Future Trends in Protective Relaying, Substation Automation, Testing and Related Standardization

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Abstract—**This paper gives an overview of the future trends in the protective relaying area including the substation automation, testing practices and standardization. Regarding the developments of relays, two major trends are predicted: relays becoming more versatile in terms of functions and capabilities; new algorithms based on unconventional techniques such as Neural networks and Fuzzy logic being introduced for protective relaying. In the substation automation area, two directions of developments are expected: integrating relays together with other Intelligent Electronic Devices (IEDs) into all-digital substation systems; using substation automation systems (including relays) as distributed Remote Terminal Units (RTUs) of Supervisory Control and Data Acquisition (SCADA) for Energy Management System (EMS) applications. In the testing area, two directions are envisioned: further development and use of digital simulators for relay testing; implementation of versatile multi-terminal test configurations for permanent use in substation automation systems. Further development of standards for data integration and information exchange is identified as being critical.**

Index Terms— **Digital Simulators, Energy Management Systems, Intelligent Electronic Devices, Local Area Networks, Protective Relaying, Remote Terminal Units, SCADA systems,**

I. Introduction

THE protective relaying area has undergone major transformation over the years from predominant use of electromechanical and solid state technologies to extensive use of microprocessor and Internet technologies. Many utilities in the world are considering, and some are already pursuing, the wide use digital relays for implementing variety of substation monitoring and control functions as well as substation automation systems. Several trends may be recognized in the following key development areas: individual relays, substation automation systems, testing equipment, and standardization.

The development of individual relays has a long history from just introducing the digital technology in the late seventies and early eighties [1], to progressing further with development of a number of digital solutions for relaying in late eighties [2], and finally coming up with variety of mature products and systems during the nineties [3]. This trend has resulted today in digital relays that have an extensive set of functions that go beyond just relaying to cover monitoring and control. In addition, an unprecedented capability to interact with substation relays and other Intelligent Electronic Devices (IEDs) that constitute all together substation automation systems is provided.

The development of substation automation systems dates back to the early seventies when first all-digital substation monitoring control and protection systems were proposed [4]. During the years, several different substation automation philosophies were proposed, but it was not until late eighties that the communication and processing technology became mature enough to start developing cost-effective systems. As a result, several efforts are under way to implement such systems, and these efforts are well supported by the development of needed standards [5].

The testing area was not recognized early enough as an important development and hence has lagged the other two developments. Finally, in the early nineties significant effort related to development for digital simulators for relay testing was undertaken [6]. As a result, open loop and real-time designs were introduced and a number of low-cost products are available on the market today [7].

It is widely recognized that the new development trends have to be followed with related developments in the standardization area. The existing standards that support future use of digital relays, substation automation systems, and new test systems are very limited today. For some of the new trends discussed in the paper it is critical to have the supporting standardization efforts. Otherwise, some of the trends may be significantly delayed or derailed as a result.

This paper is aimed at surveying the future trends in the mentioned areas. The first part of the paper talks about future trends envisioned for the individual relay developments. Next, a prediction of where the substation automation system development may go is given. The final part talks about future trends in developing the test systems. A discussion of the needs in the standardization area is provided at the end.

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II. INDIVIDUAL RELAY DESIGNS

A. *Enhancing functional capabilities*

The most visible trend is to make relays more universal and flexible. This translates into introduction of more functions and related designs that are capable not only of accommodating new functions, but also making the implementation very flexible and even configurable by the user. Table I provides a list of new functions that may be found in a typical transmission line relay today as well as some functions that are expected to be a part of a relay in the near future. It may be noted that many of the functions mentioned in Table I are already available, but the wide spread of their implementation is not expected until several years down the road. The reason for this relatively slow acceptance of such devices is not the limitation of the present-day technology to meet the requirement, but the reluctance of the users to venture in the new applications without fully understanding the cost benefits.

TABLE I
EXAMPLES OF NEW FUNCTIONS IN TRANSMISSION LINE RELAYS

FUNCTION	DESCRIPTION
Fault Location	Implementing accurate algorithms using two-terminal data and synchroniz. sampling
Disturbance Recording	Capturing various disturbances including faults and power quality events
Use of DPR as an RTU	Performing operator-initiated switching of circuit breakers and disconnects
Circuit Brkr. Monitoring	Monitoring performance of circuit breakers using analog and contact/status measurmnt.

