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A SURVEY AND CLASSIFICATION OF THE DIGITAL COMPUTER RELAYING LITERATURE

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Abstract - The application of digital computers to the protection of electrical power systems was first considered by Morrison [1,67] and Ramamoorty [2,67] in papers published in 1967. Interest in this research area has grown rapidly and with this interest the volume of publications. The purpose of this paper is to provide a comprehensive bibliography of the Computer Relaying, CR, literature together with a classification to assist those interested in this literature. Trends are identified and some probable future developments projected. The bibliography contains 129 references arranged alphabetically within the year of publication. This paper is intended to augment the positive contributions of the Bibliography and Publicity Subcommittee of the IEEE Power System Relaying Committee, as well as the efforts of some individuals who have previously published earlier bibliographies in this area.

INTRODUCTION

The field of Computer Relaying, CR, that is the application of digital computers to electric power system protection, began in the late 1950's. In the intervening decade many research projects have been undertaken and completed by utility companies, electrical manufacturers, public and private research organizations, universities, and others. Over one hundred papers, theses, and reports were published in the first ten years and the rate now exceeds two dozen per year. Nevertheless, few of these publications [3,73;6,77; 9,77;1,75;21,75;12,71;5,70]* were concerned about a systematic classification and categorization of the published literature in this field. The authors wish to share the results of their comprehensive survey of the CR literature performed in preparation for research in this area. Extensive manual searching using traditional methods was employed together with computer aided searching of the machine readable indices.

In addition to providing a comprehensive bibliography, this paper provides a classification and categorization of this literature, and some description of the basic system approaches taken by several recent projects which are developing prototype Computer Relaying, CR, systems. Part two of the paper contains the description of the classification of the literature, and the categorization of the references given in the bibliography. Part three describes the several different approaches taken to the CR design problem ranging from the first single computer systems to the mini and micro computers used today in distributed configurations. Conclusions are contained in part four and the bibliography of 129 references follows. The references are arranged alphabetically by year and numbered sequentially within each year. This notation was taken to facilitate possible later updates which may be desired of this bibliography. The references cover the time period from 1967 through the middle of 1978. The authors have obtained copies of 93% of the papers cited using normal, generally available acquisition procedures.

* The notation [3,73] refers to the third reference in the year 1973.

CLASSIFICATION AND CATEGORIZATION OF THE COMPUTER RELAYING LITERATURE

Classfication and categorization of the CR literature to date have been somewhat narrow. Most of the bibliography papers were either simple listings of the citations [3,73;9,77], or were concerned only about available CR algorithms and their characteristics [6,77;21,75]. Some of the papers were of a more general type with good bibliographies [12,71;5,70] but these were not strictly related to the CR field. Only one [1,75] bibliography type paper has been devoted specifically to the classification and categorization of the CR literature.

The classification scheme used in this paper first divides references into the following classes:

1) papers based on graduate thesis research work, both masters and doctoral
2) papers concerned with the apolication of microprocessors to the CR problem
3) papers on digital methods for CR
4) special topics in CR

Each of these classes will be further divided as shown below. It should be emphasized that the division is not intended to be unique, but rather a convenient scheme for access to the literature. Thus one reference may appear in more than one class and/or category.

Academic Theses

Papers based on thesis work constitute 10 percent of the total references and many times are important in setting new directions for work in the CR field. The following references relate to doctoral work [13,77;24,75;25,75;5,73;4,72;6,70;2,67]. These references relate to master level work [11,77;8,72;11,72;1,71;2,71;2,63]. Many of these authors are cited in later references showing new work which has built upon the thesis work. The bibliographies given in these papers are generally very comprehensive and informative relative to the time they were prepared.

