Study Committee B5
Special Report for Preferential Subject 2

Life Cycle Management of Protection and Control Systems

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SUMMARY

This report reviews the contributions for the 42th Cigré Session related to Preferential Subject 2 of Study Committee B5 - Protection and Automation, on Life Cycle Management of Protection and Control Systems. Fifteen countries (Austria, Brazil, Canada, China, France, Germany, Japan, Malaysia, Romania, Slovenia, Spain, Switzerland, The Netherlands, UK and USA) have submitted seventeen papers covering a wide range of issues on asset and life cycle management of protection and control systems (PCS). For discussion the papers and associated questions are organized in five general topics common to Life Cycle Management.

KEYWORDS

Protection and Control Systems (PCS), Asset Management, Life Cycle Management, Protection Testing, Automation and Protection Refurbishment. Modernization, IEC 61850, Protection Data and Configuration Management, Protection Maintenance.

INTRODUCTION

Protection and control systems must be managed considering that they have a finite life cycle, like any other asset of modern power systems. Obsolescence or end of life of PCS devices may stem from different causes, ranging from physical deterioration or functional inadequacy up to market inability to provide sufficient spare parts for maintenance.

Asset management, as applied to PCS, comprises the set of technical and administrative actions taken to maximize return on investment and to exploit asset full capacity during the whole life cycle while minimizing cost and risk to power systems. Return can be measured in economic terms or other technical aspects like reliability, dependability, security etc.

The papers submitted to this session cover different aspects of the subject. For the purpose of discussion, they are organized in five key topics:

A) Testing methods for protection and control systems;
B) Impact of IEC 61850 on testing and asset management;
C) Lifetime management of protection and control systems;

D) Remote management of protection and control systems; and
E) Exploitation of protection and control systems.

Ten questions have been raised to motivate the discussion on these topics, after a brief summary of each paper.

A. TESTING METHODS FOR PROTECTION AND CONTROL SYSTEMS

Testing of protection and control systems aim to uncover hidden failures resulting from design and engineering, as well as software or hardware defects developed during transportation, mounting, commissioning and operation. Testing is also the recommended task for predictive or preventive maintenance, to develop confidence in their operation, and to diagnose causes of PCS failures.

Five countries have contributed with four papers related to this topic. The following is a summary of each paper and some questions that may be raised related to this issue.

Summaries

Paper B5-203, ***On Site Conjunctive Test of Feeder Protection,*** by A.H. Abu Bakar, from Malaysia, outlines a method to speed up functional testing of new feeders in liberalized electricity markets. Traditional methods of testing individual relays are compared to the simultaneous fault injection on several relays, powered by test sets with multiple current sources and a sequencer software to generate state transitions. The use of conjunctive tests is also emphasized for testing failures on existing relays.

Paper B5-204, ***Experience on Substation Automation Systems Field Test,*** by S. Gal, F. Balasiu, T. Fagarasan and G. Moraru, from Romania, reports the experience of the Romanian Transmission and System Operator in commissioning numerical protection and control systems. For line protection systems, field testing includes visual inspection and operation of all external connections and signals to and from the relay. Two testing devices with GPS synchronization are used to check teleprotection schemes and autoreclosing logic, while Comtrade records simulate power swings for out-of-step conditions.

Paper B5-214, ***Testing of Distance Protection Relays***, by A. Apostolov, B. Vandiver and D. Tholomier, from USA and Canada, overviews the spectrum of distance protection testing, from individual elements to complex functional schemes. Communication accelerated systems with multiple monitored signals require time coordination with analog signals simulating pre-fault load flow and post-fault currents, single and multi and evolving faults, synchronous and asynchronous power swings, mutual coupling and current compensation during sequential tripping, single pole trip and reclosing. To cover such a wide spectrum, the paper proposes a structured test approach based on the protection functional hierarchy, and a rule based expert system to improve the efficiency of the overall testing process.

Paper B5-215, ***Testing of Modern Bus Protection Systems***. by A. Apostolov and B. Bastigkeit , from USA and Austria, overviews the designs of two types of distributed bus bar protections, based on current balance on the bus, or on directional comparison detected by remote units. Testing of these systems require the sequential testing of merging and remote units, followed by the central unit. Several conditions need to be tested like stability for normal and fault conditions, time to operate, CT saturation, breaker failures, overloads, power swings and reclosing. IEC 61850 based systems require special measures to generate and monitor distributed GOOSE and SMV messages, and to synchronize distributed test sets to perform field commissioning and maintenance. GPS is suggested as the recommended method to synchronize distributed test sets.