B. *Introducing new techniques (algorithms) for relaying*

The traditional relaying algorithms, such as impedance (distance) relaying of transmission lines, have been know for over 70 years [8]. They have been successfully applied in the new solutions based on microprocessor technology as well. Right now, such techniques are a standard solution, which is expected to stay in use for a long time to come. However, it has been recognized that in some special cases the standard solutions may fail due to various reasons. Because of that, and based on curiosity, a number of new techniques were explored for the purpose of relaying. Notable attempts are related to the use of intelligent systems such as Neural Nets (NN) and Fuzzy Logic (FZL) [9,10]. Those solutions have not been yet proven as reliable and robust enough to be widely used but some examples of very promising developments have been reported [11,12]. It is an expectation that these techniques will be used in implementing some relaying functions in the future but it is not expected that this will happen on a wide basis within at least next five years. Table II gives some examples of the functions implemented using NN and Fuzzy logic techniques. It may also be mentioned that a visible trend will be to use the intelligent techniques in aiding the decision-making performed by the traditional algorithms. Typical examples of this approach are the fault detection and classification applications.

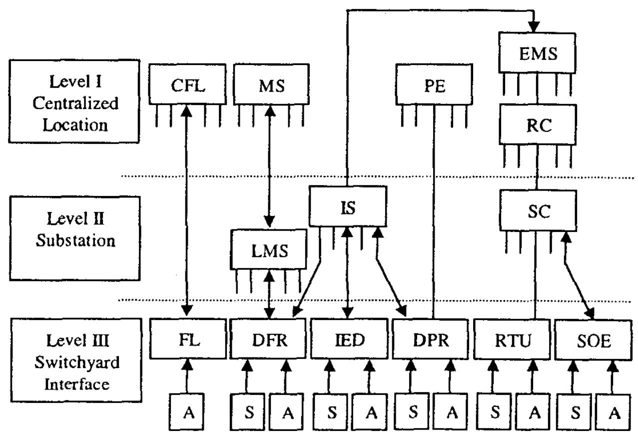
TABLE II
EXAMPLES OF NEW APPLICATIONS OF INTELLIGENT TECHNIQUES

TECHNIQUE	FUNCTIONS
Neural Networks	Fault detection, classification, location, and zone determination
Fuzzy Logic	Fault detection, classification and characterization

III. SUBSTATION AUTOMATION SYSTEMS

A. *Integrating relays and other IEDs*

This trend is already well underway. To illustrate the existing situation, Figure 1 provides an example of typical IEDs used today [13].



Fugure 1. Substation IEDs typically used today

Figure 1 indicates that most of the IEDs today are dedicated to a given function or set of functions. The examples are: fault locators (FLs), digital fault recorders (DFRs), digital protective relays (DPRs), remote terminal units (RTUs), sequence of event recorders (SOEs). Each of the devices has its own analog (A) and status (S) inputs as well as its own user interfaces. The examples of the dedicated interfaces are: centralized fault location (CFL), local and centralize master station (MS) for DFRs, integrated substation (IS) for variety of IEDs, protection engineer's console (PE) for DPRs ,and substation, regional and system-wide control centers (SC, RC, EMS). The designs are tuned to a given application and may not be easily interfaced to or utilize for a different application. This means that the front end processing such as data filtering and sampling, A/D conversion, processing word length as well communication characteristics such as physical connectors, data formats, and communication protocols are quite different. The future trend will be to make the individual IEDs more compatible and even universal. If this is achieved, a variety of new application may be expected in the future. To illustrate a desirable development, Figure 2 gives some aspects of the new approach. It may be observed that all IEDs are easily interfaced, which assumes their properties will be quite similar in the future. Further use of this architecture is discussed next.

