protective relaying algorithm calculations should be completed in the time frame of approximately 1 ms; protective relaying algorithm should recognize a fault and initiate the tripping in the time frame of 4 to 10 ms.

I/O characteristics. It is interesting to note that there are overlapping zones for different protection functions in terms of I/O signal connections. As it is shown in Figure 1, data needed for a line protection come from breaker which is providing data for the bus protection as well. Also, tripping signal outputs for two different protection functions are connected to the same breaker. This situation should be carefully analyzed when an Integrated System interfaces are designed, becouse there is a possibility to provide a common interface for the mentioned signals.

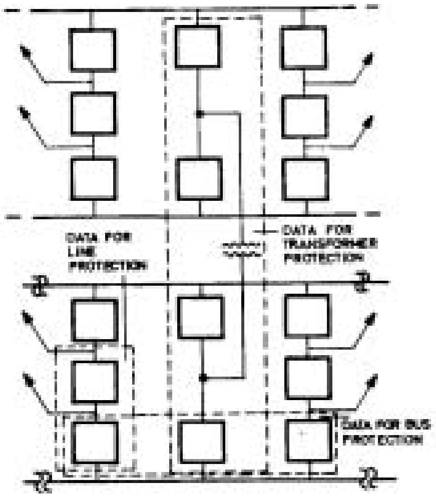

Fig. 1. One line diagram of a substation

Operational requirements. Protection functions operate as direct control functions which means that there is a closed loop which enables comparison of input signal values with the preset values, and tripping signals are issued if there is a defined mismatch. Each of the protection functions is autonomous and requires separate wirings for all I/O signals that are generated, and there is no need for data exchange among various protection functions.

Control Functions

Those functions include: autoreclosing, automatic switching sequences, load shedding, LTC control, auxiliary breaker and switch operations.

Time response. This parameter for the control functions requires sampling time to be in order of tens of milliseconds. Algorithm operation response time may vary and typically ranges from several milliseconds for autoreclosing to several hundred of milliseconds for circuit restoration and several seconds for LTC control.

I/O characteristics. Control functions I/O signals are connected in parallel with the protection signals to circuit breakers and switches. There is a hardwired arbitration logic performing a task of determining which breaker and/or switch should be operated by either control or protection function. Some of the control functions require status information from all of the breakers and switches in a substation, and are capable of operating all of them.

Operational requirements. Some of the control functions need a coordination at the substation level since actions taken by those functions are related to all of the apparatus in substation. Typical functions of this nature are automatic switching sequences, load shedding and LTC control for parallel transformers.

Data Acquisition Functions

The following functions are considered as typical: sequence of events recording, alarming, operator and revenue metering, oscillography.

Time response. Parameter of interest is the resolution with which the data are captured. There is a fearly wide range of requirements in this respect. SOE recording requires resolution in order of 1 ms, which is comparable to the resolution for protective relaying and high speed control functions. Oscillography requires sampling rate of at least 1KHz, which is requirement for revenue metering as well. Alarming and operator metering have relaxed requirements asking for sampling rate of several hundred of milliseconds.

I/O characteristics. Data acquisition functions require signal connections with data flow directions from field apparatus to data acquisition subsystem. Signal sources for analog inputs are instrument transformers with differerent clases of accuracy for protective relaying, operator metering and revenue metering signals.

Operational requirements. Data acquisition functions have to present a large ammount of collected data to several users. There is a problem associated with data storage requirements. Most demanding data acquisition situations are associated with disturbances in the substation operation, which then requires high speed data collection and presentation to the operator.

Operator Interface Functions

Most commonly provided outputs to the operator come from mimic boards, CRT displys, printing and recording devices and signal panels. Operator initiated inputs are generated using switches, pushbutons and typewriter-like keyboards.

Time response. The most critical requirements in this respect are placed on the CRT interfaces. It is needed that each operator action creates a response which will appear on the screen after 2-3 seconds at most. If completion of action requires several seconds, the CRT interface should generate responses which keep operator informed about the progress of the execution.

I/O characteristics. In this case I/O characteristics are related to formats for representing the data to both local and remote operators. There is a need to use several I/O devices for representation of different formats including charts, lists, tables and one-line diagrams. Also, the interface should enable operator to access data related to power apparatus, to change parameters of the control and protection functions, and to operate breakers and switches.

Operational requirements. It should be noted that operator interface functions are very critical in accepting the Integrated System concept. It should be possible for operator to examine the status of the computer system as well as the substation apparatus. Also, there should be a provision for system testing, maintenance diagnostics, system reconfiguration and system parameter changes.

