

INTEGRATING DATA AND SHARING INFORMATION FROM VARIOUS IEDs TO IMPROVE MONITORING, CONDITION-BASED DIAGNOSTIC, MAINTENANCE, ASSET MANAGEMENT AND OPERATION TASKS

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Introduction

As it is well known, different Intelligent Electronic Devices (IEDs) may be utilized for collecting field data in any given substation. If substation automation systems are installed, data integration using a substation PC is a relatively easy task. What are the benefits of utilizing the substation data for various purposes remains the subject of a discussion in the industry. Protection and EMS groups use the substation data for traditional applications such as analysis of fault clearing and SCADA functions respectively but the use of substation data for automated diagnostic, condition-based maintenance, asset management and operations is not widely understood and practiced. This paper is addressing the issues of data integration and information exchange as the means for getting multiple groups of utility staff and/or applications to use the same data.

To illustrate the above points, the discussion is centered on data being recorded by protective relays, digital fault recorders, and circuit breaker monitors. Besides the traditional uses of the data, some new applications are also defined. The paper concentrates on several new automated applications namely disturbance analysis [1], circuit breaker monitoring [2], substation topology monitoring [3], and system state estimation [4]. To implement the mentioned applications, data integration across several IEDs has to be performed. The benefit of implementing the mentioned applications is availability of diverse information that, even though obtained from the same data, can be utilized by different groups of utility staff such as maintenance, protection, asset managers, dispatchers and substation operators. Recent solutions developed by the author and his associate illustrates what kind of information is extracted and how the mentioned groups may use it [1]-[4].

The main goal of the paper is to bring to the attention of the diagnostic and maintenance groups the approaches of using filed-recorded data for their benefit while other groups of utility staff may also utilize the same data. This concept of integrating

data, processing it to obtain different information, and using the information by variety of groups of utility staff is presented as the main future strategy for making better utilization of IEDs while improving performance of various groups of utility staff [5]. This strategy may lead to better return on investment, reduction in operating cost, and improvement in overall customer satisfaction.

Background

Performance of any group of utility staff may be tied to two important criteria: automation and quality of information. For various historical reasons, neither the automation nor quality of data is at the desired level today. This can easily be confirmed by looking at every day activity of any of the utility groups. Most of the data analysis and extraction of information is performed through manual means.

For example, if one focuses on the maintenance activity, the information is primarily related to off-line records of previous maintenance activities, equipment inspection and repair actions, and nameplate ratings. The records are used to perform future maintenance planning, which again is a manual action based on data retrieval, analysis and decision-making performed by the responsible individuals. Hence, the automation is almost non-existent and most of the information is based on historical data created by the maintenance crews and not related to on-line monitoring of the actual field performance of the equipment. Today's opportunities in this area are quite different. Condition-based data can be made available and utilized together with the off-line data to improve the quality of information, and all of the data retrieval, analysis and decision-making can be performed automatically. Combined, the maintenance planning and execution can significantly be improved [6]. The time to make the decisions, the quality of decision-making, and the final outcome of the maintenance activity can significantly be better than before.

To contrast the existing practice, a scenario where the automation and better quality of information are used to enhance the overall process is briefly described. As an example, maintenance actions associated with circuit breakers are considered. One particular maintenance action, namely circuit breaker testing, is looked at in more detail. Traditionally, this action is carried out in long intervals, typically a year apart. The breaker is disconnected from the rest of the system and operated intentionally while the signals from the breaker control circuitry are recorded [7]. The analysis of the waveforms is performed on the spot making an assessment if more detailed breaker inspection and repair should be pursued [8]. The whole process of collecting and analyzing the data as well as extracting the information and making decisions is done manually and depends on the experience and skills of the individuals performing the

tasks. As a result, the assessment of the circuit breaker performance is very subjective and circumstantial, tied to the moment when the action is taken and to the experience of the individuals performing the task. On the contrary, the whole process can be automated and performed each time the breaker is operated either in the normal course of action such as operator initiated switching or as a consequence of the protective relaying initiated fault clearing. In this scenario all the data recording and analysis as well as information extraction and decision-making are automated, and performed each time the breaker is operated. It is obvious that such an approach does not depend on the lack of consistency among maintenance crews, and does not represent a circumstantial evidence. Since the process is automated, the consistency of analysis and decision-making is embedded in the automated process and the time intervals for making the assessment are reduced to every circuit breaker action. The proposed scenario offers some major improvements in:

