NSF Conf. on Computer Relaying
Blacksburg, VA, USA, Oct 87.

PROSPECTS FOR INTEGRATED CONTROL AND PROTECTION SYSTEM APPLICATIONS IN ENERGY MANAGEMENT SYSTEM IMPLEMENTATIONS

M. Kezunovic, Senior Member, IEEE
Texas A&M University
College Station, Texas

B. Perunicic*
University of Illinois
Urbana Champaign, Illinois

ABSTRACT

This paper is related to the Energy Management System (EMS) implementations where an Integrated Control and Protection System (ICPS) is used in place of a Remote Terminal Unit. The three major issues are analyzed in the paper: ICPS characteristics, prospects for ICPS applications and implementation issues. The characteristics covered are: functions, digital algorithms and data base architecture. Prospects for digital algorithm selection, and synthesis as well as new approaches for data acquisition, control and protection functions are also discussed. Finally, the following implementation problem areas are indicated: distribution of architecture and allocation of functions; system hardware and software; system communications and time synchronization; digital signal processing algorithms; testing tools and methodology. The major research areas for further study are outlined in the conclusions.

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* Visiting professor at University of Illinois for 1986/87 academic year. Present address: Electrotehnicki Fukultet, 71000 Sarajevo, Yugoslavia

INTRODUCTION

This paper is concerned with issues related to the use of a Substation Integrated Control and Protection System (ICPS) as a part of the overall Energy Management System (EMS) design. There are several ways of using an ICPS for the EMS applications. A case where a SCADA Remote Terminal Unit (RTU) is substituted by an ICPS is discussed in this paper.

The analysis given in the paper is motivated by two aspects of the Substation Integrated Control and Protection concept. First, it should be recognized that a number of ICPS-s are being developed around the world today where either some or all of the substation functions are implemented using microprocessors and digital algorithms (1,2). However, the final conclusion about justification of such an approach has not been yet reached (2,3). It is believed that the substitution of all the substation devices by one multi-microprocessor system may not be justified solely based on the grounds of the cost/performance improvements achieved localy at the Substation level. Therefore, it is suggested that a broader consideration should be undertaken where an ICPS design is evaluated based on an overall EMS application. The second aspect is related to the level of "integration" or "coordination" provided among various functions in an ICPS. It is again an impression that new approaches may be taken regarding architecture distribution and function allocation strategy (4,5), which might be quite different from the ones based on the stand alone substation application. Finally, discussion given in the paper is concentrated mostly on the prospects for the ICPS applications. The implementation characteristic of the RTU-s and ICPS-s that are available today are taken into account when some design details of the new approach are discussed (6,7).

The first part of the paper is devoted to the discussion of some new features that are unique to the ICPS designs and are not available in the RTU implementations. Those features are related to the functions, algorithms and data bases of an ICPS. Second part of the paper is related to the utilization of the mentioned features in an application of the ICPS as a part of the EMS design. A detailed discussion of the application prospects and implementation aspects is given in this section.

ICPS FUNCTIONAL CHARACTERISTICS

The following two questions are elaborated on in this section. What are the functional improvements that ICPS brings regarding the performance criteria set for RTU-s? What are the new functions that are introduced by ICPS which are not included in RTU designs?

The first question is somewhat hard to answer because there is a wide variety of functions available in different RTU designs (6) so the criteria for the comparison become difficult to define. However, some of the most important differences may be identified as given in Table I. It should be noted that some Data Acquisition Interface improvements are also shown, but it is because they affect the functional performance.

Table I. Functional Improvements

Criterion	Functions/Characteristics	RTU	ICPS
Data Acquisition Interface	Sampling frequency	0.5KHz $\leq$	2KHz $\leq$
	Sampling	scanning	instant. for all channels
	Analog measurements	transducers	direct from samples
	Dynamic range	60Hz signals	60Hz + transients
	Programmable gain ampl.	no	yes
	Self checking	moderate	extensive
	Switchyard wiring	classical	data sharing
Data Acquisition, Recording and Monitoring	Oscilography	not common	common
	Operator measurements	using transducers	no transduc. but algorithm
	Revenue metering	revenue meters	no meters but algorithm
	SOE for local display	not common	common
	Historical data on switch. eqpt. operations	moderate	extensive
	Power transf. monitoring	moderate	extensive
	Fault Location	not common	common
Control Functions	Breaker failure initiate	not common	common
	C.B. autoreclosing	not common	common
	Synchro-check	not common	common
	Automatic switch. sequences	moderate	extensive
	Local load management	moderate	extensive

The second question is much easier to answer since there is an obvious functional novelty, the protective relaying functions. It should be also recognized that a distributed computer system architecture of an ICPS is in general much more complex and computationally more powerful than the one found in an RTU. Hence, some new functions are simply an outcome of this fact (8). An example are elaborate system functions that support maintenance and testing procedures. Table II gives an overview of the new functions and features.