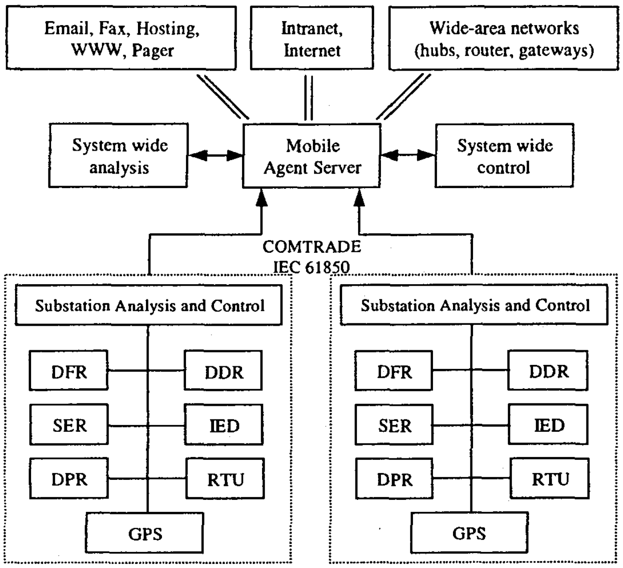


Figure 2. Future developments in the substation automation design

B. *Substation automation as a part of SCADA/EMS*

It has been known for a long time how substation automation would fit the applications that are presently implemented using standard substation solutions. However, how the substation automation systems may fit the overall SCADA design for future EMS implementations is not as obvious. Some developments in this direction are recently reported in the literature [14], but much more ides can be explored. This process will take a long time, so it is not expected that substation automation system will be fully utilized for EMS applications for a long time to come. However, it is expected that the use of substation automation systems for implementing some basic and enhanced SCADA functions will be fully embraced pretty soon. For this to happen, all substation IEDs would need to be connected to the Global Positioning System (GPS) of satellites for sampling synchronization, the intranet and Internet connections will need to be available, and advanced software technologies for data processing and dissemination such as mobile agents, would need to be utilized. Table II gives a list of potential applications in this direction.

TABLE II
SCADA/EMS APPLICATIONS OF SUBSTATION AUTOMATION SYSTEMS

FUNCTION	DESCRIPTION
Switching Sequences	Automated execution of control and restoration sequences
Fault analysis	Automated analysis of fault data from DFRs, DPRs, SERs, FLs, and other IEDs
State Estimation	Enhancing the traditional State Estimation with local substation data
Just-in-time Maintenance	Performing on-line monitoring and failure analysis of circuit breakers, power transformers, instrument transformers, etc.

IV. TEST SYSTEMS

A. *Portable digital simulator solutions*

The simulator technology has matured to the pint where low-cost high-performance solutions may be found on the market [8]. The next step is to provide the diversity needed to meet a variety of testing needs. This may be accomplished in the hardware area by providing a variety of interfaces to accommodate for different output power levels of the simulators. An example of the options for open-loop simulators is shown in Figure 3.

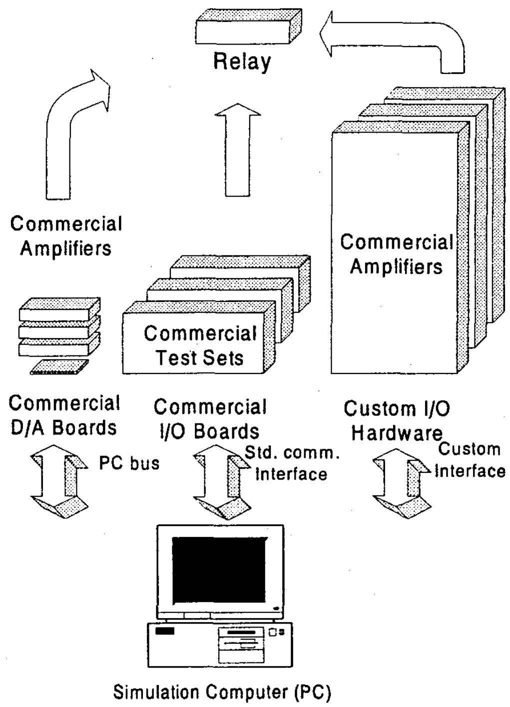


Figure 3. An advanced hardware configuration of an open-loop simulator

Regarding the software performance, the expectations are that more flexibility will be available to run transient tests aimed at evaluating application properties of a relay. To accomplish that, the methodology of application evaluation will need to be better understood so that an agreeable set of tests may be standardized. At present there is very little guidance on how to perform transients test to assess the application performance of a relay. A software configuration that represents a good start for further enhancements in this area is shown in Figure 4.

One additional trend is also very probable in this area. The real-time simulator configurations will become more compact and eventually will be implemented using portable PCs. This will bring the ultimate in flexibility to the users and they will be able to perform the transient tests rather easily both in the field and labs.

