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A Distributed Processing Microprocessor Based Hierarchically Structured (DMH) Relaying System - Some Basic Considerations

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ABSTRACT

The development of LSI components has stimulated research on the problem of applying a number of microprocessors interconnected in a suitable network to perform more of the applications previously performed by single computer systems.

The area of Computer Relaying (CR) is the environment in which one dedicated, relatively large computer system (at least a minicomputer) has been investigated previously.

This paper discusses some problems related to the new concept of CR based on a network of microcomputers. A new Distributed Processing Microprocessor Based Hierarchically Structured (DMH) system for the protection of electric power systems is discussed. Up to date techniques and technologies applied to perform the protection function are briefly evaluated as they are related to the DMH concept. Some basic characteristics related to the protection of power systems are analyzed. Considerations related to the new concept are stated and the basic logical structure of the DMH system is specified. A design example of a Microprocessor Based Distance Protection (MDP) device is given as a part of the proposed overall system. Performances of the proposed DMH system are discussed and some ideas for further work are outlined.

I. INTRODUCTION

As the complexity and the level of transmission voltages of the power systems increase, the importance of the protection function within the overall functioning of the power system is increasingly becoming a popular issue. The cost of protection equipment is also an inseparable issue which comes into any considerations related to power system protection.

Reflecting all other relevant issues, the importance and the cost of the protection function have challenged the people at the utility companies, research institutions and universities to adopt the newest technologies and to develop improved retrods and equipment for protection. CR is developing as a result of these efforts.

Specific performances of digital computers were recognized by researchers concerned with power protection applications sometime in the late 60's. Since that time, around 100 technical papers and publications [1,2,3] have been written on the subject and a number of research projects completed at the utility companies, research institutions and universities.

Our intentions in this paper are to introduce a new concept that could be applied to perform several protection functions within the power system, namely the DMH concept. In order to justify the importance of the DMH approach a brief evaluation of the research carried out in the past is given in Section 2. In Section 3 some basic considerations of the protection task within the power system from the point of view of the DMH concept are analyzed. The basic logical characteristics of the DMH system are introduced in Section 4. In Section 5 the specific example of the MDP unit as a part of the DMH system is discussed. Section 6 gives some conclusions and some new ideas for further research activities.

II. SUMMARY OF CR RESEARCH

One of the first papers which presented the theory used in a prototype CR application was published in 1969 by Rockefeller [4]. This work was extended and the results were used as a basis for the first prototype computer relay made and tested by Westinghouse Corporation and Pacific Gas and Electric Company. This project was the first installation which allowed intensive testing procedures to be performed and significant experience to be gained. Results were published in several papers [e.g. 5]. Westinghouse Corporation is currently working on a joint project with Pennsylvania Power and Light Company and this latter project has undergone serveral stages [6].

American Service Power (AEP) Corporation has been working on the CR problem since 1971 and later on they started a joint project with IBM Service Corporation. Several separate and joint publications appeared as a result of the investigations undertaken by these two companies [e.g. 7, 8]. AEP continued the research efforts and the results are presented in reference [9].

General Electric (GE) Corporation and Philadelphia Electric (PE) Company initiated a joint project and the results of the theoretical and the practical investigations were recently published [10].

Bonneville Power Administration (BPA) Company and Boeing have completed a joint project to develop a quarter cycle relay [11]. Boeing has developed an algorithm and completed a report to BPA describing the high speed relay operation. BPA is currently in the process of developing a prototype which will be implemented in the near future.

A lot of individuals at the universities were also working on different aspects of the CR problem.

Significant efforts in the area were carried out at the University of Missouri-Columbia since the late 60's. Researchers there have examined several aspects of the CR problem and the results were reported in a number of publications [e.g. 11, 12].

Several authors from Iowa State University have published some reports of their investigations [11, 12].

Authors from Washington State University have recently published some reports [13, 14] concerned with methods for transmission line protection and transformer protection.

Recent publications from Oklahoma State University [15] and the University of Kansas [16] are reporting on some aspects of the applications of microprocessors to perform the power system protection function.

There were also a lot of significant efforts made in the field of CR by the research institutions and universities outside the U.S.A..

Since 1960 several papers by authors from the University of New South Wales (UNSW)-Australia [e.g. 17, 18] were published. Each was a result of the study carried out at the UNSW and is related to the application of computers to perform CR of the transmission lines and transformers.

Long term efforts to analyze the theoretical aspects of the algorithms used in digital protection as well as their application to the generator, transformers, and transmission line protection were conducted at the University of Calgary, Alberta, Canada [e.g. 19, 20].