Table II. New Functions and Features

Class	Functions	Features
Protective Relaying	Transmission Line	distance, overcurrent, pilot, current differential
	Transformer	current differential, overcurrent, overexcitation
	Bus	percentage differential, overcurrent
	Circuit Breaker	breaker failure initiate, breaker protection
	Shunt Reactors	overcurrent, differential, turn-to-turn
	Transfer Tripping	use of transfer-trip transmitters/receivers
Monitoring	Comm. channels	pilot and transfer-trip channel
	Line loads	excessive line current, out of step
	Power transformers	overload, temperature, gas, current, MW, MVAR
	Switching eqpt.	pole disagreement, auxiliary contacts, timing
Control	Automatic Synchron.	synchronism checking and synchronizer closing
	Tie Tripping	heavy power outflow, declining frequency
	Automatic switch. seq.	bus transfers, sectionalizing, transformer in/out
System Functions	Maintenance	self-testing, self-diagnosis
	Testing	automated maintenance testing
	Reconfiguration	automatic switching of redundant modules
Operator Interfaces	System services	control and displays for maintenance and testing
	Data presentation	one-line diagrams, oscillography, measurements, SOE, protective relaying settings and charact.

DIGITAL ALGORITHMS FOR DATA ACQUISITION CONTROL AND PROTECTION

It is well known that digital algorithms that support data acquisition, control and protection functions in a substation are based on the samples of either analog signals or status signals. The algorithms that process the equipment status signals such as alarms, indications, sequence of events and switching sequencies are not that different in ICPS designs comparing to RTU-s. The only difference for the status signal processing algorithms are improvements in higher sampling rates, more elaborate sequence of events and automatic switching sequences implementation.

Digital Algorithms for Analog Signal Processing

The major difference is in the area of digital algorithms used for processing of analog signals. The protective relaying digital algorithms are related to the new functions not being previously associated with an RTU. Also, the basic mathematical form of these algorithms may be applied to definition of new algorithms for some classical RTU functions such as revenue metering and operator measurements.

It is well known that a number of digital algorithms for protective relaying is introduced up to now (9). The following two characteristics are critical for understanding some new features provided by those algorithms: the signal sampling is performed all the time starting from the moment of the power-on switching of an ICPS; these algorithms may be easily adjusted to provide various performances regarding different criteria set for calculated values. Further discussion of the new features obtained using digital algorithms for analog processing is illustrated by a brief analysis of the digital algorithms implemented for calculation of various transmission line quantitities.

The largest group of digital algorithms is available for distance protective relaying of transmission lines (9). It should be noted that these algorithms may be used to calculate either the line parameters or the phasors V and I. Another group of these algorithms may be used to obtain various parameters of the traveling waves present on the line at the moment of the fault. The most important conclusion is that some of the algorithms may be used to calculate almost any quantity related of a transmission line such as: line parameters; phasors of V and I; active, reactive power; power factor; frequency.

Regarding accuracy of the protective relaying algorithms, it can be shown that it varies from algorithm to algorithm depending upon different power system conditions and digital relay design characteristics (9). If the application conditions are known, then an algorithm ranking may be performed which enables selection of the algorithms that suits the given application (9). The given algorithm performance in this case is a function of two sets of algorithm characteristics. One set of characteristics is related to the basic algorithm form and the other set is related to the extended algorithm form which accomodates the basic algorithm adjustments needed for performance improvements of various protective relaying functions (10).