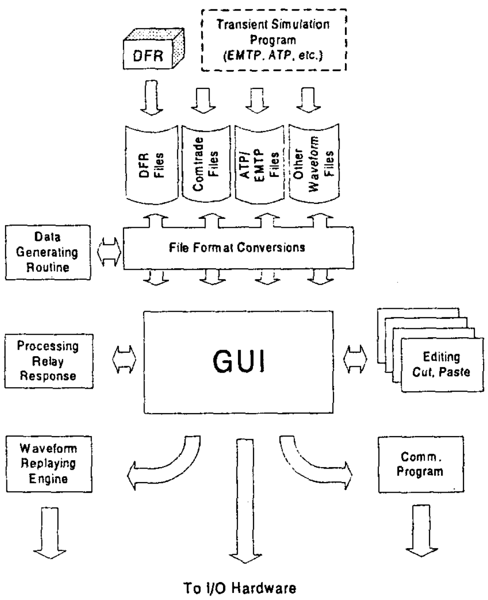


Figure 4. An advanced software configuration for an open-loop simulator

B. Fixed testing configurations

This development is pretty new even as a concept and it is not very clear if it will gain some acceptance in the future. When testing complex substation automation systems, one can only do it today by performing the test signal injections at some IEDs, and doing it for selected IEDs at a time. In order to assess the overall performance and make sure that all the interaction among different IEDs are properly implemented, one may wish to test several IEDs at the same time by simultaneously providing test signal injection at the inputs. This may simply not be possible with the existing test equipment.

One of the trends in the future may be to provide a fixed digital simulator configuration in each substation, at a cost that may not exceed a cost of a single relay. In that case a set of electronic switches that may even be remotely controlled will allow the maintenance personnel to perform transient tests by using a fixed digital simulator that is placed in the rack together with other IEDs, and connecting several inputs for simultaneous injections of test signals. In that case the whole testing process may be performed from a remote site, and the performance of the substation automation system may also be assessed from a remote location by conducting the tests and recording the results via Intranet. This would require that the digital simulators reach a point where the cost is quite low and the design is very compact. The existing designs of open-loop simulators are not necessarily too far away from having the design features needed for this application.

V. STANDARDIZATION

A. Further evolution of the existing standardization efforts

Several existing standardization efforts are important for the future trends. One important standard is COMTRADE [15]. In addition to the original COMTRADE standard specification, there is the latest IEEE revision [16] and IEC version [17]. Having three versions currently in use increases a possibility of not being able to exchange data among different types of IED software packages due to inconsistencies between different versions. Once this obvious obstacle is circumvented, the next issue is the ability to exchange the transient data among different IEDs, including relays. While some IEDs, such as Digital Fault Recorders (DFRs), have the COMTRADE data file as a standard feature, many other IEDs, including relays, do not. In some cases, such as power quality meters, there is completely different standard called PQDIF proposed for data exchange [18]. Further more, the definition of the COMTRADE frames does not allow a unique description of the application meaning for the signals. To help clarify this inconsistency, the standardized IEEE file naming convention for time sequence data was recently introduced [19]. The proposed convention defines coded schema for naming the data files. Such file names can enable easier handling of large volume of files as well as unique file identification. The proposed file naming convention contains unique information about the event: date, time, station, company, duration, location etc. Benefits of using this standardized file-naming schema should encourage IED related software vendors to provide the naming convention support, which is not a common feature today.

Another example of an important standardization is the substation automation communication protocol embodied by the IEC 61850 [5]. This standard is close to being finally approved within IEC but there are still unresolved issues between the IEC version and the version prepared by EPRI and the Utility Initiative and proposed by IEEE in the USA. It is important that these efforts are harmonized and the repetition of the COMTRADE experience of producing different version be avoided.

B. Future standardization efforts

There are quite a few areas that will need further standardization if the mentioned trends are to be feasible. Only a few most relevant examples will be discussed here.

The standardization in the relaying area is needed regarding several applications such as: entering setting, exchanging internal relays data, defining settings for various types of relays. In the substation automation area, IEC 61850 covers the main need, and it is expected that a variety of additional standards along those lines will be proposed. For the testing of relays, standardization of test cases and related power system models will be very desirable.

VI. Conclusions

This brief survey of future trends indicates the following major expectations:

- Individual relays will be improved by using better algorithms and more elaborate communications
- Substation automation systems will be more consistent in the design of hardware and software to allow more comprehensive data integration and information exchange
- Testing equipment will undergo further development and its use will expand for both individual relays and substation systems
- Standardization trends will have to continue to allow for further developments in the above mentioned areas.