Digital generator protection and some specific problems related to the digital protection algorithms were also investigated at the University of Saskatchewan, Saskatoon, Canada [21, 22].

Authors from Imperial College, London-England have published the results of investigation of several aspects of CR [23, 24] as well as authors from Cambridge University who also reported results of their study [24]. The Great Britain Institution of Electrical Engineers (IEE) had organized the "Development of Power System Protection" conference in April 1975 [24]. More than 40 papers related to the experience of the British companies and universities working in the field of CR were presented.

Some other publications reporting on research done in the field of CR in some other European and Far East countries have also appeared.

Authors from India [25], Japan [26], Switzerland [27], France [28], Belgium [29], Italy [30], and Sweden [31] have reported some theoretical as well as some practical aspects of the problem.

This brief review of CR research has the main purpose of emphasizing the variety of problems that were investigated and the number of environments in which the research was conducted.

In this review we have not mentioned any research activities related to the development of special purpose digital relaying hardware as well as specific traveling wave theory applications to CR. These topics are very interesting from the point of view of our investigation, but as far as the discussion in this paper is concerned, these topics are beyond the scope of our specific interests.

Evaluation Criteria

Because of our specific interest in the DMH concept in this paper we will evaluate two specific characteristics of the research activities given above:

-computer systems
-CR algorithms

Computer systems used for the CR applications so far were either standard minicomputers: Digital Equipment Corporation PDP11/20, 45 [12], PDP15 [22]; Varian V72 [30]; PDP8 [17, 18]; Scientific Data Systems Sigma 2 [21, 22]; IBM System 7 [7, 8], or some special purpose minicomputers: Westinghouse P-2000 [5], System Engineering Laboratory SEL 840A [32], etc.

It can be seen that the computers used for CR are, on an average, standard minicomputers with relatively standard architectures and the following average characteristics:

-16 bit word length
-16 K core memory
-1 usec instruction cycle time
-interrupt capabilities
-several modes of addressing
-flexible I/O characteristics (DMA, etc)
-large variety of available peripherals
-high level language as well as assembly language options

It should also be noted that the above mentioned computer systems do not possess some desired characteristics, e.g.:

-parallel processing architecture
-distributed processing features
-special programmable I/O units
-smart terminals were not used
-minicomputers are not linked in any network configuration
-on an average, microprogramming features are not used
-etc.

Computer algorithms are discussed in most of the mentioned publications and deep theoretical evaluation of these algorithms is beyond the scope of our paper.

Some specific features of the mentioned CR algorithms that are of particular interest in our futher discussion should be emphasized:

-generally algorithms are digital representations of analog relaying functions implemented in conventional relaying systems.
-algorithms are intended for sequential calculations and manipulations.

There appears to be no evidence of efforts:

-in developing algorithms which will be of the modular character suitable for concurrent processing.
-in relating some calculation needs of algorithms to special purpose computer (digital signal processing) applications.
-in simplifying required calculations of the algorithms in order to make them suitable for fast computer applications.
-etc.

Applications of microprocessors to the CR field were discussed so far in very few publications [15, 16, 28] and the following sections of this paper are discussing this topic in more detail.

III. SOME BASIC CHARACTERISTICS OF THE PROTECTION RELAYING AS THEY ARE RELATED TO THE DPR CONCEPT

In this section the following protection systems will be considered:

- "classical" relaying systems (electromechanical and static relays)
- Computer Based Relaying (CBR) systems
- Microprocessor Based Relaying (MBR) systems

Terms CBR and MBR are introduced in this section in order to distinguish between two classes of computer systems used as protection systems: large computer systems (at least minicomputers) and microprocessor computer systems (microcomputers).

All three types systems mentioned above will be compared and discussed through the discussion of several basic requirements of any system:

1. Utilization, or the percentage of time the system is efficiently used.
2. Accuracy, or ability to give an optimum response to a certain set of conditions.
3. Speed, or the ability to react quickly to a change in the inputs.
4. Flexibility, or the ability to adapt to functional changes.
5. Reliability, or the ability to provide predetermined changes in the outputs given a predetermined change in the inputs.
6. Security, or the ability to provide changes in the output conditions only when certain specified changes take place at the inputs.
7. Availability, or the ability to remain in the "ready to operate" mode.
8. Maintainability, or the ability to pass easily from a faulty state to a healthy state.
9. Simplicity, or the ability to perform the required functions with minimum hardware and minimum interaction between subsystems.
10. Low cost.