- The quality of information considered
- The timing of making the assessment
- The means of obtaining better information

Quality of information. One simple notion widely present in the utility industry is that the quality of information is achieved through data integration. The more data, the better information has been an underlining motivation for a variety of development projects pursued to integrate various type of data including the data collected off-line and on-line. One difficulty with this process is that the improvement in the quality of information is not readily available through the integration alone, but requires rather elaborate processing of data aimed at correlating the data, eliminating redundant data, computing certain parameters, and utilizing the parameters for decision making. Unless this process is automated, the mentioned tasks become overwhelming and the whole purpose of integrating the data may appear meaningless.

To illustrate the point, Table 1 indicates how the quality of information may be improved in the case of circuit breaker monitoring. It should be noted that the information quality in this case is obtained by: a.) Getting additional data from different IEDs, b.) Establishing a clear temporal element in the data analysis, and c.) Taking advantage of the time-series analysis of the historical data.

Timing of information. Besides the quality, timing of obtaining the information is critical. Both absolute and relative time in power systems play an important role. In the maintenance tasks, the time is critical as well. First, in the absolute sense, it is important to know when the inspection and maintenance actions are done since the status of the equipment changes in time. In the relative sense, it is important to know when a given

Table 1

Factors affecting the quality of information

Multiple data sources	Temporal analysis	Historical assessment
CB monitors: control circuit signals, vibration, gas pressure	Sequence of control signal initiations and changes in circuit breaker status	Number of operations and assessment of the opening/closing times
Digital fault recorders: "A" and "B" contacts, phase current changes	Sequence and correlation of changes of the status contacts and CB currents	Consistency of "A" and "B" contacts and their reliability
Protective relays: duty cycle currents, $I^2 \cdot t$	Timing of CB operations and current interruptions	Assessment of the duty cycle over long time

peace of equipment is engaged in an action with the respect to its own life cycle. Knowing the time when the information is obtained can drastically impact the quality of decision-making.

Going back to the circuit breaker monitoring example, one can focus on two most important aspect of information timing, namely the one associated with assessment of the circuit breaker failure rate, and the one associated with the engagement of the circuit breaker in the reconfiguration of the power system. Obviously, a correlation should be made between the two analyses and the circuit breaker should be selected for operation only when the estimated probability of the failure rate is relatively low. Since the balance between the two assessments always carries a level of uncertainty if the breaker is going to operate correctly, a risk-optimized approach to the decision-making about the engagement of a given breaker needs to be considered.

Means of obtaining better information. A number of different means can be considered: a.) Correlating data, b.) Using redundant data, and c.) Understanding cumulative impacts. In general, there are many approaches to the mentioned tasks. Some examples for data correlation include correlation between analog and contact data. In power systems, many actions are initiated with commands that cause a change in contacts of the switching or control equipment, and as a consequence, analog quantities such as currents and/or voltages are affected. Knowing the exact sequence between the changes, one can use this fact to infer additional information from the correlated data. Redundant data is very common in power systems since many IEDs

collect the same field quantities. The use of redundant data is very useful when trying to verify the final status of a contact or the actual value of a measured analog signal. Utilizing redundant data is not a common practice today but can easily be implemented. Finally, understanding cumulative impacts is also very important. If the power apparatus were subjected to the stressful conditions a number of times, or if they were repaired very often can distinctively affect the “health” of the equipment and hence its remaining life and probability of failure.

Regarding the circuit breaker example, the importance of the mentioned means of obtaining better information can be explained further as given in Table 2.

Table 2

Means of obtaining better CB monitoring information

Data Correlation	Redundant Data	Cumulative impacts
Interpreting CB cause effect sequences	Multiple IEDs measure CB status and analogs	Counting number of CB operations
Making relationship between status changes and changes in analogs	Confirming CB status based on multiple indications of the status	Taking into account number or repairs and calculating failure rates

Data Integration Related to Assessment of the Circuit Breaker Status

Traditional assessment of the circuit breaker status is made based on the recordings from a given intelligent electronic device (IED) connected to the breaker. In most typical applications this IED is the remote terminal unit (RTU) of a supervisory control and data acquisition (SCADA) system. However, other IEDs such as digital fault recorders (DFRs), sequence of events recorders (SERs), digital protective relays (DPRs), and circuit breaker monitors (CBMs) may also be used for this purpose. In most of the applications, the information of interest is the open/close operating status of the breaker. In some special instances, currents flowing through the breaker, control mechanism signals, signals from various specialized monitors (pressure, vibration, “dirty” contacts), and timing of the autoreclosing and breaker failure logic are also of interest. The type of information and its use is driven by the specific staff group within utility being responsible for assessing various aspects of circuit breaker operation.