Computer System Functions

There is a number of functions aimed towards operation of the computer system. Those functions are: automatic restart, self-checking, programs initiation, power failure recovery, system synchronization, tests and diagnostics, maintenance and fail-over switching.

Time response. This requirement is very much dependent on the specific strategy used for system operation, failure recovery and maintenance. However, the most critical time response requirements are in the order of several milliseconds. This situation is related to fail-over switching and to system synchronization function.

I/O characteristics. It is interesting to realize that most of the I/O signals for these functions are generated within the computer system itself. Operation of hardware and execution of software creates various events which are then used by the computer system functions to create outputs which can be directed towards hardware or software modules in the system.

Operational requirements. Those requirements depend on the overall organization of the computer system architecture, hardware, software, and communications. Generally speaking, there are two extremes of computer system operation: loosely coupled and tightly coupled processor operations.

ORGANIZATION OF AN INTEGRATED SYSTEM

Taking into account functional characteristics discussed in the previous section, it is possible to view functional organization of an Integrated System as a hierarchical structure (Kezunović, 1981b). This is shown in Figure 2. It is relevant to emphasize the following characteristics of the functional organization:

- functional levels,
- data flow.

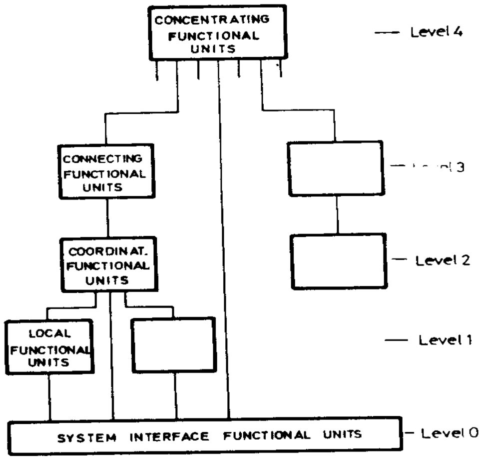

Fig. 2. Hierarchically structured functional organization of an Integrated System

Functional Levels

As it can be seen from Figure 2, there are 5 functional levels within an Integrated System.

Level 0. This level is related to the system interface functions. It includes interfaces to the switchyard equipment and to the local and remote operators.

Level 1. All of the direct control functions are associated with this functional level. It accomodates a number of local functional units which are related to specific portions of the substation switchyard. Typical example are various protection functions which can be viewed as local functional units.

Levels 2 and 3. Those levels enable exchange of data between local units and concentrating functional units at the highest level in the hierarchy. Functions at those levels enable exchange of information among various control, protection and data acquisition functions as well as information exchange between system operators and switching and measuring equipment in the substation switchyard.

Level 4. This level accomodates functions which are related to the operation of the overall substation. It provides interfaces for local and remote operators and some control functions that need information from all of the switching equipment are located at this level.

Data Flow

A brief discussion of the most important data flows within an Integrated System reveals three most prominent data sources.

Substation switchyard. The largest ammount of data for Integrated System comes from the substation switchyard equipment. This data has digital or analog form and is processed by system functions in order to make an operational decision, or in order to make a record of this input data. Most of the data is processed by the control and protection functions contained in the local functional units. However, some substation switchyard data is retransmitted to either some local units that do not have access to this specific data, or to the centralized level in an Integrated System.

Operator interfaces. There is significant ammount of data that is beeing presented to an Integrated System by local and remote operators. This data containes either controls for the switchyard equipment, or requests related to operation of the computer system.

System functions. Each of the system functions performs processing of input data comming from the outside. As a result, there are generated tripping signals, in the case of control and protection functions, or data exchange signals in the case of data acquisition and computer system functions. These sources of data can be located at any of the functional levels within an Integrated System, and data can be routed to system interfaces located either at level 0 or at level 4.

DISTRIBUTION OF COMPUTER SYSTEM ARCHITECTURE

This section presents strategies that can be applied in distributing computer system architecture. Different configurations sugested in this section are selected after a carefull analysis of functional characteristic and system organization (Kezunović, 1982). The following topics are discussed:

- elements of a distributed architecture
- possible architecture configurations

Elements of a Distributed Architecture

The main elements of a distributed system architecture are: microprocessors, communication subsystem, system memory space, I/O subsystem.

Microprocessors. The system considered is a distributed processing computer system. This implies that system consists of a number of microprocessors that are interconnected to form some sort of local area network of microprocessors. It allows for various application functions, allocated to different processors within the system, to be executed simultaneously. The overall system response time is increased as well as the processing power. It is expected that standard 16-bit microprocessors can be utillzed to form the distributed processing computer system.