1. Utilization

It is a known fact that classical relays (electromechanical and static) are very poorly utilized devices. They are sitting on the lines "watching" for possible faulty conditions, in order to react. Of course, one can say that relays are utilized 100% since they are connected to the power systems all the time. But, if there is a way to perform the same functions of basic relaying and some other functions at the same time, then utilization of the classical relays is questionable.

CBR systems are devices which are in general intended to perform some functions besides the protection function. Nevertheless, since CBR systems are performing sequential operations as opposed to the parallel operation of analog relays, the calculation burden placed on digital computers is very heavy, and therefore the available time that could be devoted to some other functions would be very small.

MBR systems could introduce a parallel (non-sequential), distributed system and therefore the calculation throughput of the system would be pretty large which implies that there would be significant computational time available for some functions other than the protection function.

2. Accuracy

Classical relays are very much dependent on the "setting" conditions and the accuracy is highly dependent on fixed setting.

CBR systems are capable of performing calculations with very high accuracy, particularly in terms of error correction and estimation procedures. Accuracy of these devices is highly dependent on the algorithm used, and it can be significantly improved by better algorithms.

MBR systems are pretty much in the same range of accuracy as CBR systems speaking in terms of the characteristics mentioned.

Since the highest degree of information is contained in the shape of the signal waveform, and digital devices are capable of examining this shape, they are capable of performing high accuracy calculations. On the other hand, electromechanical relays are acting on the rms, static on the peak values and these values contain less information than the signal wave shape.

3. Speed

Classical relays have speeds that range from several cycles (electromechanical) to one cycle, and may operate as fast as 1/4 of a cycle (static relays).

Digital computers are capable of performing required calculations very fast, on the order of one cycle time or less, but since most of the algorithms require information about the signal up to one cycle time, the speed is highly dependent on the algorithm used. Besides the algorithm requirements for high speed, the basic technological capabilities of digital computers are not pretty well with a processor having an instruction cycle time on the order of 1 μsec or less, a memory cycle time in the order of a couple of hundred nanoseconds and A/D conversion times in the order of a couple of hundred microseconds.

Microprocessor devices were claimed to be slower than digital computer devices, but bipolar microprocessors can satisfy any of the functional speed requirements given above. Of course, the bipolar devices are expensive, but MOS devices with cycle times under 5 μsec are also available today. DPR structure using distributed processing algorithms (DPA's) would provide concurrent processing which could increase the speed of the required calculations.

4. Flexibility

Consideration of flexibility strongly favor digital systems because there is tremendous flexibility in the adjusting and changing of different features, doing that either automatically or at least with minor hardware changes. A MBR system has more additional features of modular expansion of the system's hardware, as well as the system's software and firmware. Special purpose hardware and programmable versions are also available.

5. Reliability

Reliability of the classical relaying systems has been questioned. Some surveys [3][4] showed that within the protection equipment, the relays are the devices most likely to fail to operate. Particularly if they have not operated for a long time, their reliability is questionable.

Digital devices are very reliable devices in general, and also have capability of self-checking procedures.

CBR systems are very reliable, assuming reasonable software reliability, but some environmental conditions can significantly influence this reliability.

The MBR device is also very reliable but its distributed configuration might introduce some unreliable situations. But if we take into account reliability versus cost considerations, then we can conclude that if the device is cheap then a high degree of redundancy, which can be considered as an improvement in reliability, might be very attractive. Reliability versus availability is also a central issue. Since the MBR device is flexible and allows easy replacement of faulty parts, the Mean Time Between Failures (MTBF) is of less concern than availability. Mean Time to Repair (MTTR) thus becomes a secondary issue if cheap and quick replacement of the erroneous devices can be performed. The relatively small size of the MBR system also allows the possibility of better protection of the system against environmental influences through appropriate shielding solutions.

6. Security

This issue is pretty much related to the reliability, availability and the maintainability issues. The particular feature of digital devices to perform self-checking security procedures is of special interest.

The MBR system could be particularly attractive because of the possibility of implementing a modular security software which could be executed in a distributed fashion, concurrently in several locations.

7. Availability

In the section on reliability some relations between reliability and availability were emphasized. This relation should be particularly carefully studied as it is related tho the DPR concept. Some of the features of interest would be the microprocessor back up devices capable of automatic replacement of the erroneous device as well as highly standardized plug-in microprocessor cards which could be exchanged very quickly.

8. Maintainability

It is probably evident that classical relaying devices require less time, skill and money to be repaired than digital devices.