Questions

2.1. Testing is the recommended preventive activity for uncovering hidden failures common to protection systems, but usually implies a temporary suspension of the protection function or an accidental trip. Sometimes it is necessary to de-energize the protected circuit to allow testing, or to use a portable substitute device to replace an IED. ***What strategies are in use or suggested by utilities, vendors and integrators to eliminate tests, or to reduce or avoid interruption of protection function, accidental tripping or planned outage of the protected circuit during testing?***

2.2. A trend of modern protection systems is the use of distributed functions. Functional testing of distributed PCS may require the sequential injection of signals that may depend on distributed information. The use of the station network is also an option to distribute test signals among IEDs, from a master test set, with the danger of impairing message traffic and throughput. ***How to coordinate a test case on a distributed PCS, with multiple dispersed test sets, guided by a master test set, avoiding undue outages?***

B. IMPACT OF IEC 61850 ON TESTING AND ASSET MANAGEMENT

The introduction of IEC 61850 standard has brought many new concepts to PCS design and devices. The asynchronous communication among distributed functions built from standardized interface modules opens new opportunities for functionalities, but poses new challenges to development, testing and management. New tools and techniques are needed to cope with the growing complexity of specifying, designing, deploying and maintaining distributed asynchronous PCS based on IEC 61850.

Five countries have contributed with four papers related to this topic, according to the summaries below, which raised the subsequent questions on this issue.

Summaries

Paper B5-201, ***Exploiting the IEC 61850 Potential for New Testing and Maintenance Strategies***, by W. Baass, T. Maeda, S. Gerspach, K.P. Brand, M. Herzig and A. Kreuzer, from Switzerland, summarizes the testing of systems based on IEC 61850, and their requirements for maintenance. The life cycle testing is divided in two parts: the first one, ranging from device type test, to integration and system test; the second one, from factory test, FAT (Factory Acceptance Test), site test and SAT (Site Acceptance Test). Maintenance test focuses on system fault analysis, periodic functional testing, repairs or replacement of IEDs and extensions. Utilities should use specific tools for periodic testing, diagnosing and system fault analysis, with access to one common SCD file for the complete system. Further investments in IEC 61850 and telecommunication knowledge are necessary from utilities, as well as in developing skills needed by maintenance staff.

Paper B5-206, ***Constraints and Solutions in Testing IEC 61850 Process Bus Protection and Control Systems***, by D. Mcginn, S. Hodder, B. Kasztenny and D. Ma, from Canada, reviews the main aspects of testing PCSs, including IEDs, wiring and interfaces, during commissioning, repair, maintenance, upgrade, expansion and component replacement. A process bus architecture is described using current switchyard interfaces that apply fiber optics to substitute massive copper wiring, in a point-to-point connection to each IED. During commissioning, substitute merging units are plugged in the control house, to be used by standard relay test set to exercise IED functions. Simplicity, safety, comprehensiveness and minimal training are listed as advantages of the process bus architecture and proposed test method.

Paper B5-209, ***Functional and interoperability Tests Using the IEC 61850 Standard Applied to Substations – Research and Development in Brazil***, by A.C. Pereira, I.P. de Siqueira, J.M. Ordacgi Filho, D. Caceres, M.E.C. Paulino and L. Biondi Neto, from Brazil and USA, describes an ongoing research project to develop a Test Lab to support teaching and testing of IEC 61850 based systems. A double optic ring Ethernet network will connect multiple vendor IEDs, HMI, GPS, NTP servers and relay test sets to perform functional, performance and interoperability tests, as well as fault simulation, test coverage and network loading. Software tools will transform text and graphic user requirements to SSD files. LAT (Lab-staging and Acceptance Test) is proposed between FAT and SAT to check the interoperability, functionality, performance and documentation of multi vendor designs before field deployment.