Communication subsystem. It is a vital part of the system since it enables required data exchanges among microprocessors and makes distributed system work. Communication subsystem can be designed using various performance measures such as: speed of data transmission, data transmission protocols, communication procedures for data exchange, physical media for data transmission.

Required speed of data transmission varies between several kbit/sec to several Mbit/sec. Data transmission protocols include the physical layer, data link control layer and the network layer. Communication procedures are related to master slave and peer-to-peer data exchange situations. Physical media used are processor multibus parallel lines and serial data links implemented using one of the following media: twisted pair, coaxial cable, fiber optic links.

System memory space. Each microprocessor in a distributed system has its own private memory. However, there is a large ammount of input data that is collected from the switchyard and processed during each sampling time. There is also a need to represent this data to local and/or remote operators. Therefore, there should be also a common memory which can be either distributed throughout the system, or lo-

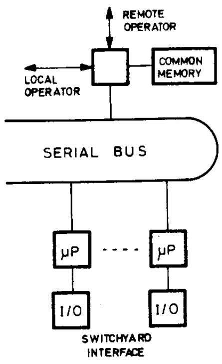

Fig. 3-a. Serial interconnections

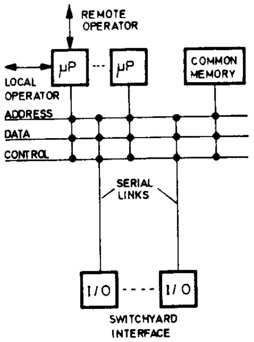

Fig. 3-b. Parallel interconnections

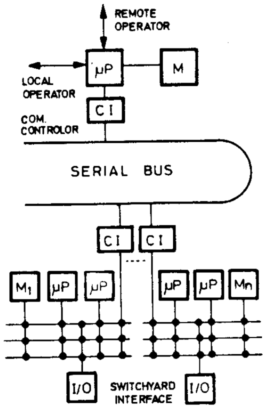

Fig. 3-c. Parallel and serial interconnections

cated at a centralized place. In the case of a centralized common memory, its location should be at a position which is easelly accessed by the operator interface.

I/O subsystem.This subsystem consists of interfaces towards the switchyard equipment and interfaces towards the local and remote operators.

Switchyard equipment interfaces can be organized in conventional way or as unconventional interface if a multiplexed data link is used. In this case several signals from a portion of the substation is multiplexed on one physical data link and switchyard data are shared by several application functions.

Operator interface can be either centralized or decentralized. Centralized interface assumes that all of the MMI devices are connected a one physical location while decentralized interface assumes that each microprocessor has its own operator interface.

Possible Architecture Configurations

There are three basic types of architecture configurations which are characterized by the physical location of the distributed computer system components. Those locations are: control house, substation switchyard, control house and substation switchyard.

Control house. The three most commonly proposed architectures are given in Figure 3-a, 3-b, and 3-c. Switchyard interfaces can be located in the control house where the signal wires are terminated, or those interfaces can be located in the switchyard.

Architecture with serial interconnections enables separate microprocessors to be directly connected to the switchyard interfaces. Specific input data can be processed at this level and some of this data can be retransmitted to the centrallzed microprocessor which provides operator interfaces. There is a common system memory provided at the centralized location for storing the overall system data. It is important to note that microprocessors at the lower level have direct access to the output interfaces going to switchyard.

Architecture with parallel interconnections provides common parallel interconnection for all of the microprocessors in the system. Switchyard interfaces as well as the system common memory are also connected to the parallel bus. This architecture enables all of the processors to operate in a similar maner with an arbitration logic implemented for solving the contention problems on the parallel bus.

Architecture with parallel and serial interconnections is implemented using clusters of microprocessors which are connected using parallel buses.Those clusters are then connected

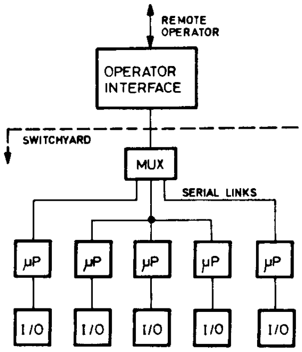

Fig.4. Distributed architecture located in the substation switch yard

with a serial link to the centralized microprocessor which provides coordination for the overall substation system. Common system memory can be distributed to each of the clusters and to the centralized location. This architecture provides a direct connection between microprocessor clusters.

Substation switchyard. This type of architecture is given in Figure 4. It consists of number of microprocessors housed in a cabinet located in the bays of the switchyard close to the switching equipment cabinets. The microprocessor cabinets are connected via serial links either to other cabinets or directly to the centralized operator panel. This operator interface panel can be located in the control house or at a cabinet in the switchyard. System memory is associated with each of the microprocessors.