Eventhough the digital devices are very reliable and therefore make the issue of maintainability less critical, it is still evident that very qualified personnel for maintenance purposes are needed.

Microprocessor based systems introduce some new aspects into the maintainability issue. The parts of the system that malfunction can easily, after replacement, be shipped to qualified and well equipped maintenance centers where quick and inexpensive maintenance can be performed. Eventhough the maintenance centers can be geographically separated from the installation location, the transportation facilities and low cost of transportation can still make maintainability highly efficient and considered together with availability and reliability highly flexible and economical.

9. Simplicity

It must be admitted that classical relaying equipment and configurations are, compared to the digital relaying systems, fairly simple, but the simplicity has to be in agreement with the level of complexity of the protection system used.

It is the authors' opinion that the DPR concept is logically simpler than any other digital relaying concept. Simplicity of the DPR concept is primarily due to its modular, distributed processing algorithm and its logical breakdown of the required functions by certain levels of functioning.

10. Low Cost

Cost is one of the major issues in the field of power system protection and is emphasized in this paper as one of the major issues of the DPR concept, too.

It is an evident fact that the cost of the classical relaying equipment and conventional digital computers have been substantially constant for a long time and do not show any significant trend towards going lower.

Microprocessor devices are showing a tremendous trend towards the lowering of its price, but their cost was also coming within some standardized limits in the last year or so. It should be noted that these limits are very low and are coming near prices of $3.00 per microprocessor chip in quantities and below $30.00 per microcomputer on a chip.

Of course the main cost reduction of the DPR system would result from mass production, but we are convinced that all other issues (1-9) discussed above should be carefully studied and utilized in order to favor the DPR concept as the less expensive way of protection.

As a conclusion to this section, it should be emphasized that digital protection systems are surely more sophisticated systems than the conventional relaying systems. This sophistication should provide a more reliable, secure, better utilized, more flexible and accurate protection system.

The other issues like maintainability, availability, cost, speed and simplicity are the characteristics that should help distinguish between the digital computer relaying concept and the DPR concept.

In the following section some basic features of the DPR system are discussed and the relation between these features emphasized.

IV. THE DPR SYSTEM-ITS ALGORITHM AND ARCHITECTURE

In order to define the algorithm and the architecture of the DPR system we will at first discuss the functional requirements of the protection function as well as its logical decision structure. This will lead to the definition of the Distributed Processing Algorithm (DPA) and the Distributed Processing Architecture (DPAR) of the DPR system. Normal and abnormal modes of operation of the DPR system are also discussed. Having defined the DPR system we will briefly discuss some procedures to analyze, specify and synthesize a specific DPR protection system. Specific characteristics of the proposed DPR system are discussed at the end.

Functional Requirements and Logical Decision Structure

Protection of transmission lines, transformers, generators and bus bars as well as many other control and monitoring functions are assumed to be the set of protection functions which our system would handle.

Protection of each of the mentioned power system elements is a local function and can be performed almost entirely locally. The situations which introduce non-local requirements are special events, like very serious faults causing damage to the control equipment, etc. Delivery of the collected data, as well as certain backup situations are also nonlocal requirements. Of course, any change of the basic electrical characteristics of the power system being monitored would also require some communication facilities between the local protection systems.

Local protection function can be fairly complex, consisting of several decision functions. Data obtained by sensors could be shared between these decision functions. Therefore, some coordinating function would be performed at the local protection systems.

While performing certain protection functions, the local protection system is actually converting the local data collected by sensors into new data base. This can be viewed as a preprocessing function, preparing data for some other users. Also, there are some abnormal situations when the local protection system requires data from other local systems and/or from the central control system. Therefore a connecting function providing a connection between the local systems and other related systems should also be provided.

It becomes evident that there should exist a point where the concentrating function could be performed. This function will mainly allow the concentration of data preprocessed at local points in order that the concentrating system can analyze the data, as well as make relevant decisions and send them to the local point and elsewhere.

We are assuming that there exists an overall protection function within the power system and therefore some central decision function also exists but, as far as the proposed DPH system is concerned, the problem of the central decision function is beyond the scope of this paper.