Improved Functional Performance

Finally, the following question may be discussed: what is the relation between the mentioned algorithms and the improved functional performance of the ICPS comparing to RTU-s? To appreciate the improvements it should be recognized that the analog quantities in RTU-s are obtained through the instrument transducers attached to the corresponding instrument transformers. Accuracy of this input channel is tuned to the performance requirements of functions for which the measurements are taken. Furthermore, sampling technique used on those channels is scanning rather than simultaneous sampling using synchronized sample and hold techniques. Therefore, the performance of the input channel is fixed and depends on the functional utilization. The consequences is that the RTU input channels are designed for specific use by one of the functions such as revenue metering, operator measurements, protective relaying.

Use of digital algorithms in ICPS brings several improvements. First, digital algorithms may be applied to the raw samples obtained by the signal conditioning circuitry. Hence, the costly instrument transducers can be eliminated (11,12). Secondly, the same basic digital algorithm may be used for diverse functions such as revenue metering, operator measurements, protective relaying, transients recording, fault location. This has the major economical impact if all of these functions can be implemented using the minimum number of input channels. Those improvements are possible if the two design principles are accommodated for in an ICPS. One is that the "data sharing" feature is available (13). The other principle is that the correlation can be made between the operational states of the power system and the corresponding samples of analog quanties.

The final point is that a clear relation between functional improvements of an EMS system and digital algorithms on the substation level needs to be established. The above discussion had given basic background for the SCADA function improvements. However, this topic is not discussed beyond the example of the transmission line functions. All the mentioned functions are either data acquisition functions used for operator of-line monitoring purposes or locally executed relaying functions. However, even these improvements are sufficient to indicate the benefits of using ICPS-s in the place of RTU-s. Nevertheless, more critical to the justification is the relation between ICPS digital algorithms and EMS control and monitoring functions executed automatically or by an operator in real time.

ICPS DATA BASE ARCHITECTURE

A number of data base issues such as organization, time synchronization and distribution are very important when an ICPS application to the EMS design is considered. The following discussion is not oriented toward the implementation issues and strategies but is rather generic aimed to explain the basic characteristics of the ICPS data base.

Data Base Organization

Data base organization is a very broad term, but it is used here to explain the way the content of the data base is formed and correlated. It should be noted that organization of the data base is hierarchical as shown in Table III. The first level contains samples taken at the same time for the entire substation or for a specific function. The samples may be either further processed in ICPS or made available with an appropriate time-tag to any user outside ICPS. The operator entered values can be either some settings or flags. These values are used by algorithms and indicate various algorithm parameters and operational modes. The second level is related to various parameters or quantities that are calculated as intermediate values for protective relaying, control and data acquisiton functions. This second level in data base is formed by using digital processing algorithms having the inputs

Table III. Hierarchical Data Base Organization

Operator displays: Alarms, SOE, Oscillography, relaying operational characteristics, indications, operator measurements	**Level 4**
Final analog values: engr. units, phasors, line parameters Final status values: alarms and indication tables, switching sequences	**Level 3**
Calculated values: signal peaks, averages, scaled analogs Status values: time-togged indications, filtered contact status	**Level 2**
Samples: Analog signals, status Operator entered: settings, flags	**Level 1**

provided by the first level data base. The third level are calculated values which can be considered as the final values for various functions. Finally, the fourth level are formatted representations of various records and displays made available for operator using a variety of man-machine interface peripherals.

Looking at this data base, it should be observed that several major improvements are made comparing to the previous data base designs in substations. First, the volume of the available data is increased by using more input channels and by monitoring these inputs channels through-out all of the power system operational states. The increased volume might be even considered as a disadvantage. However, the possibility to improve information content and realibility through data aggregation and data compression techniques is increased. Secondly, a number of new quantities are calculated that were not available in any other system designs before. The new digital signal processing algorithms are used, and hence the new quantities are available. Thirdly, data content is related to all of the operational states of the power system. This provides for a feature that a number of quantities in data base may be used with adequate accuracy for various data acquisition control and protection function that corresponds to only some specific operational state. Typical examples are protective relaying functions, which are executed mostly in the emergency state, and revenue metering function which is relevant to the normal operational state only.

Data Base Synchronization

This issue is fairly complex when ICPS is connected. The complexity is related to the number of synchronization problems that are present. One problem is sampling synchronization and there are several aspects such as: synchronization to the power line frequency, synchronization between samples used for various functions within a substation, synchronization to the sampling frequency at a different substation. Specific issue is synchronization to the real-time clock and time tagging. Finally, a synchronization of the frequency of data base quantity updates is also present. The issue of data base synchronization will not be further elaborated on, but it should be noted that various synchronization strategies and techniques may be utilized either locally at a substation or on a broader scale of the entire system (15). The final point is that the EMS application of ICPS would certainly require a thorough study of all of the mentioned issues of data base synchronization.