Paper B5-216, ***Reaching out Seamless and Cost-Effective Automation beyond IEC 61850***, by O. Huet, J.Ph. Tavella, T. Coste and J. Hughes, from USA and France, describes a UML formalization and extension under development by EDF R&D of parts of IEC 61850 standard. A static model is complete and made public while a behavior model is under development. Stereotypes and new classes are introduced to gather the static and meta-model views, as well as functional information, in a single representation. Dynamic models are defined for ACSI services using UML sequence diagrams. Future development will address the instantiation of objects from the UML model directly from an SCL file, the inverse generation of a PCS from UML, and the generation of test sequences to validate the design. The model will be submitted to IEC for further evolution of the standard.

Questions

2.3. The introduction of IEC 61850 opens the possibility to model a PCS as a network of logical nodes that can be simulated as software modules. Off-line and on-line models can be used for design, integration, relay setting, testing, fault analysis, maintenance, network loading and throughput analysis. ***For which purpose are software models and simulators used or suggested by utilities, vendors and integrators of protection and control systems?***

2.4. Point-to-point (hard fibered) connectivity among IEDs and merger units has been suggested to avoid active devices on the process network. For testing, the merger unit should be replaced by a test merger, by switching cables on a patch panel, in the absence of a test mode on the merger unit. The danger of switching cables must be weighed against the danger of active network switching during testing. The need of testing must also be decided considering the existence of online supervision of PCSs. ***What methods and architectures are in use or suggested to reduce the risk and to ease PCS testing, refurbishing and maintenance?***

C. LIFETIME MANAGEMENT OF PROTECTION AND CONTROL SYSTEMS

The heavy use of software on protection and control systems has made them susceptible to frequent changes, versioning and volatility from new developments. These features contrast with the trend of hardware standardization, relative stability, interchangeability and longer life cycle. Lifetime of PCS is now impacted by this mixed composition, affecting the methods used for life cycle management.

Three countries have contributed with three papers related to this topic, according to the summaries below, which raised the subsequent questions on this issue.

Summaries

Paper B5-202, ***Substation Automation Systems: Evolutions and Perspectives in Terms of Life Cycle Management for Digital SAS***, by L. Hossenlopp, D. Margraitte, R. Kubelek and I. Boullery, from France, discusses the main issues related to life cycle management of Substation Automation Systems (SAS), with emphasis on hardware and software obsolescence. IEC 61850 offers new and interesting perspectives regarding these issues. Human resources are cited as an essential aspect related to life cycle management, to assure their motivation in working with old products while absorbing new and changing technologies. RTE approach to life cycle management cover requirements concerning obsolescence, version management and hardware replacement in contracts for digital SASs.

Paper B5-211, ***Experience in the Refurbishment of the Secondary System in the Spanish Transmission Network***, by J. Muñoz, D. Garcia, J.C. Sanchez, G. Molina, J. Vesteiro and J. Corera, from Spain, reports on Iberdrola and REE experience in refurbishing the protection schemes of the Spanish transmission network. A standard design was used to reduce commissioning and maintenance time, cost and human resources, while keeping compatibility with existing philosophies. Standardized IEC 61850 compatible cabinets integrate protection, control, communication, ancillary services and auxiliary equipments. A SCADA system is used to supervise all new protection devices, acquiring and analyzing disturbance data. Results show a reduction in protection failures, device lifetime, misoperations and time to restoration after a fault, but also an increase in investment in stocks, training, system complexity, protection integration and resources dedicated to firmware/software upgrades and versioning.

Paper B5-217, ***Current Status and Future Trend of Operation and Maintenance of Protection Relay Systems in Japanese Utilities***, by A. Takeuchi, H. Kameda, M. Usui, K. Sekiguchi, C. Komatsu and F. Kumura, from Japan, reports a cooperative study of Japanese utilities and manufacturers about current practices of operation and maintenance of relay systems. Under a deregulated environment the replacement of protection has been prolonged, with digital relays tested at every six years, while previous relays were typically tested every two years. For restoration and fault analysis, emergency actions are taken by utilities which cooperate with manufacturers to carry further analysis, supported by a software tool developed by CRIEPI. The study suggests that some periodic tests could be abolished as most failures are detectable by automatic supervision and remote failure management. Replacement schedules are based either on age, failures, function enhancement or available stocks.