Control house and switchyard. As it can be seen from Figure 5, one part of distributed system is located in the switchyard and other part in the control house. Switchyard-based microprocessors are located close to the switching equipment. Those microprocessors are interconnected using serial links and are also connected to the control house equipment. Microprocessors in the control house are connected using parallel data buses. Operator interfaces and common memory space are provided at this hierarchical level as well.

ALLOCATION OF FUNCTIONS

This section is concerned with strategies for allocating application functions to processors within a distributed computer system. Some of the most attractive strategies are discussed making a relation to tradeoffs in system performance. Discussion includes the following topics:

- grouping of functions,
- allocation strategies for given architectures.

Grouping of Functions

It is extremely important to note that digital algorithm implementation of control, protection and data acquisition functions shows that there is a number of common algorithm processing modules that can be shared among the mentioned functions. Therefore, there are at least three approaches for grouping the functions: traditional, unconventional, compromising.

Traditional approach. This approach assumes strict separation among control, protection and data acquisition functions. It is not only that software modules have to be separated, but also the hardware has to be uniquely allocated. This means that each of the mentioned functions should be implemented using separate microprocessors, which use a separate memory space as well. It is also assumed that

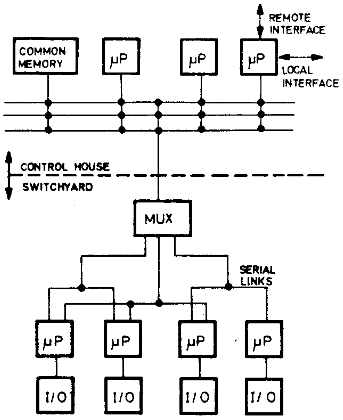

Fig.5. Distributed architecture located in control house and the switchyard.

conventional signal wiring is used. As it can be seen, this approach is very much alike the approach taken using electromechanical and solide state technologies.

Unconventional approach. A full utilization of flexibilities introduced by the LSI technology is applied in this approach. Application functions are assumed to consist of a number of software modules which perform specific data processing. If there is a modul which in needed in several protection functions, then this modul is used once and its capabilities are shared among related application functions. A one step further is taken by allowing sharing of input data as well. It has been shown that some of the input data is shared by at least two application functions. Therefore, a multiplexed data link can be used to bring this data to a location in distributed computer system where this data can be shared by a number of software modules.

All of the mentioned possibilities show that unconventional approach enables optimization of computer system resources by grouping the functions in the most siutable way as far as data processing is concerned.

Compromising approach. As it always has been, there is an approach that compromises the two oposite approaches. In our case this approach assumes a strict separation between control and protection functions, but data acquisition functions are implemented using software modules of the control and protection functions. In some instances there is only input data sharing among those functions. This implies that there are microprocessors performing either control or protection functions. Those processors perform required data processing and then this data is passed on to data acquisition processors. Input data is brought to protection functions using dedicated signal wires, and there are dedicated signal wires for tripping and blocking signals as well.

Allocation Strategies for Given Architectures

The selected architectures given in Figures 3-a, 3-b, 3-c and Figures 3 and 4 are particularly suitable for specific allocation strategies. Those strategies for each of the architectures are discussed emphasizing advantages and disadvantages.

Figure 3-a. This distributed architecture is suitable for conventional function allocation (Phadke, Horowitz, 1979). Each of the protection functions such as line, transformer and bus protection are allocated to a separate microprocessor next to the switchyard interfaces. Control functions are also allocated to a processor at this level. Data acquisition and operator interface functions are performed by a processor at the upper level in the hierarchy. Serial bus for data exchange among processors in the system is a low speed standard serial data bus. Signal wiring to the switchyard is of the conventional type.

Advantages of such a system are: it resembles all of the design criteria of conventional systems, it can be built in a modular way by adding each new function as needed, organization of software is straight forward, communication system is quite simple, system testing is simplified. Disadvantages are the system cost as well as the difficulty in implementing new application functions which can be developed using this system architecture.

Figure 3-b. This proposal (Malik, Hope, 1981) assumes that separation of functions is retained by allocating functions to separate microprocessors on the bus. There is an advantage in providing a common data base accessable by all of the processors. It is also easy to implement the proposed architecture by using a standard Multibus structure. However, this system requires quite a complex arbitration scheme for accessing the parallel bus and this can be a major bottle-neck for implementing high speed protection functions. This architecture can be promising if use of array processors is considered for this application.