Data Base Distribution

There are several aspects to be considered. One is the physical distribution. This problem is very much related to the strategy for distribution of architecture and allocation of functions (5). In any way, data base physically may be either distributed or concentrated at one place. Another approach to data base distribution is a topological one. The topology that is the most obvious is the substation topology organized around substation switchyard bays. Yet another approach is functional data base distribution. This implies that each of the application functions or group of those would have a corresponding relation to the data base distribution. A different distribution is the one that is correlated to the operational states of the power system. In this case data is collected so that it corresponds to the normal, alert, emergency and restorative operational states. Any combination of the mentioned ways for data base distribution is also possible.

As a conclusion, it should be noted that data base architecture of an ICPS can be quite different from a RTU data base. On the other hand, it may be also designed to look very much alike RTU as far as SCADA data base is concerned. This flexibility, along with some new features discussed, needs to be utilized when an EMS application of ICPS is considered. This is probably going to be, besides algorithms, the key design issue in an EMS system implementation. The following sections are aimed to discussing some of the major implementation prospects and requirements.

PROSPECTS FOR ICPS APPLICATIONS IN EMS IMPLEMENTATIONS

There are several ways to address this problem. One way is to discuss EMS design requirements and to try to define an ICPS design approach to meet these requirements. The other approach is to discuss ICPS design requirements and then to try to fit these in an overall EMS implementation. Further discussion is related to the second approach for the simple reason that all of the implications of the ICPS capabilities on the EMS implementation approaches are not yet fully understood. Hence, the following discussion gives some guidelines as how some of the ICPS capabilities may be utilized for some EMS functional improvements.

Digital Algorithm Selection

It is felt that any of the prospects discussed below are contingent upon existance of a methodology for digital algorithm selection and synthesis. The reason is that the performance of the various EMS functions might heavily depend on the algorithms used at the ICPS level for either measurements or control. Since a number of algorithms have been already proposed for various functions such as revenue metering (12), phasor measurements (11) and protective relaying (9), it is important that a classification scheme and evaluation methodology for the existing algorithms is available. Examples of such a methodology for protective relaying algorithms are published in the literature (9,16,17).

Methodology for Synthesis of Digital Algorithms

Another problem is to define a methodology for algorithm analysis and synthesis if some new algorithms are needed with specific sensitivity properties. An example of the bilinear form applications to the algorithm analysis and synthesis is discussed in this section. This example is related to the digital algorithms used for calculation of active power, reactive power, RMS values, transmission line parameters R and L and system frequency.

The bilinear form of the two sequences of samples x_n and y_n calculated in the discrete time n and denoted BF_n is given by the following expression:

$$BF_n = \sum_{k=0}^{N} \sum_{m=0}^{N} h_{km} x_{n-k} y_{n-m} \qquad [1]$$

The quadratic matrix **H** defining the bilinear form:

$$\mathbf{H} \stackrel{\triangle}{=} \{h_{km}\} \qquad [2]$$

will be named the weight matrix. Its dimension is $(N+1) \times (N+1)$ where $N \triangle t$ is the width of the window defining available samples. For the sake of simplicity, the samples of the harmonics are considered in this example:

$$\begin{aligned} x_n &= X \cos(nd + \phi) \\ y_n &= Y \cos nd \end{aligned} \qquad [3]$$

where: X, Y - signal magnitudes

ϕ - phase angle between two signals

$d = \frac{2\pi\omega_0}{\omega_s}$ - electrical angle between two samples

ω_0 - system frequency

ω_s - sampling frequency

It can be shown that the value of the bilinear form can be expressed as a sum of the constant term BF^c and the variable term BF_n^v :

$$BF_n = BF^c + BF_n^v \qquad [4]$$

These two terms depend on two functions defined on the weight matrix. The first function determines the constant part, and is denoted as $H^c(p)$:

$$H^c(p) = \sum_{k=-N}^{+N} h_r^c \cdot p^r \qquad [5]$$

where:

$$h_r^c = \sum_k \sum_m h_{km} \qquad 0 \le k \le N \qquad [6]$$
$$k - m = r \qquad 0 \le m \le N$$