Questions

2.5. Life cycle of system devices may depend on their physical lifetime or functional obsolescence. For new equipment, a defined reserve stock is usually included on the procurement phase. For old equipments, cannibalistic replacement has been practiced by utilities to combat hardware obsolescence, by substituting an obsolete equipment to generate stock parts for similar pieces in operation. ***What criteria are in use or suggested, based on physical lifetime or functional obsolescence, for dimensioning spare parts for new and existing PCS devices?***

2.6. Maintenance interval of PCS differs among utilities, which base their choice mainly on experience, stocks, manufacturer recommendations, opportunity, similarity, empirics etc. Optimum interval depends on availability of adequate mathematical or statistical models of PCS degradation, and may differ among protection, control and refurbished devices. ***What practices, criteria and statistical models are used or suggested to predict the time related reliability of PCSs and their expected life time, and to define optimum test frequencies?***

D. REMOTE MANAGEMENT OF PROTECTION AND CONTROL SYSTEMS

Integration of telecommunication and PCS, with a rapid migration to digital technologies, pushed by a tendency to unattended stations, brings the need and opportunity to develop remote management systems to PCS. The possibilities range from simple remote supervision and fault analysis, to a complete SCADA system for management of settings and remote configuration of IEDs. Issues are raised related to PCS and power system security, as well as corporate information safety, brought by remote accessing and managing of PCS.

Five countries have contributed with three papers related to this topic, according to the summaries below, which raised the subsequent questions on this issue.

Summaries

Paper B5-205, ***Remote System and Change Management of Substation Automation Systems***, by F. Baldinger, T. Jansen, W. van Buijtenen, M. van Riet, F. Volberda and F. v. Er, from The Netherlands, describes the architecture and requirements of a remote system for managing PCS and its application at the Dutch utility NUON. The architecture includes current, voltage and breaker interface modules to an IEC 61850 based Central Control Unit using an Ethernet protocol on fiber optic cables. Measures are proposed to reduce the risk from software changes based in protection, examination, modularity and conformity to specifications. Data handling requirements cover completeness, integrity, confidentiality, continuity and protection against accidental changes. Software is subject to authentication, integrity check, traceability, installation consent, testing, backup and recovery mechanisms. Difference analysis is proposed as a tool to manage and supervise the whole process.

Paper B5-208, ***Evaluation of Protection System Performance Using DFR and Relay Comtrade Files***, by M.A.M. Rodrigues, J.C.C. Oliveira, A.L.L. Miranda, M.V.F. Figueiredo, R.B. Sollero, L.A.C.D. Castillo, F.D. Campos and N.F. Costa, from Brazil, presents the result of a joint work of CEPEL and utility LIGHT S.E.S.A, to develop an automated analysis system to evaluate operation of protective relays. The system uses simplified models of relays to compare their expected behavior to registered signals taken by DFRs. Comtrade waveforms from DFRs are classified and subjected to fault analysis, using signal processing and event diagnosis based on heuristic methods. Protection performance is determined based on coherency of measured state with expected states determined by an expert system, and a comparative analysis of the results against simulations of relay elements. A set of dynamic web pages helps browsing the repository contents.

Paper B5-213, ***Intelligent Power System Protection Data Management and its Practical Impact upon Protection and Automation Life Cycle Management Strategies***, by Z. Schreiner, J. Bizjak and A.J. Middleton, from UK, Slovenia and Germany, describes the ongoing development of an Intelligent Operative Maintenance Management system at Elektro Ljubljana in Slovenia. The system intends to manage operational data related to protection and automation systems. Simplification and standardization of protection testing is proposed using a methodology termed SOR to be supported by a Power System Test Library that is independent of relay and test set. Testing data is generated based on relay settings and transferred via appropriate interfaces to various testing software. The system manages protection data, settings, test templates, test results and fault disturbances necessary to test and asset management.

Questions

2.7. Online Data Base Management Systems (DBMS) of fault data and protection settings seems to be a solution for utilities to cope with the growing dimension and complexity of relay data. SCADA systems are being specialized to supervise the status, outages, operation, configuration, maintenance and versioning of PCS systems. ***What techniques, experiences and projects are there about the use of on-line DBMS and SCADA systems, using remote communication, to supervise PCS configuration, operation and fault data?***

2.8. Utilities, integrators, metering authorities, independent operators and maintenance contractors may have interest in accessing and changing PCS settings from remote locations, from intranet or extranet networks. Grid rules may have to be adapted to cover such cases. ***What techniques, practices, grid rules and planned projects***

are there about on-load testing and remote changes of PCS settings, software and firmware?