DFA and DFAP of the proposed DPH system

From the discussion given above we can define the following DFA's:

1. There is a set of different algorithms performed by local points. Local point algorithms can be performed concurrently.
2. There is a set of coordinating algorithms for each particular protection function which coordinate execution of the local point algorithms.
3. Separate algorithms are necessary to handle communications between the local points and the concentrating point. These algorithms are logically dependent and are executed in some arbitrary order.
4. A set of algorithms is necessary to coordinate the execution of the algorithms given above (1, 2, 3). Since algorithms 1, 2, and 3 can be performed concurrently, the algorithms of the concentrating point should coordinate possible interactions between algorithms 1, 2 and 3.
5. There exists a distributed data base which is preprocessed by algorithms 1, 2 and 3 respectively, and made available to algorithm 4. The data base at each stage of transformation is stored and maintained as a local data base and is interfaced until the moment when the distributed data base is updated as a whole. There exists a set of algorithms which takes care of the described operations that are performed on the distributed data base.

DFAP characterization are:

1. There are 4 levels in the hierarchy where the following units are located:
   - -Local processing units (level 1)
   - -Coordinating units (level 2)
   - -Connecting units (level 3)
   - -Concentrating units (level 4)
2. Levels 1, 2 and 3 represent the major part of the DPH system. Level 4 is intended for minicomputer applications but depending upon the situation, it could be implemented using microprocessors.
3. The proposed DPH system consisting of levels 1, 2 and 3 is intended for a single substation application where level 4 would be monitored by a minicomputer. This situation determines the number of units at each level of the DPH system.
4. Each level has its own memory storage and it is connected to the common bus of that level.
5. The flow of information data in the structure is mostly from local points up to the concentrating point. The flow of control data is mostly from the concentrating point down to the local points but in both the mentioned cases there is a possibility of reverse flow of the information and control data.
6. Interrupts are issued ordinarily in the direction from level 4 towards level 1 but, on some rare occasions the other direction is also possible but in a stepped fashion from level to level.
7. Ordinary, polling and scanning capabilities are used for normal reporting procedures established between levels 1, 2, 3 and level 4.

Proposed DPH system

The proposed system is represented in Figure 1. The configuration given in Figure 1 operates in two basic modes:

- -The normal mode of operation
- -The abnormal mode of operation

The normal mode of operation assumes, basically, the concurrent operation of local systems with an established procedure for reporting the status data to the concentrating system. The system can be viewed as a transformation system which takes data from the system at level 0 (sensors), preprocesses that data, makes some decisions and sends the data to the upper levels. So there exists a transformation and updating of local data bases, while the flow of information is from lower levels to the upper levels. There is an established order as to how the concentrating system takes data from the lower levels, makes decisions and sends back the control data.

The abnormal mode of operation changes, in a sense, the operational characteristics of the system given above. In an abnormal situation one of the local systems detects the abnormality and reports that immediately to the upper levels.

Depending upon the importance and complexity of the abnormal situation, help might be requested through all of the levels up to the concentrating system. In this case, all other local point systems would perform almost totally independent operations, allowing the concentrating system to be devoted to the local point system where the abnormality has occurred. These "independent" local point systems should also be ready to respond to possible unusual requests for information and control data. After the abnormal situation vanishes the restorative mode of operation should establish all the conditions required for the normal mode of operation.

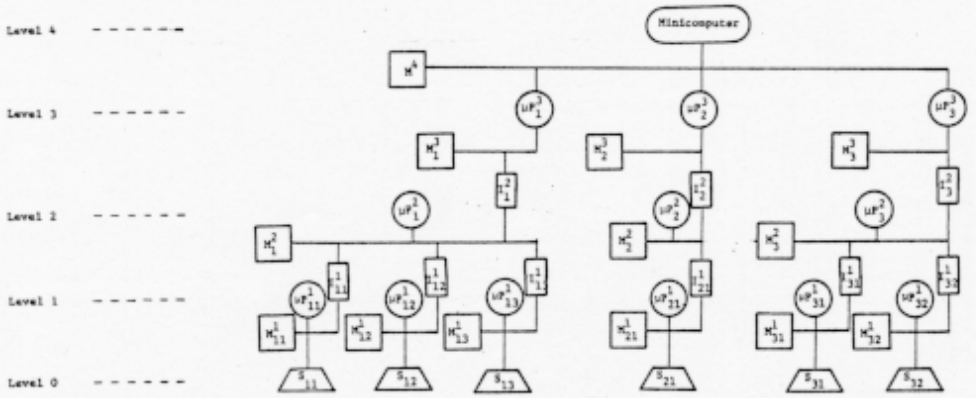

Figure 1

M^i_{jk} - Memory on the i th level, belongs to the j th local point and is of the order k at that local point (index k appears only at level 1)

uP^i_{jk} - Microprocessor on the i th level, belongs to the j th local point and is of the order k at that local point (index k appears only at level 1)

I^i_{jk} - Interface module on the i th level, belongs to the j th local point and is of the order k at that local point (index k appears only at level 1)

S_{jk} - Sensor belonging to j th local point being of order k

A procedure for analysing, specifying and designing of a DPH system.