The other function determines the variable part and is denoted as $H^v(p)$:

$$H^v(p) = \sum_{k=0}^{2N} h_r^v \cdot p^r \qquad [7]$$

where:

$$h_r^v = \sum_k \sum_m h_{km} \qquad 0 \le k \le N \qquad [8]$$
$$k + m = r \qquad 0 \le m \le N$$

The constant and variable term are then respectively equal to:

$$BF^c = \frac{XY}{2} |H^c(e^{-jd})| \cdot \cos\left[\phi + \angle H^c(e^{-jd})\right]$$

$$BF_n^v = \frac{XY}{2} |H^v(e^{-jd})| \cdot \cos\left[2\ nd + \phi + \angle H^v(e^{-jd})\right] \qquad [9]$$

In this manner the design of the weight matrix for a particular value of d reduces to the choice of suitable functions $H^v(p)$ and $H^c(p)$. Next, the choice of these functions is discussed.

The variable term given in equation [9] has an average equal to zero and a period equal to the one half of the fundamental harmonic period. Its presence is obviously not desirable for power and line parameters calculation. This term will vanish if the following condition is fulfilled:

$$H^v(e^{-jd}) = 0 \qquad [10]$$

This is a condition where e^{-jd} has to be a zero of the polynomial $H^v(p)$. The variable term will vanish for any d if $H^v(p)$ is indenticaly equal to zero. That is the case when:

$$h_r^v = 0 \qquad r = 0, 1, \cdots, 2N \qquad [11]$$

Geometrically, the condition [11] means that the sums of matrix elements in anti-diagonal and all the sub-anti-diagonals have to be zero. Such weight matrices will be named constant-valued. The bilinear form defined by a constant valued weight matrix will have a constant value regardless of system and sampling frequencies. Such matrices are obviously quite suitable for power and line parameter calculations.

The constant term BF^c depends on product of two phasors' magnitudes and their mutual phase shift. If signal x(t) is the voltage and y(t) is the current of the same circuit, then the constant term can be used to calculate active and reactive power. The active power will be obtained if

$$H^c(e^{-jd}) = 1 \qquad [12]$$

The reactive power will be obtained if:

$$H^c(e^{-jd}) = j \qquad [13]$$

If two signals are equal $x_n = y_n$, the form will be quadratic , and the constant term value will be:

$$QF^c = \frac{X^2}{2} ReH^c(e^{-jd}) \qquad [14]$$

The square of RMS value will be obtained if

$$ReH^c(e^{-jd}) = 1 \qquad [15]$$

Obviously, the weight matrices suitable for active power calculation can be also used for the RMS calculation.

The resitance and reactance of the line can be expresses in terms of P,Q and $I^2/2$ as follows:

$$R = \frac{V}{I}\cos\phi = \frac{\frac{VI\cos\phi}{2}}{\frac{I^2}{2}} = \frac{P}{(RMSI)^2} \qquad [16]$$

$$w_oL = \frac{V}{I}\sin\phi = \frac{\frac{VI\sin\phi}{2}}{\frac{I^2}{2}} = \frac{Q}{(RMSI)^2} \qquad [17]$$

In this manner the calculation of line parameters reduces to the calculation of active power, reactive power and the square of the magnitude.

The rest of the proposed methodology is related to the selection of suitable weight matrices . It should be noted that the weight matrices may be selected in various ways.

depending upon the specifications for the sensitivity of the algorithms. Therefore, this methodology of selecting the weight matrices is a vehicle for selection and synthesis of the algorithms that are suitable for applications in various power system operational states.

Data Acquisition and Processing

As it was discussed earlier, there is an extensive data base available in an ICPS located in a substation. As far as the EMS use of this data is concerned, it should be noted that the data is more versatile and of higher accuracy then what was available in the RTU-s. Also, more powerfull processing capabilities are available if an ICPS is used at the substation level. Therefore the basic SCADA function of an EMS can be definitely improved. Several possibilities for improvements should be recognized.

The first approach is to take advantage of the fact that more data is available at the ICPS level. Based on that, it is possible to provide data with increased information content to be transmitted to the Control Center. An example is historical data on switching equipment operations obtained at the substation level. The other example is historical data obtained on power transformer loading. In both cases local processing off the available historical data may be used to extract more conclusive data about the equipment status. This data with a higher information content may be sent to the Control Center to be used for planning purposes.