E. EXPLOITATION OF PROTECTION AND CONTROL SYSTEMS

Protection and control systems are designed to attend a large spectrum of applications. This range is growing as new equipment and transmission voltage levels are available to power system designers. As PCS evolve to multifunction IEDs, full exploitation of their capabilities depends on adequate human training and on settings to changing needs and specific configuration requirements, as well as the adoption of novel protective concepts in new schemes. Managing of relay settings is now a requirement of many companywide strategies for asset management.

Six countries have contributed with three papers related to this topic, according to the summaries below, which raised the subsequent questions on this issue.

Summaries

Paper B5-207, ***Key Technical Problems of Protective Relays Developed for 1000 kV UHV Transmission***, by Z. Xu, Q. Yang, S. Huang and T. Bi, from China, reports on the key aspects of protecting 1000kV, 600km UHV transmission lines under construction in China. Distributed capacitances and shunt reactors present resonant oscillations large enough to reduce sensitivity of differential current protection and enlarge the measuring error of distance relays. For differential protection, a method is proposed to refer the measured currents to a common reference point on the line. For distance protection, the Bergeron impedance inherently represents the distributed parameters, avoiding specific compensation. About 300,000 laboratory dynamic simulations show these techniques can satisfy the Chinese operation requirements for 1000kV UHV lines.

Paper B5-210, ***Simplicity Versus Complexity in Relation to the Reliability of Protection Schemes***, by A.I.J. Janssen, I. Karakoç, M.J.M. van Riet and F.J. Volberda, from The Netherlands, addresses the issue of increasing complexity of protection systems, and their impact on human errors, against a simplified standardized solution. The suggested scheme comprises a redundant telecommunication network with a single multi-function relay per bay. Breaker Failure Protection (BFP) is considered unnecessary for today’s reliable circuit-breakers technology. This competes with current trends of protection redundancy with double relays using different principles from different makes, backed-up by a BFP scheme. The proposal is supported by statistics taken from 2½ years operation of distance protection of 150 and 110kV lines.

Paper B5-212, ***K-factor and Mutual Coupling Correction on Asymmetrical Overhead Lines for Optimum Reliability of Distance Protection***, by U. Klapper, A. Apostolov, D. Tholomier and S. Richards, from Austria, USA, Canada and UK, raises the issue of the impact of a correct determination and use of K-factor, the ground impedance matching factor and mutual coupling on the performance and reliability of distance protection. Measurements made in four continents confirm an average error of 63% in the calculated value, with significant differences among phases and mutual coupling among asymmetrical overhead lines and power cables. Since there is no standard to define K-factor, different relay introduce different errors, resulting usually in overreaching or underreaching for different phases. It is suggested, in upcoming relays, to use individual impedance settings and K-factors for all possible fault loops, instead of a unique value.

Questions

2.9. Human intervention is shown as a major cause of protection failure or undue PCS operation. Design simplification has been proposed to reduce human intervention, and to make PCS more reliable. Current trends in PCS design points to multifunctional relays (with programmed logic, metering, fault recording, automatic supervision, testing functions etc.). ***How can human intervention be reduced considering the current trend to sophisticate the design of PCS?***

2.10. Many factors affect the measured value of transmission line parameters, compared to calculated values. Bergeron impedances, traveling waves and high frequency techniques are suggested concepts for new UHV line protections. Impedance measurements can be done off-line or on loaded lines, during maintenance, commissioning or staged and real faults, or possibly by the relay during commissioning. ***What experiences and techniques can be reported for on-load or off-load measuring of line parameters, mutual coupling and asymmetries, and their differences to calculated values?***

FINAL REMARKS

Software plays an increasing role on PCS as compared with hardware. Virtualization and distribution of IED functions is under course, while standardization of hardware is a possibility in the future. Traditional methods of lifecycle management are mainly oriented to hardware administration, lacking adequate tools to manage software assets.

To cope with these tendencies, new tools for managing software based PCS are needed. Capabilities to use software models, administration of changing user requirements, configuration databases, distributed real time applications, local and wide area networking, software versioning, remote access, automated testing and security issues are novel requirements not found in traditional asset management tools, current grid rules or on the protection engineer toolbox.