

DAY PROBLEMS OF POWER SYSTEM  
AUTOMATION AND CONTROL,  
GLIWICE, POLAND, MAY, 1985.

MICROPROCESSOR APPLICATIONS IN ELECTRIC POWER SUBSTATIONS AND POWER PLANTS-  
-STATE OF THE ART AND FUTURE TRENDS

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**Abstract.** This paper gives a discussion of the state of the art and future trends related to microprocessor applications in Electric Power Substations and Power Plants. Present microprocessor-based developments are classified into two major categories: single device and system implementations. Discussion of future trends is related to performance improvements and introduction of new concepts and functions. Finally an overview of the theoretical, conceptual, technical, operational and economic issues is given.

**Keywords.** Digital computer applications; microprocessors; power station control; power system control; digital protective relaying, electric power substation automation.

INTRODUCTION

Application of microprocessors to Substation Automation and Power Plant Control started in the mid 70-ties. Introduction of the third generation of technology, the LSI technology, was aimed toward achieving several benefits. Major benefit expected was the cost/performance improvement.

A number of developments of microprocessor-based data acquisition, control and protection devices and systems did take place since the mid 70-ties. Major developments took place first in the U.S.A. and Japan to be later on spread over the Europe, Australia, Far East and elsewhere. Mentioned developments were undertaken by almost all of the companies in the business of data acquisition, control and protective relaying equipment manufacturing as well as by universities, research sections of the Utility Companies and other research organizations. This effort resulted in development of several dozens of different microprocessor - based devices and systems for data acquisition, control and protection. Most of those were tested in various environments including Research Labs, High Power Labs and Electric Power Systems. There are also over 500 references published at various conferences through out the world related to the mentioned subject.

However, it is interesting to note that there are not very many types of microprocessor-based data acquisition, control and protection devices and systems available on the world market today. It is believed that the main reason for this situation is complexity of theoretical, conceptual, technical, operational and economic issues which are to be resolved before the microprocessor applications become a wide spread practice in the Power Industry. It is also believed that major problems rela-

ted to the mentioned issues are already resolved and it is expected that microprocessor-based devices and systems will appear in much larger numbers and varieties of types on the world market in the second part of the 80-ties.

STATE OF THE ART

Microprocessor applications in Electric Power Substations and Plants can be classified in two major categories: single device implementations and system solutions.

Single Device Implementations

Those implementations are similar in concept to the conventional devices since the major functional and performance characteristics are preserved. Table 1 gives a list of typical developments for the major application areas: protective relaying, control and data acquisition.

However, it should be noted that use of microprocessors did bring some significant improvements comparing to the implementations that are based on the previous generations of technology. Major improvements are regarding the performance, flexibility of design and improved testing and maintenance.

It has been shown, by several reported developments, that microprocessor-based designs can provide better accuracy in determining the required parameters to be used for decision making in protective relaying, control and data acquisition. It was also shown that programmability of microprocessor-based devices provides possibility of very flexible changes of settings, internal parameters and algorithm designs. Further more, application of microprocessors enabled implementation of quite elaborate test procedures including self-checking features, extensive CRT test

Table 1 Single-Device Microprocessor-Based Implementations

FUNCTION	REFERENCE	FUNCTION	REFERENCE
<u>Protective relaying</u>		<u>Control</u>	
- Distance	(Kezunovic, 1984a)	- Load Tap Changer	(Grondin, 1981)
- Overcurrent	(Redfern, 1983)	- Automatic Switching Sequences	(Weatherall, et.al. 1980)
- Frequency	(Sullivan, 1980)	- Automatic reclosing	(Redfern, 1983)
- Differential Transformer	(Thorp, et.al, 1981)	- Generator start/stop	(Griffin, 1982)
- Breaker Failure	(Spooner, 1980)	- Load Shedding	(Ghai, et.al., 1980)
- Sunchro-check	(Ghai, et.al., 1979)	- SCADA RTUs	(Lau, et.al. 1982)
- Voltage	(Aucland, et.al, 1980)	- Circuit breaker control	(Barret, et.al., 1982)
- Motor protection	(Penman, et.al., 1982)		
<u>Data Acquisition</u>		<u>Data Acquisition (continued)</u>	
- SOE Recording	(IEEE, 1977)	- Fault Location	(Takagi, et.al. 1981)
- Allarm Logger	(Mulder, et.al., 1978)	- Transient recording	(Bornard, et.al., 1983)
- Revenue Metering	(Schweitzer, 1978)		

displays and possibility of elaborate historical data collection and analysis for the maintenance purposes.

System Solutions

Application of microprocessors enabled a variety of system solution approaches to be taken. Major characteristics of the system solutions are introduction of new functions and concepts which were not feasible by using the previous technologies. The following discussion gives illustration of some of the typical system solution approaches.