An implementation approach is also to utilize higher accuracy of the ICPS data to obtain better performance of some of the EMS functions that use this data. An example that has been investigated is related to improvements in the static state estimation function (18,19).

Another approach is to introduce an application where data collected at the ICPS level in the emergency state may be used to assist dispatchers, protective engineers and maintanance personal. There are several applications that may be defined where this data is used for analysis of the post-fault situations. In this case the mentioned data do not necessarily have to be transmitted to the Control Center, but they may be transmitted to the offices of the relevant personal. However, the major improvement is expected if a use of these data is aimed to aid an operator in making decisions concerning time critical emergency operational state. In this case some new functions and techniques need to be developed as an extension of the Control Center EMS designs (20,21).

The next approach is to use the processing power at the substation level to execute some data compression and aggregation functions so that the amount of data transmitted to the Control Center is reduced. The same feature can be applied for the supervisory control functions so that the amount of data transmitted from the Control Center is reduced. In this case a control signal obtained from the Control Center can initate a whole switching sequence which is programmed and executed by the ICPS (22).

Local Substation and Centralized Control

It is obvious that an ICPS provides more processing power and more elaborate data base needed for the local substation control then what is provided in an RTU. This is primarily related to implementation of the following substation functions: LTC control, load shedding, synchro-check and automatic synchronizing, restoration switching sequences. Therefore, the only question is: to what degree those functions need to be coupled to the Control Center functions so that an overall EMS design is improved?

Another question is: what are the new possibilities for the EMS control function allocation strategies where some of the Center control functions could be distributed at the substation level (23)? Clear understanding of the benefits of the approach is not yet available, so it is yet to be seen what are the feasible approaches.

Adaptive Protective Relaying

One of the most critical questions is: what are the benefits of having the protective relaying functions being a part of the overall EMS design? This question has not yet been answered by the on-going research results. However, a very promising approach that needs further investigation is the adaptive protective relaying concept.

Initial investigations indicate that some definite benefits regarding overall protective relaying system performance may be achieved if the protective relaying system can obtain some system data from the Control Center (24,25). Also, it has been suggested that the power system control during fault disturbances may be enhanced if the protective relaying system operation is closely coordinated with the Control Center functions (26,27,28). Nevertheless, it should be noted that in most of these investigations adaptive relaying is considered to be based on the feasibility of on-line changes of relay settings and functions. This assumes that the conventional protective relaying concept is maintained since the protective relaying is still an on-off local automation. It is believed that some future investigations should be also directed toward developments of the control strategies where protective relaying function becomes a system control function implemented using adaptive controllers located in the substations and power stations.

In any case, an ability of an ICPS to accomodate quite elaborate digital algorithms for tracking of the analog system quantities in all of the abnormal states is certainly a powerfull environment for implementation of very advanced protective relaying and control concepts. Particulary interesting in this respect is the possibility to design and implement digital algorithms which may be tuned to the particular power system conditions and accordingly be selected for appropriate digital signal processing applications.

IMPLEMENTATION ISSUES

From the previous discussions, it becomes obvious that implementation of an EMS design may be drastically affected if an ICPS is used in the place of an RTU. Of course, this statement is only valid if an attempt is made to take advantage of the ICPS capabilities so that improved performance of the existing functions is achieved as well as an introduction of some new functions is proposed. In either case, it should be recognized that some new implementation issues need to be resolved both at the Control Center and at the Substation level. The approach taken in this paper is to view that problem from the ICPS side, so further discussion is related to the implementation issues concerning the ICPS design.

Distribution of Architecture and Allocation of Functions

The most critical question here is what kind of functional coordination is required at the Substation level? This relates to the existing data aquisition, control and protection functions as well as to the new functions that are yet to be defined. In any case, the architecture needed will be some form of the distributed processing microprocessor-based architecture. The question arises as what level of coupling is needed among various processes (algorithms). Right now the ICPS designs provide very little coordination among various functions (5). The architecture is based around processing clusters which are pretty much, function and algorithms wise, replica of the conventional devices (7,8). It is believed that even moderate coordination of the substation functions for the EMS applications should require at least function allocation strategy that is quite different from the strategy taken in the conventional substation equipment designs.