Microprocessor Applications to CR

This class has arisen during the past three years with the rapid development of microprocessor technology. The importance of this class is evident since it also contains 10 percent of the total citations [4,78;7,78;3,78;9,78;10,77;11,77;14,77;17,77;20,77;6,

75;11,75;23,75;24,75]. These papers report on the consideration of the microprocessor hardware for the implementation of digital filters, Input/Output modules, communication modules between elements of a distributed system of computers, and for the arithmetic and logic processing required. Microprocessor hardware can be tailored in particularly cost effective ways as compared to that which was possible with prior computer technology. It is reasonable to expect that microprocessors will become increasingly important in solving the CR problem, and that this will be reflected in an even larger fraction of the literature in the years ahead.

Digital Methods for CR

Because a large fraction, approximately 75 percent, of the references fall into this class, it is appropriate to further categorize into subclasses as follows:

1) Overall substation approach and general concepts for computerized protection
2) Digital protection of transmission lines outside the substation
3) Protection of apparatus within the substation

There are forty-three papers related to the overall substation protection problem and to general concepts for digital protection of electric power equipment [7,73;8,78;3,77;10,77;11,77;17,77;2,76;3,76;6,76;10,76;11,76;2,75;3,75;4,75;5,75;9,75;15,75;20,75;23,75;24,75;25,75;3,74;4,74;6,74;7,74;1,73;2,73;8,73;1,72;5,72;7,72;8,72;9,72;3,71;4,71;2,70;3,70;5,70;6,70;7,70;1,69;2,69;1,67]. Most of these papers report on trends in CR development. The earlier papers generally are concept oriented while many of the later papers deal with the simulation or hardware testing of elements for substation protection systems.

There are thirty-six papers dealing with various facets of the protection of electric transmission lines [1,73;5,73;9,73;10,73;11,73;1,77;2,77;5,77;13,77;14,77;15,77;16,77;18,77;21,77;22,77;7,76;8,76;18,76;19,76;21,76;22,76;5,74;5,73;5,73;7,73;2,72;3,72;10,72;1,71;7,71;8,71;9,71;10,71;11,71;3,69;2,68]. The most common technique for solving the distance protection problem is some variation of Fourier analysis of the voltages and currents of the faulted line. Important considerations are how many samples are required, and how fast can the required calculations be made.

There are nine papers dealing with the protection of apparatus other than the transmission lines, i.e., transformers, busses and generators [6,78;4,77;19,77;8,76;9,73;10,73;11,72;13,71;1,70].

Special Topics References

References in this class are categorized as follows:

1) Specialized hardware
2) Theoretical considerations of algorithms
3) Strategies for switching
4) Back-up protection
5) Simulation and testing
6) Fault location
7) Miscellaneous topics

Although most of the CR literature considers at least some aspects of the hardware implementation, the following references particularly emphasize the hardware aspects of CR systems [2,71;5,71;6,71;].

The effectiveness of CR systems is very heavily dependent upon the algorithms chosen for implementation. The following references provide descriptions and some comparison of different algorithms suggested for use in CR systems [4,73;12,73;5,77;13,77;5,76;1,75;11,75;12,75;14,75;1,74;4,72].

The switching strategies aspect of the CR problem are particularly investigated in the following references [10,75;13,75;3,73].

Reliability is a very important design consideration for power system protection. The matter of back-up protection is considered in detail in the following citations [3,75;4,75;6,75;7,75].

Simulation is a useful tool for the evaluation of proposed CR systems. The ultimate judgement must be made by field testing. The following references deal with the simulation and testing of CR systems and components [12,77;20,77;13,76;14,75;15,75].

In order that the optimum protective action can be taken in the event a fault occurs, it is necessary that the location of the fault on the power system be determined with sufficient precision. The fault location problem is considered in the following references [9,76;15,75;5,73].

Within the larger context of CR, some writers have dealt with problems such as more restricted environments, the general problems of timing required to attain real-time operation, and the performance of hardware elements such as analog-to-digital converters [7,77;4,76;12,75;2,74;3,74;7,74;3,73; 4,73;1,69;2,67].