VII. References

[1] IEEE Tutorial Course, "Computer Relaying," IEEE Course Text, Publ. # 79-E40148-7-PWR, July 1979.

[2] IEEE Tutorial Course, "Microprocessor Relays and Protection Systems," IEEE Course Text, Publ. # 88EH0269-1-PWR, July 1987.

[3] IEEE Tutorial Course, "Advancements in Microprocessor based Protection and Communications," IEEE Course Text, Publ. # 97-TP120-0, 1997.

[4] G.D. Rockefeller, " Fault Protection with Digital Computer," IEEE Trans. Power App. Syst., Vol. PAS 88, pp 438-462, Apr. 1969.

[5] IEC Std. 61850, "Communication Networks and Systems in Substations," work in progress, International Electrotechnical commission, [On line], Available: www.iec.ch.

[6] M. Kezunović, B.A. Pickett, M.G. Adamiak, G.E. Alexander, K.R. Carr, G. Chirco, J. Esztergalyos, M. Jerosolimski, W.C. Kotheimer, R. Marttila, J.L. McElray, S.M. McKenna, P.G. McLaren, R.J. Murphy, J. Nordstrom, R. Ryan, V. Skendzic, S.I. Thompson, D.A. Tziouvaras F.M. Phillips, T. Sakaguchi, R.B. Sollero, "Digital Simulator Performance Requirements for Relay Testing," IEEE Transactions on Power Delivery, Vol. 13, No. 1, pp. 78-84, January 1998.

[7] Test Laboratories International, Inc. "Relay Assistant – Digital Simulator Software," [Online], Available: http://www.tli-inc.com.

[8] W. A. Lewis and L. S. Tippet, "Fundamental Basis for Distance Relaying on 3-Phase Systems," *AIEE Trans.*, Vol. 66, Feb. 1947, pp. 694-708.

[9] M. Kezunović, "A Survey of Neural Net Applications to Protective Relaying and Fault Analysis," *Engineering Intelligent Systems*, Vol. 5, No. 4, pp. 185-192, December 1997.

[10] A. Ferrero, S. Sangiovanni, E. Zappitelli, "A Fuzzy-Set Approach to Fault-Type Identification in Digital Relaying," IEEE Trans. On Power delivery, Vol. 10, No. 1, January 1995, pp169-175.

[11] S. Vasilic and M. Kezunovic, "An improved neural network algorithm for classifying the transmission line faults", IEEE PES Power Winter Meeting, New York, NY, Jan. 2002.

[12] M.M. Saha, B. Hillstrom, B. Kasztenny, E. Rosolowski, "A Fuzzy Logic Based Relay for Power Transformer Protection," ABB Review, January 1998, pp 41-48.

[13] M. Kezunovic, "Data Integration and Information Exchange for Enhanced Control and Protection of Power Systems," Hawaiian Intl. Conf. On System Sciences, Hawaii, January 2003.

[14] M. Kezunovic, T. Popovic, "Integration of Data and Ehchange of Information in Advanced LAN/WEB Based DFR Systems," Fault and Disturbance Analysis Conference, Atlanta, April 2002.

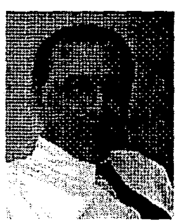
[15] IEEE Std. C37.111-1991, "IEEE Standard Common Format for Transient Data Exchange (COMTRADE) for Power Systems", IEEE Inc., 1991.

[16] IEEE Std. C37.111-1999, "IEEE Standard Common Format for Transient Data Exchange (COMTRADE) for Power Systems", IEEE Inc., 1999.

[17] IEC 60255-24, "Common format for transient data exchange (COMTRADE) for power systems", First Edition 2001-05, International Electrotechnical Commission, 2001.

[18] IEEE P1159.3/D8, "Draft: Recommended Practice for the Transfer of Power Quality Data," IEEE Standards Office, 2002

[19] "File Naming Convention for Time Sequence Data", Final Report of IEEE Power System Relaying Committee Working Group H8, 2001 Fault Disturbance Analysis Conference, Atlanta, Georgia; and the Spring 2001 Meeting of the IEEE Power System Relay Committee



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