System Hardware and Software

Existing ICPS designs are mostly based around 16-bit MOS technology commercially available microprocessors (7,8). Application software is pretty much written in an assembly language and the system software is very simple. Any elaborate requirements regarding EMS applications would very likely require quite different hardware and software design characteristics.

It is expected that the desired system hardware would be 32-bit microprocessors. Processor architecture which supports execution of parallel processes (algorithms) would be required. Further more some advanced parallel multiprocessor system architectures might be desired as well as some custom design signal processing chips. Certainly, due to some time response requirements, bipolar technology might also be utilized.

Software issues are expected to be much more involved. Any additional functional coordination within the system should be reflected in an adequate system software support. It is believed that some advanced topics in the operating system design for parallel processes as well as in the design of data base management software need to be understood and applied. Regarding programming languages, it is expected that some new language designs are required. Even a hardware implementation of various languages might be desired in sometime response most critical applications. Special attention needs to be paid to the philosophy of development of the system services software required for testing and maintanance purposes including the operator interface services.

System Communications and Time Synchronization

This issue is extremely important since it directly affects overal substation ICPS performance. It is expected that new ICPS applications to the EMS designs would require more elaborate exchange of data within an ICPS as well as among various ICPS around the system. Further more, it is expected that more involved signal sampling synchronization requirements are going to be present due to the fact that ICPS functions are going to be correlated among various substations and between substations and the Control Center.

The local substation communication problems are primarily related to the internal ICPS communication requirements . The solutions proprosed up-to-day are based around standardized local area networks (29). However. future approaches might asked for some customed design approaches(30). The inter-station communications are resolved using either standard approaches or fiber-optic applications (31). The future solution to this problem might be special data transmission networks which would enable efficient communications amount any logical or physical nodes in the power system. Local substation signal sampling synchronization is resolved today in a relatively simple way where the synchronization signal is hard wired. This problem can be resolved using various software techniques also. The inter-station synchronization is a more complex problem and also either hardware or software techniques can be implemented. It is believed that future solution to the synchronization problem should be linked to the system real-time synchronization. In this case the entire problem could be resolved using radio transmitters and receivers for the real-time standard signal. However, the cost justifications needs to be provided in this case since this solution can be quite costly.

Digital Signal Processing Algorithms

It is authors' opinion that a variety of microprocessor based implementations of the digital signal processing algorithms for different data acquisition, control and protection devices and systems had produced an impression that the issues of digital algorithms analysis and synthesis are pretty much known and resolved. The discussion given in this paper suggests that this is not the case even when the standard applications are considered (9). More elaborate signal processing requirements comming from the new

ICPS applications will definitely ask for further study of the mathematical models used as background for the future development of tools an methodologies for digital signal processing algorithm analysis, synthesis and evaluation.

Testing Tools and Methodology

It is obvious that some new application of ICPS require some advanced tools and methodologies for algorithm and system design testing. The conventional approaches might not be adequate (32) having in mind that some elaborate testing of various system operational states might be required. It is believed that some new testing philosophies are needed not only for the system design verification procedures but also for the algorithm simulation purposes. The testing of some theoretical and implementation concepts might be related to the system dynamics which are on the time scale of several millisecond to several seconds. Solution to this problem might require development of some new computer methods for both control of the conventional simulation tools and for system dynamics simulation.

CONCLUSIONS

This paper indicates number of features of ICPS which may be utilized for various improvements of the EMS designs if an ICPS is used in place of a RTU. However, the paper also indicates that quite a few issues need to be further studied in order to provide some final answers to the question as what will be the benefits of such an approach. It is also suggested that the problem area to be studied is a multidisciplinary one and hence future research topics should be carefully selected and coordinated to reflect this need. The following research issues need further attention:

- Mathematical modelling tools and methodologies for analysis and synthesis of digital algorithms for signal processing.
- Coordination strategies for existing ICPS functions and definition of new functions at the substation and Control Center level for EMS applications.
- Distributed processing computer architectures for support of the ICPS functions: algorithms, hardware, software.

- Data communication networks for inter- and intra-substation and Control Center applications.
- Testing tools and methodology for analysis of the dynamic behaviour of digital signal processing algorithms and functions in various operational states of a power system.

Finally it should be noted that study of the mentioned issues should be guided by the cost/performance criterium set for the overall power system monitoring and control strategy. Therefore, an ICPS design should be evaluated based on its use for the EMS system improvements rather than solely on the basis of classical substation applications.

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