The above classification and categorization of the CR literature suggests the following areas in which additional effort invested would likely promote the development and implementation of CR systems:

1) Critical comparison and evaluation of alternative approaches to the CR problem,
2) Investigation of the theoretical limitations of alternative algorithms for the several components of the necessary processing and decision making,
3) Analysis of requirements for the protection of power system equipment other than the transmission lines, i.e., transformers, busses, and generators,
4) The design and development of a totally integrated substation protection and control system which also communicates appropriately with the other computer based systems for operation of the total power system.

Some work has been done in all of these areas, and work may well be in progress which has not yet been reported, but more effort seems to be justified.

Although much work has been done in the past three years and much work is currently underway relative to the application of micro-computers and networks of microcomputers to the implementation of CR systems, it is expected that the level of effort invested in this area will substantially increase in the future.

Based upon review and study of the references cited in the bibliography, the trends of past work and projections of probable future activity are considered in the next section.

TRENDS IN THE DEVELOPMENT OF COMPUTER RELAYING SYSTEMS

The work reported in the late 60's and early 70's dealt with general consideration of the CR problem. It was established that, in principle, faults could be

detected and located by digital methods, although the digital hardware available at that time could not provide an implementation that would be cost competitive with existing relaying hardware. The CR problem was often considered in the context of the larger question of the application of computers to substation control and protection. In retrospect it is interesting to note the strong differences of opinion among different authors relative to the possibility of the use of a large, centralized computer system to solve the computer relaying problem.

Since 1970 when the first results of a joint project between Pacific Gas and Electric and Westinghouse, PRODAR, were published, there have been a number of investigations of the application of computer relaying to the specific problem of the protection of electric power transmission lines. Joint projects have been popular as a means of bringing together the breadth of expertise necessary to deal with this problem. Other examples are IBM and American Electric Power and General Electric and Philadelphia Electric Company. It is interesting to note that the consideration of centralized computer systems was declining in favor of the use of minicomputers for the implementation of proposed CR systems.

In the period 1973-1975 much work was accomplished and reported on the study of algorithms applicable to the CR problem. The availability of microcomputers stimulated the first considerations of this type of hardware for possible implementation of CR algorithms and functions.

In the period 1975-1978 the consideration of the use of microcomputer hardware increased because of the increasing capability and decreasing cost of the integrated circuits used in the manufacture of microcomputer systems. The design of the first prototype systems for CR was begun in this period. Again many of these projects were joint ventures as illustrated by the following list: Westinghouse and Pennsylvania Power and Light, Bonneville Power Administration and the Boeing Company, General Electric and Philadelphia Electric, American Electric Power and most recently the EPRI Substation Automation Project.

A major and important activity in the next five years will be the testing and evaluation of these prototype systems within the operating environment of selected electric utility systems. It is also expected that initial investigations into the general problem of integrating CR into the general solutions of the larger problem of substation automation will be completed and prototype systems proposed to implement these concepts.

It seems reasonable to expect that in the last half of the next decade some CR relaying systems will become commercially available as systems which can be readily applied to the protection of electric power systems. It is also expected that prototype design and evaluation projects will be carried out in the area of integrated substation automation systems. These integrated systems will incorporate the functions of now separate systems such as: sequential event recorders, remote terminal control units, SCADA systems, and Computer Relaying systems.

These projections may be too optimistic, but it is the authors' firm opinion that the proposed developments are technically feasible. Furthermore, the further improvements in the performance to cost ratios of digital computer equipment will surely make such systems very attractive when compared to alternative approaches to solving the problems of controlling and protecting electric power systems in the coming decades.

CONCLUSIONS

The literature on the subject of Computer Relaying, CR, has been surveyed and classified to provide assistance to those interested in this material. An overview has been provided of the development in this field, and projections suggested for the next decade. The development to date, and the expected future developments in the area of microcomputers, has had and will have a very substantial impact on Computer Relaying. It is expected that distributed networks of microcomputers will dominate the systems to be developed.

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