SCADA System. Application of microprocessors to Supervisory Control and Data Acquisition (SCADA) Systems is historically one of the first system applications of microprocessors in Electric Power Systems. There are quite a few SCADA Systems available on the market today. Some new designs are particularly interesting regarding design flexibility introduced and addition of some advanced local data processing functions (Lau, et.al., 1982).

Unconventional Monitoring System. Use of microprocessors enabled new approach of special purpose system designs. An example is a monitoring system designed for power transformers. Such a system enables overall monitoring of the power transformer parameters such as: Saturation curves, Loss of life, Overexcitation, Gas content, Partial discharges, Insulation damages (Poyser, 1982; Bose, 1981). Microprocessor application provides not only monitoring and display of the mentioned parameters, but also extensive analysis of the operational state of the power transformer.

Universal Data Acquisition and Control System. This solution consists of a universal microprocessor system architecture which can be programmed and configured for a specific function implementation. One such a solution provides possibility of implementation of

any one of the following functions: Voltage control, Automatic switching sequences, Automatic reclosing, Generator sequence control, Generator efficiency monitoring, Revenue metering collection, Allarm logging, Fault level monitoring (Cheetham, 1980).

Distributed Power Plant Control System. There are a number of microprocessor-based distributed process control systems that are available for Thermal Power Plant control and monitoring. There are also number of similar systems which are used for automation of the Hydro Power Plants. Major characteristic of those system is their physical distribution within the Plant with extensive communication subsystem used for exchange of the required data.

Integrated Substation Control System. Those systems are multiprocessor-based and provide full control and data acquisition in a High Voltage Substation. There are several of those systems that are already implemented and installed in a substation (Kezunovic, 1984b). Typical functions performed by those systems are: Acquisition and data base up-dating, Output execution, Remote/Local control, Automatic control, Processing of analogs, Automatic execution of selected sequences.

Integrated Control and Protection System. Application of microprocessors enabled new system concept to be implement which combines in one system both control and protective relaying functions. There are several developments in the world related to the Integrated Systems but it can be noted that design approaches undertaken are quite different (Kezunovic, 1984b). Major differences are related to computer system and communication architecture as well as to functional allocation strategy.

## FUTURE TRENDS

It is expected that future trends will be a continuation of the two major trends present today: single device implementations and system solutions. However, there are several new developments that are expected to be undertaken within the two major trends.

### Single Device Implementations

New developments are expected in the area of new functional implementations and in the area of cost/performance improvements.

Protective relaying. It is expected that future developments will introduce new microprocessor-based protective relays to cover the functions that were not implemented so far using the new technology. Example are bus-bar, generator and machine protective relays.

Cost issue will require further investigation of the optimal hardware/software solutions. Performance issue will ask for more elaborate analysis of test, maintenance and operator interface requirements and appropriate implementation strategy.

Control. New developments are expected in the area of the switching equipment control. It is believed that a trend will be to develop microprocessor-based circuit breaker control devices which will enable improved operation and maintenance of the circuit breakers. Some new developments of the local Substation and Power Plant automation devices for control of switching sequences are also anticipated.

Cost/performance improvements in this area are related more to the cost/performance effects that new microprocessor-based devices can provide regarding the operation of the switching equipment and the generation machinery.

Data Acquisition. Major trends are expected in the area of more elaborate operator interfaces and optimization of the processing hardware. The new developments are expected to introduce quite extensive operator capabilities in data displaying, logging, time-tagging and analyzing. It is also believed that there will be more device designs which enable processing of several functions using the same hardware. Example are operator metering devices which can provide measurements of the major power system parameters such as voltage, current, frequency, power and energy using only voltage and current samples and employing the same processing hardware.

Another example are Transient Recorders which can be used, in the normal states of power systems, as data acquisition and measurement devices.

Cost/performance improvements are based on the above operator interface and hardware utilization improvements.

### System Solutions

Future trends in this area seem to be related to further development of the various strategies for functional integration. This further leads to new developments in the area of multimicroprocessor system architectures and Local Area Networks for distributed processing.

Integration of similar functions. This approach assumes integration within the following groups of similar functions: protective relaying, control and data acquisition. Therefore, it is expected that new Integrated Systems for overall protection, control or data acquisition will be developed for Substation and Power Plant applications.

Major benefits expected from those systems are again in the area of cost/performance improvements. However, this consideration needs new assessment since now the improvements are expected on the overall level of protection, control or data acquisition for a complete Substation or Power Plant.