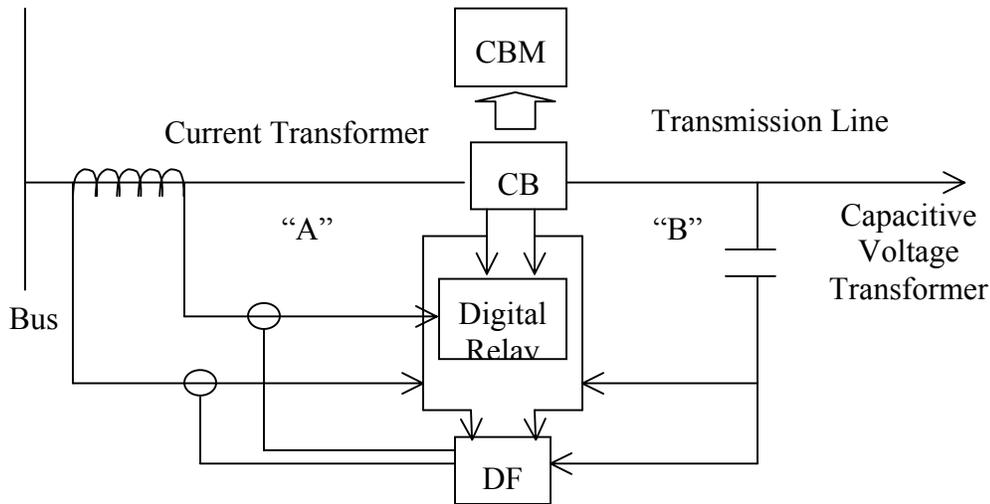


Figure 1
 Connection of DFR, DPR and CBM to a circuit breaker

Once the existence of the “wealth” of data and information related to the circuit breaker operating status are recognized, the question remains as what may be the benefits from integrating the data through some unconventional means. Figure 1 illustrates one situation where the circuit breaker may be connected to three different IEDs, namely digital fault recorder, digital protective relay and circuit breaker monitor. Types of signals being monitored in this case by each of the IEDs are described in Table 3.

Table 3

Description of the types of signals for DFRs, DPRs, and CBMs

Digital Fault Recorder	Digital Protective Relay	Circ. Breaker Monitor
“A” and “B” contacts	“A” and “B” contacts	“A” and “B” contacts
Phase currents	Phase currents	Phase currents
Relay trip signal	Relay trip signal	Trip and close initiate
Recloser timing signal	Recloser timing signal	Trip and close currents
Breaker failure initiate	Breaker failure initiate	“X” and “Y” coils
Comm. scheme signals	Comm. scheme signals	DC supply

From the diagnostic standpoint, each of the IEDs provides interesting information, in many cases based on the identical data. To better understand the reasons for wanting to integrate the data, the following points need to be discussed:

- Multiple measurements of the same signals
- Coverage of CB status
- Functional relevance of the recorded data

Multiple measurements of the same signals. Table 3 clearly indicates that all the three IEDs mentioned in this example measure several signals that are the same. For example, all three IEDs measure phase currents, “A” and “B” contacts and relay trip signal. This fact creates redundancy in the measurements that is always desirable since it can be used to verify the accuracy of the measurements. Many different signal processing and logic schemes may be employed to explore the benefits of the redundancy.

Coverage of CB status. While each of the mentioned IEDs is recording some of the same signals as the others, each of the IEDs also records some unique additional data. The example are the internal control signals recorded by CBM, transient behavior of phase current under variety of switching and fault clearing events recorded by DFR, and additional internal protective relay logic signals associated with the autoreclosing and breaker failure actions of the breaker captured by DPR. The additional signals provide additional “view” of the circuit breaker status, and combined provide much more information about the CB status than if they were looked at individually.

Functional relevance of the recorded data. While often neglected, it is very important to associate the recorded signals with the specific action that the breaker was engaged in. The reason is rather simple: a correlation between the function and recorded data can provide additional clues about the breaker status. This comes from the fact that manual and /or automatic control actions on the breaker are accompanied with some additional signals from the associated operators and/or controllers, so monitoring of the sequence of such signals gives expected final open/close positions of the breaker, and hence allow one to anticipate what should be the expected status.