Analysis

It is felt that the first stage in the process of establishing a DPH system is the defining of the EPA's. A possible set of EPA's could be classified into the following categories:

-Protection EPA's
-Data flow EPA's
-Control flow EPA's
-Communication EPA's (including communication protocols)
-Security EPA's

Protection EPA's are of primary interest in our case, but all other EPA's are also important.

Concurrent with defining basic EPA's, a level assignment of the particular stages within the particular EPA should be performed.

Protection EPA's would, in general, include transmission liner protection, generator protection, bus bar protection, transformer protection, etc.

Fault detection, classification and verification would be parts of the overall protection EPA which could be assigned to the lowest level of the DPH system. Higher levels would accomodate a breaker tripping function, breaker failure analysis function, back up protection, etc. Some detailed analysis of system disturbances, logical decisions following fault clearance, etc., would be the functions assigned to level 2 of the structure.

Data flow EPA's would be generally related to the alarm monitoring and data logging functions as well as to the data acquisition and event recording functions.

Data acquisition and data logging functions would be directly related to the lowest level of the DPH structure, namely the sensors. Alarm monitoring and event recording would be assigned to the coordinating level. All other levels would monitor the transmission of the data from its origin at lower levels to the terminating points at the highest level.

Control flow EPA's would generally be related to the generation of the breaker tripping signals, adaptive reclosure signals for simple abnormalities, supervisory control, etc.

The lower level systems in the structure would generate control signals mostly at the moment of the fault, while the highest level system would normally generate control signals.

Communications EPA's would handle DPH channels, I/O devices control, interrupts, memory hardware, control of modems, etc. The major part, of course, is the hardwired communications protocol which would enable communication within the DPH system.

The communication EPA's assignments to the different levels of the DPH system should enable fast and reliable communication and would depend on the choice of the communication channel used. The connecting system will provide substantially all of required inter module communications.

Security EPA's would perform standard instrumentation monitoring functions, device self-checking procedures, contingency analysis, etc.

It should be noted that security EPA's would be fairly equally distributed throughout all the levels of the DPH system.

Specifications

Having defined EPA's "horizontally" and "vertically", an estimate of the complexity and the calculation requirement of the particular EPA should then be made. As a result of this there will develope hardware specifications defining hardware sufficient to carry out the requirements of the EPA's. This, of course, would not be in conflict with the general DPH system defined but, on the contrary, would specify the particular functions related to the general elements of the DPH system as well as the number of desired elements at each level of the structure.

Syntnesis

The synthesis process would consist of designing the software and firmware for the specified hardware.

Since the DPH system is assumed to be standardized, hardware wise as well as software wise, the synthesis procedure would have to deal primarily with the accomodation of the specified function, to the general elements of the system.

Characterization of the proposed DPH system

All of the parameters discussed in Section 3 could now be discussed in more detail. However, we will assume that it will be more interesting to summarize some important features of the DPH system which would involve several of the parameters given in Section 3 at the time.

These features are:

1. The DPH system can be developed as a general system which could be applied to most of the protection environments.

2. Hardware structure could be made fully programmable allowing for specific characteristics to be incorporated in the general system.

3. Hardwired communications protocol should be flexible enough to allow fully expandable and flexible microprocessor networks.

4. Hierarchical architecture of the microprocessor network provides an optimal throughput of the data and control messages, and is fully suitable for the logical requirements of the protection function. Deadlock situations are highly unlikely for the given flow of interrupts.

5. Redundant memory configuration at each level enables a store-and-forward way of transmitting data from local data buses to the central data base. It also allows a data block transfer without placing a great data flow burden on common buses at each level.

6. Redundant hierarchical configuration was not particularly discussed, but the interchangable network as it is described would allow attachment of any number of redundant pieces of hardware without any particular problems.

Having defined the DPH system we can proceed to the discussion of the design processor for a MPP system. This can serve as an example of the proposed overall design procedure.

V. MPP SYSTEM

Our primary interest in this section is to give an example of how one of the protection elements of the DPH system, namely the MPP system, can be designed. This particular choice is due to the fact that the distance protection of the transmission lines is the most discussed problem among all other given in the literature related to CP. Therefore, there are several well discussed issues which could be related to our concept.

In order to analyze the MPP system we will discuss related DPA and, after that, related DPAR will be discussed. Finally, the operating characteristics of the MPP system will also be discussed. Some of the MPP system characteristics related to the overall DPH concept will be particulary emphasized.