Integration of diverse functions. This trend assumes integration of diverse groups of functions such as control and protective relaying, data acquisition and control, data acquisition and protective relaying and integration of all of the three groups. This integration could be implemented on a limited basis regarding particular power apparatus such as power transformer, circuit breaker, generator. Another trend is to perform integration on the level of Substation or Power Plant. Therefore, it is expected that various microprocessor-based system and communication architectures will be developed to support the mentioned trends of functional integration.

Evaluation of the cost/performance benefits achieved by those systems will definitely require a new approach. It is needed to develop new criteria for performance evaluation and new methodology for cost evaluation assessment for an obvious reason that the Integrated Systems of this type do not have an equivalent in the classical designs.

Improved local/remote automation. Integration of functions of either type, as was discussed in the previous sections, brings new possibilities regarding the local/remote automation of Substations and Power Plants. It is believed that there will be new system developments introduced with improved local and/or remote automation functions. One trend could be to develop multimicroprocessor systems for extensive local monitoring, control and protection. Yet another trend is to develop integrated Substation and Power Plant systems which will be a part of the remote Energy Management System.

Major benefits of improved automation are related to better performance in operation of Substation and Power Plants in the most critical situation of emergency operation. Furthermore, benefits are expected in the area of extensive data acquisition and analysis for the maintenance purposes.

## ISSUES TO BE RESOLVED

There are number of issues to be resolved in order for microprocessors to become wide accepted technology in the area of Substation Automation and Power Plant Control.

### Theoretical Issues

Digital algorithms. A number of algorithms for digital relaying, control and data acquisition were proposed so far. However, there are very few studies that are related to comparison and evaluation of the proposed algorithms. It is believed that analysis, synthesis and evaluation of digital algorithms are the key problems to be resolved in order for digital techniques to become superior to previous techniques regarding the performance improvements.

To illustrate the digital algorithm problem, it is appropriate to indicate the major dilemma that exists regarding selection and evaluation of digital algorithms for protective relaying of transmission lines. As it is well known, there are number of algorithms proposed which can be classified into two major categories: fundamental frequency and traveling wave algorithms. A question that is still open is related to development of criteria for selection of the optimal algorithm for a particular Power System environment. Another problem of equal importance is related to definition of a Generalized Algorithm Form which can be reduced, under certain conditions, to an optimal specific form (Kreso, 1984).

Automation and Control Strategy. It is believed that use of microprocessors, and digital computer techniques in general, enable introduction of new automation and control strategies. An example are possibilities for adaptive relaying as well as possibilities for distribution of some Energy Management Functions to the local level of Substations and Power Plants.

### Conceptual Issues

Classical vs. unconventional design. It is evident that microprocessor applications enable device and system implementations which do not resemble characteristics and philosophy of the classical designs. An obvious example are Integrated Control and Protection Systems which enable unconventional implementation of both control and protection functions in one system. Further more, functional allocation can be such that one processing unit contains algorithm portions of several different control and/or protection functions (Kezunovic, 1983).

On the other hand, it is well known that design practice in almost all Utility Companies is very well defined and strict regarding separation of control and protection devices even to the point of separate wiring as well as separate testing and maintenance procedures. Therefore, it is expected that much

closer collaboration between Utility Companies and the manufactures will take place in the future in order to form a mutual understanding and acceptance of the new designs.

Data sharing. This concept is further extension of the unconventional design issue. It is possible to use serial high speed links, such as fiber-optic links, to multiplex data collected in the switchyard for purposes of data acquisition, control and protection. This data is then brought to the microprocessor-based system, demultiplexed and distributed over a communication system to the appropriate processing unit. This is, therefore, a departure from the conventional wiring practice. It is an open question what technical issues need to be resolved in order for Utility Companies to consider this approach cost attractive but at the same time reliable and conceptually feasible.

Another example is use of unconventional transducers whose output signal is generated in a digital form. This will enable a direct use of transducer digital output data by a microprocessor. It will also enable design of processing algorithms which can be used for several different protective relaying, control and data acquisition functions.

### Technical Issues

Hardware. It is well known that different protective relaying, control and data acquisition functions require different characteristics of hardware. For example, most of the protective relaying functions require 16-bit hardware while most of the control and data acquisition functions require 8-bit hardware. On the other hand, some complex control functions and transient recording functions require 16-bit hardware. Therefore, it is needed to define criteria for optimal hardware selection for various functional implementations.

Another problem is selection of the appropriate hardware for the most complex and time critical functions such as protective relaying of transmission lines. An on-going practice is to use either bipolar 16-bit processor or a multiprocessor MOS implementations for Distance Relaying, for example. Some other thoughts are that 32-bit processors are required for this function. Future investigations should answer this question of maximum hardware requirements related to Substation Automation and Power Plant Control.