Information Extraction and Exchange

This section further expands the concept of data integration by explaining how different groups of utility staff may use the integrated data. When the integrated data is made available, specific data processing may be deployed to extract information relevant to the interests of different groups. The main point is that such information will be more complete and comprehensive than the information otherwise made available to the

same groups through traditional means. To illustrate the point, first the traditional uses of data are discussed. This is done through Figure 2 where the traditional monitoring infrastructure designed for serving specific groups of utility staff is shown. As a contrast, Figure 3 shows a different solution where the data integration and information exchange is deployed, and as a result, a variety of different groups of utility staff can now be served through the same monitoring infrastructure. Table 4 gives a summary of the types of information that each of the staff groups can now receive, which was not available to them with the previous infrastructures shown in Figure 2. As a result of the proposed data integration and information exchange, the following benefits are possible:

- Understanding the historical trends
- Assessing the status on-line
- Having better planning tools for future CB use

Understanding the historical trends. Monitoring CB status over a period of time, and having such data for all the breakers in the system provides unique opportunity to extract historical trends. The trends can be associated with a given type of breaker, a given location (substation) in the system, or a selected time interval. This allows one to study impacts that a particular maintenance strategy, or a CB purchasing strategy may have on the overall reliability of CB operations. This information is very important when determining future strategies for CB maintenance and investments in future purchases. Such information may be of interest to many groups of utility staff such as asset managers, maintenance personnel, and even protection engineers.

Assessing the status on-line. Knowing the CB status at any point in time is crucial for both the automated and manual operation of the breakers. It is a well known fact that determining the status with high level of accuracy is not an easy task, and each given type of the IEDs may not be able to do it as reliably based just on the information collected by this IED. However, having redundant data about the status obtained through data integration assures a very high accuracy in determining the status. Once this information is available, the dispatchers in particular can have a much higher level of confidence in executing switching commands, in particular when some emergencies in the system are being experienced.

Having better planning tools for future CB use. Knowing the circuit breaker “health” at any given time allows planners to decide which circuit breakers should be involved in every day actions in configuring the system. The ability to compute the failure rate for each circuit breaker based on the cumulative knowledge about the condition of the breaker provides the information needed to make maintenance-optimized decisions