DPA characteristics of the MPP system

Having studied digital algorithms that are available in the literature for distance protection we have come to the conclusion that there are very few studies [6, 11, 21, 23] which were related to the comparison of the available algorithms. In particular there are not very many publications available on studies related to some overall problems like: transient analysis of the faulted signals, comparison of the different mathematical models used in distance protection algorithms, estimation of the errors introduced by different sampling rates, suitability of different algorithms to computer applications, etc. By no means are we disregarding the research efforts made so far in the area, but we are emphasizing the lack of firm criteria for selection of a particular algorithm. It could be achieved if there were operating field installations to evaluate alternative algorithms.

With relative confidence we have selected the Fourier analysis impedance distance relaying algorithm as the one that satisfies conditions of speed, flexibility, accuracy and applicability for digital implementations. Detailed analysis of the Fourier analysis algorithm can be found in a number of references [e.g. 19, 24, 25].

Algorithm requirements that we are considering are related to fault detection, classification and fault verification.

Fault detection algorithms are based on the Mac and Morisson technique [17] of comparison of each sample with its corresponding value from the cycle before. After detection of a difference between several sequential corresponding values the fault classification procedure is initiated.

The fault classification procedure can be performed using either voltage or current samples (depending on what values are used for the fault detection procedure). Assigned counter values used for detection procedures can be manipulated in addition to neutral current or voltage value in order to determine the appropriate V-I pair used for the verification procedure.

The fault verification procedure consists of calculation of impedance values and checking if these values are within the specified tripping zone.

A selected V-I pair is assumed to be in the form [19]:

$$V_a = V_{da} + jV_{qa} \qquad (1)$$
$$I_a = I_{da} + jI_{qa}$$

Values given in (1) are calculated using the following formulae:

$$X_d = \sum_{k=k}^{N=k-1} x(k)\sin(k\omega_0 T/8) \qquad (2)$$
$$X_q = \sum_{k=k}^{N=k-1} x(k)\cos(k\omega_0 T/8) \qquad k = 1, 2, 3, \ldots$$

where: N-number of samples per period

T-period equal to $1/f_0$

f_0-fundamental frequency equal to $\omega_0/2\pi$

Therefore, using (1) and (2) we can calculate values for R_a and X_a as:

$$R_a = \frac{V_{da}I_{da} + V_{qa}I_{qa}}{I_{da}^2 + I_{qa}^2} \qquad X_a = \frac{V_{qa}I_{da} - V_{da}I_{qa}}{I_{da}^2 + I_{qa}^2} \qquad (3)$$

Values calculated in (3) are the ones that are used for the tripping decision.

Harmonic and D.C. rejection of the proposed algorithms can be tested and it has been shown [15] that this algorithm responds fairly well to most of the disturbances.

The sampling rate used in our algorithm was discussed in several publications and was recommended to be in the range between 8 and 32 samples per cycle. Our selection is 12 samples per cycle because this sampling rate introduces some symetry in the algorithm formulae allowing easier implementation using a digital device [8].

The accuracy and speed trade-off values limit the desired characteristics of the proposed digital relaying technique. The best accuracy is obtained if full cycle data is available, but this introduces significant delay in the relay response. It is shown [8, 19] that 1/2 of a cycle and above are the response speeds that could be achieved with tolerable accuracy.

Filtering features must be introduced in order to remove high harmonics of the signal which would cause aliasing because of the sampling rate frequency. Of course, the proposed technique assumes the fundamental frequency (50 Hz) signals and it has to be taken into account when additional filtering is performed either by the technique itself or by some separate filtering.

DPAR characteristics of the MPP system

Operational modes of the MPP system

In the normal mode of operation the conditioning circuitry at level 0 performs filtering, sampling and the conversion of the signal into the digital form. This circuitry also shifts the data to the related microprocessors at level 1. Each microprocessor takes related V-I values and constantly performs the detection routine using that values. Each of the microprocessors, in coordination with the other two processors, preprocesses the data required by the classification routine. This data is stored in the common memory accessible to the coordinating unit. The rest of the

time the level 1 processor will monitor the conditioning circuitry operation, the conversion of data operation and some other values related to security operations, data recording, breaker operation, etc. The coordinating unit is monitoring functions related to the communication control, data storage, report organization, preprocessing of the data for higher levels, etc. The connecting unit at level 3 is mostly concerned with communication functions as they are related to the interface to the common sub operations. This device also monitors interrupts coming from either direction.