Figure 3-c. This approach is suitable for accommodating new design phylosophies as far as the unconventional functional grouping goes (EPRI Workshop, 1979). It is convinient to accommodate protection functions and some of the high speed control and data acquisition functions in the microprocessor clusters at the lower level. Each of the clusters can be related to a bay in the substation switchyard. All of the needed data can be brought through a common multiplexed data link to the cluster. Application functions can be allocated in the optimal way to the processors in the cluster and input data can be shared as needed. After data is processed, it is passed on to the microprocessor which provides operator interface functions. This processor also performs some of the control functions that are related to the overall substation.

This architecture optimizes needed hardware and software and therefore reduces system cost. There is a possibility of reducing the signal wiring cost as well. A great advantage comes from possibilities to develope new application functions by providing complex strategies for control, protection and data acquisition associated with specific power apparatus. On the other hand this architecture and allocation strategy are quite involved for design since they are a breakaway from traditional design phylosophy. There is also a need to ese the most advanced hardware, software and communication concepts which affect the development risk, which is also associated with the commercial affect. An example of such a situation shows that markets for this type of systems are yet to be developed (Sigiyama and others, 1982).

Figure 4. This situation enables strict separation among application functions by having each of the control, protection and data acquisition functions allocated to a se-

parate microprocessor. System signal wiring is conventional and function response time is optimized. This system is straight forward to build, it is easy to test and easy to expand and/or modify. However, there is a problem associated with bringing microprocessors close to the sources of severe EMI which is radiated from circuit breaker arcs and transmission line transients. Nevertheless, this concept seems to be quite attractive (Pavard and others).

Figure 5. This architecture enables conventional allocation of protection and high speed control functions by providing a microprocessor, located in the switchyard, to perform either protection or control function. Signal wiring is conventional using separate interfaces for separate functions. On the other hand, there are several microprocessors located in the control house. Those processors perform control, data acquisition and operator interface functions that require data related to the overall substation. This architecture is therefore a good compromise between the traditional solutions and new concepts and it would be interesting to develop and test such a system (Miegroet and others, 1981). Possible disadvantages of such a system may come from the system cost considerations.

CONCLUSIONS

It is quite clear that microprocessor applications in Electric Power Substations have opened new possibilities for designing control, protection and data acquisition systems. Distributed processing approach has enabled concept of integration of all of the substation functions to be implemented. However, there are various strategies for architecture' distribution and functional allocation in an Integrated system which have to be carefully investigated in order to optimize system performance criteria. A number of different approaches for Integrated system design. that are beeing investigated today, show that there is no unique approach that is widely accepted. Therefore, it is needed to investigate all of the technical, commercial and operational practice issues in order to make the final decision. This paper has given basic considerations in that respect.

REFERENCES

EPRI Workshop. (1979). Control and Protection of Transmission Class Substations. EPRI, Publ. No WS 79-184. U.S.A.

Kezunović, M. (1981a). Digital Protective Relaying Algorithms and Systems-an Overview. Electric Power Systems Research Journal, 4, 167-180, Switzerland.

Kezunović, M. (1981b). A System Approach to the Design of An Integrated Microprocessor Based Control and Protection System. 8th IFAC World Congress, XX.60-XX.65. Japan.

Kezunović, M. (1981c). Hardware, Software and Communication Requirements of an Integrated Substation Control and Protection System. A.I.M. Conf. on Data Processing for H.V. Power Systems, 10.1.-10.7., Belgium.

Kezunović, M. (1982). Distributed Architectures for an Integrated Microprocessor Based Substation Control and Protection System. 17th Universities Power Engineerig Conference. paper No 7.1. England.

Malik, O.P., Hope, G.S., (1981). Design Concepts for A Distributed Microprocessor-Based Transmission Line Control and Monitoring System. 8th IFAC World Congress, XI.143-XI.147., Japan.

Miegroet, P., Goemiune, P., Monseu, P. (1981). ALPES: Une Famille D' Equipements Programmes pour Les Postes des Reseaux Electriques. A.I.M Conf. on Data Processing for H.V. Power Systems, 9.1-9.11., Belgium.

Pavard, M.M., Bornard, P., Boussin, J.L., Tesseron, J.M. (1981). Digitisation of Line-Control Functions in EHV Substations. 8th IFAC World Congress, XX.54-XX.59, Japan.

Phadke, A.G., Horowitz. S.H. (1979). Report on Computer Applications for Integrated Substations on the American Electric Power System. Colloquium of CIGRE Study Committee No. 34, Australia.

Sigiyama, T., Kameoka,S., Maeda, K., Kaneda, A., Goda, T. (1982).Development and Field Experience of Digital Protection and Control Equipment in Power Systems, IEEE PES Winter Meeting, Paper No 82 WM 173-3, U.S.A.