Software. Those issues can be divided in two major groups: programming languages and system software.

At it is well known, the desired level of programming languages is the high level languages. However, the real time execution requirements call for use of the assembler languages. It is also evident that some simple control and data acquisition algorithms can be implemented using the high level languages while some complex control, fast data acquisition and protective relaying algorithms

require use of assemblers. Future investigations are to give some answers to the questions of optimal selection of language levels for various applications, optimal mix of high level and assembler language modules in one implementation, need for design of a special purpose language for microprocessor Power System applications.

System software issues are related to the question of possibility to use the commercially available operating systems or specially designed executives. Further more, the question arises about the need for operating system services in most of the Substation and Power Plant applications.

Microprocessor and Communication System Architectures. This issue needs further investigation to define optimal architectures for various applications. A good example of possible choices are various architectures for Integrated Control and Protection Systems (Kezunovic, 1983; Kezunovic, 1982). It is believed that further studies should be performed in the area of architecture evaluations regarding cost/performance characteristics.

Another issue is related to use of the proposed communication system architectures for the Local Area Networks. It is believed that number of the proposed protocol standards such as CSMA/CD, Token Bus and Token Ring will be wide accepted standards in the future. Therefore, future studies should be concentrated on investigation of possibilities for use of these standards in Substation and Power Plant microprocessor-based systems.

#### Operational Issues

Operator interfaces. Improvements are related to the types and means of data displays. It is possible to use digital displays organized in unconventional ways. It is needed to further investigate operator interface requirements having in mind the new displaying possibilities.

The new functions provided are related to possibilities of displaying internal settings of the devices. Further more, it is possible to perform an on-line change of the settings. Yet another possibility is to provide a remote operator interface for the device and systems. All of those new functions have to be evaluated in terms of their necessity and compliance with the existing operational procedures.

Testing and maintenance. It is possible to design special purpose testing programs which enable straight forward execution of the testing procedures. If one adds self-checking and diagnostic features, then the testing possibilities are quite enhanced. However, an open question remains regarding selection of the optimal testing procedures for various devices and systems.

Maintenance practice can be significantly improved and changed using the microprocessor designs. It is possible to keep track of hi-

storical data for off line analysis of maintenance requirements. It is also possible to use redundancy architectures and repairing strategies which enable more efficient maintenance. This, further more, provides improved availability which makes the issue of reliability less prominent. Finally, the software maintainability issue needs further analysis.

Design and documentation. As it was mentioned earlier, microprocessor application could introduce unconventional device and system implementations including the unconventional wiring practice. Therefore, it is needed to develop new design procedures to reflect this change.

Documentation practice is changed by a simple fact that microprocessor implementations provide both hardware and software solutions. Therefore, software documentation is a new requirement. Analysis of appropriate methodology for software and hardware documentation is one of the future problem areas.

#### Economic Issue

Evaluation of new functions. Application of microprocessors did bring, as was discussed previously, possibility of new functions implementation. Typical example are extensive operator-interface capabilities available for almost all designs. Therefore, it is important to note this fact and to develop an appropriate cost evaluation procedure which will judge the benefits achieved by implementing the new functions versus their cost.

Evaluation of new designs. Problem of definition of the appropriate cost evaluation procedure is even more elaborate in the case of the new designs. It is quite difficult to assess the cost issue for new designs since they are significantly different from the conventional designs. Therefore it is extremely important that further economic investigations concentrate on this issue in order to define methodology for the cost evaluation.

Life cycle cost. Microprocessor based implementations bring new issue of appropriate life cycle cost estimates. First, it is important to determine the direct life cycle cost that includes the cost of design, installation, commissioning, maintenance. The procedure to determine the direct life cycle cost needs to be reexamined since microprocessor applications did bring some new aspects to the problem.

However, the most difficult issue, and yet probably the most important, is the issue of indirect life cycle cost estimate. This is related to the cost savings achieved in the overall Electric Power Substation and Power Plant operation due to the use of improved microprocessor-based device and system designs. Answer to this problem will probably be an answer to the following question asked frequently: What are the cost/performance benefits that microprocessor technology brings to the area of Substation Automation and Power Plant Control?



## CONCLUSIONS

It was indicated that there are variety of microprocessor-based devices and systems developed so far for the protective relaying, control and data acquisition purposes for Electric Power Substation and Power Plant applications. On the other hand, it is noted that at such smaller number of the mentioned developments are available on the world market. It is expected that the future developments will bring even more types of devices and systems. It is also expected that larger number of those devices will appear on the world market, particularly in the area of Protective Relaying and Integrated Systems. However, it is believed that quite a few issues need to be further investigated and resolved in order for microprocessor applications to be accepted as a benefit regarding the cost/performance criteria.

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