In the abnormal mode of operation the single line microprocessors at level 1 detect the abnormality and decide on which V-I pair is required by the level 2 microprocessor for the calculation of values given in equations (2) and (3). After the classification is performed the microprocessors at level 1 establish a direct data path to the level 3 processor. This processor now performs the "worst case" calculation (about 1000 micro seconds long). This is the only time when such a long calculation time is required since after all values of the series (2) are calculated, then for each following sample only an update of the series is calculated and that takes significantly less time. Single phase processors spend their available time on the monitoring of the breaker tripping signals and other functions related to faulted data recording. In the case of severe faults the coordinating unit calls the concentrating unit to directly interface the whole local protection unit to the concentrating unit in order for some more complex strategies and activities to be performed.

The MPS system can be represented as in Figure 2:

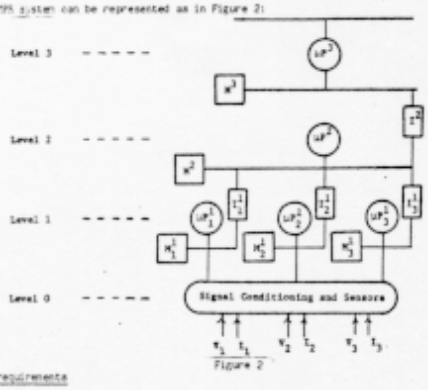

Figure 2

Time requirements

We can assume the following time requirements for the desired hardware functions as readily available:

sample-and-hold	5 msec
A/D conversion	10-20 msec

Filtering requirements are around 1 msec but this should be added to the overall response time.

The following microprocessor characteristics can be assumed as a readily available:

Hardware divide	10-20 msec	add	2 msec
Hardware multiply	10 msec	Instruction cycle time	1 msec

If we assume that time requirements for the conditioning of a total of 6 signals are approximately 100 msec then we can assume that the time available for other calculations can be obtained as follows:

$$T = \frac{1}{60} = 16.6 \text{ msec}$$

If we have a sampling rate of 12 samples per cycle the the time between samples is:

$$\delta \approx 1.4 \text{ msec} \times 1400 \text{ msec}$$

If our algorithms require, for example, 32 multiplications, 24 additions and 6 divisions, then the total time for the worst case calculation can be in the order of 1020 msec. Therefore, 400 msec are left for functions other than fault verification.

Characteristics of the proposed MCR system

All of the characteristics given in section 3 can be discussed again, but instead we will just emphasize some features which combine several characteristics from section 3 at the time:

1. The system as a whole can be implemented as a fully programmable system allowing for maximum adaptability to particular environmental conditions.

2. All thresholds values in the detection and classification procedures, as well as all zone determination values in the verification procedure, can be implemented as programmable features.

3. The conditioning circuitry can also be programmed for different filtering requirements and sampling rates through digital filtering methods implemented as firmware in the microprocessors.

4. The communications interface circuitry can also be programmed for different types and rates of desired communications.

5. The basic software of single phase units, the concentrating unit and the connecting unit can be implemented using programmable memories allowing for total flexibility of the system.

It must be admitted that some other DPA's [9] could be implemented, which perform detection classification and verification functions in a way different from the one we have used, but the basic distributed processing characteristics are still valid. It is particularly evident if our intention to implement some other functions applied the basic functions of our system is considered.

VI. CONCLUSION

As a conclusion to our discussion we want to emphasize the following, in our opinion interesting, points discussed throughout the paper:

1. The main characteristics of the research performed in the field of CR so far is primarily based on single, large scale computer systems (at least a minicomputer) and algorithms are not classified as DPA's.

2. The introduction of LSI technologies in the early 70's have given some new possibilities to the consideration of the CR as a whole.

3. The DMH concept is a logical and feasible possibility for the implementation of LSI to the CR problem.

4. DPA's, functionally divided "vertically" and "horizontally", as well as the DPAR of the proposed DMH system, are very suitable for actual protection system requirements.

5. New operational features achieved by the DMH concept system are very much advocating the DMH as an attractive approach for further investigations and implementation in CR systems.

6. The MSP system is a representative example as to how one of the protection tasks-distance protection of the transmission line-can be implemented as a part of the DMH system.

This paper evolved from some analysis and studies of the CR field performed in our department. We are currently in the stage of specifying the design requirements for DPA's and DPAR for the protection of the different elements of the power systems. Some design activities for the overall protection system based on the DMH concept have already been performed and we are looking forward to publishing the results in a future paper.

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