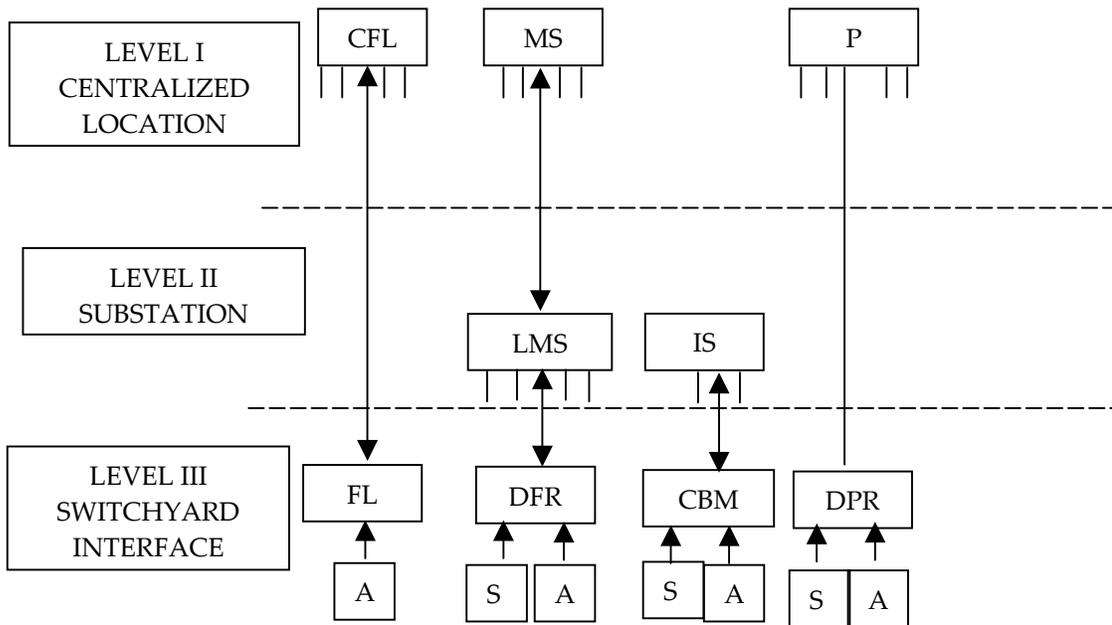


Figure 2
Traditional infrastructures and users

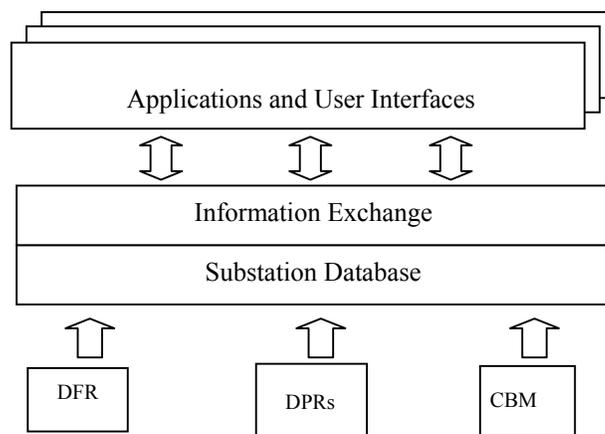


Figure 3
New infrastructures and users

Table 4

Type of information available to the utility groups

Asset managers	Maintenance	Dispatchers	Protection
Availability of CB	Repair scheduling	Real-time status	Operation timing
Cost of CB repair	Diagnostic tools	Breaker failure	Fault clearing
Risk of using CB	Failure rate	Switch. sequence	Switch. Sequence
Future purchases	Required parts	Autoreclosure	Autoreclosure
Impact on system reliability	Maint. strategy	Fault clearing	Restrikes

regarding the CB uses. With such decision-based approach to normal and emergency control involving breaker operations one can make the best choices regarding system operation, which is the main purpose of improved asset management planning.

Conclusions

This paper makes several important points about the possibilities to improve CB monitoring and diagnostic capabilities:

- Integration of data from different IEDs provides additional information related to CB
- Extraction of information and its sharing can significantly contribute to better assessment of CB capabilities by many groups of utility staff
- To better understand the breaker “health” one may utilize both historical and real-time information that is obtained through using the integrated data
- Allowing various utility staff groups to benefit from the data integration and information exchange allows better performance in the areas of asset management, diagnostics and maintenance, protection, and operator-initiated control.
- To achieve the desired data integration and information exchange, new standards and software tools need to be developed.
- Retrofitting existing solutions to achieve the mentioned goals is one of the major cost/performance requirements when pursuing future solutions of data integration and information exchange

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References

- [1] M. Kezunovic, T. Popovic, D.R. Sevcik, A. Chitambar, "Automated Fault Analysis Using Advanced Information Technology for Data Integration and Information Exchange," *2004 General CIGRE Session*, Paris, France, August 2004.
- [2] M. Kezunovic, Z. Ren, G. Latisko, D.R. Sevcik, J. Lucey, W. Cook, E. Koch, "Automated Monitoring and Analysis of Circuit Breaker Operation," *IEEE Transactions on Power Delivery*, Accepted for publication, 2004.
- [3] S. Jakovljević, M Kezunović, "Software for Enhanced Monitoring in Integrated Substations," *Power Tech 2003*, Bologna, Italy, June 2003.
- [4] S. Jakovljević, M. Kezunović, "Advanced Substation Data Collecting and Processing for State Estimation Enhancement," *IEEE PES Summer Meeting*, Chicago, July 2002.
- [5] EPRI Final Report, "Data Integration and Information Exchange: Impact On Future Substation And EMS Applications And Related Implementation Requirements," Palo Alto, January 2004
- [6] M. Kezunović, X. Xu, D. Wong, "Improving Circuit Breaker Maintenance Management Tasks by Applying Mobile Agent Software Technology," *IEEE/PES T&D 2002 Asia Pacific Conference*, Yokohama, Japan, October 2002.
- [7] "RTR-84 Circuit Breaker Response Recorder," Hathaway Systems Corporation, Belfast, Ireland.
- [8] L. T. Rumfield "Circuit Breaker Diagnostic Response Testing Using the RTR-84 Response Time Recorder," presented at the *Sixty-First Annual International Conference of Doble Clients*, June, 1994.