by Mladen Kezunovic, Convenor (US)

New Trends for Automated Fault and Disturbance Analysis

by CIGRE Working Group B5.20

The goal of the report published as Brochure 424 in August 2010 is to serve as a guide for the application of automated fault and disturbance analysis systems. The purpose is not to cover the design issues because it is understood that the technology may evolve making particular design solutions quickly outdated but to analyze the methods and tools used in fault and disturbance analysis, the developments in technology and how they can be implemented in automated analysis systems.

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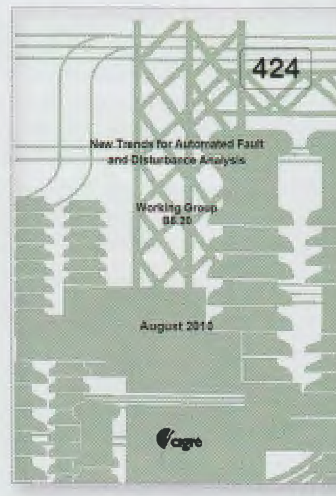

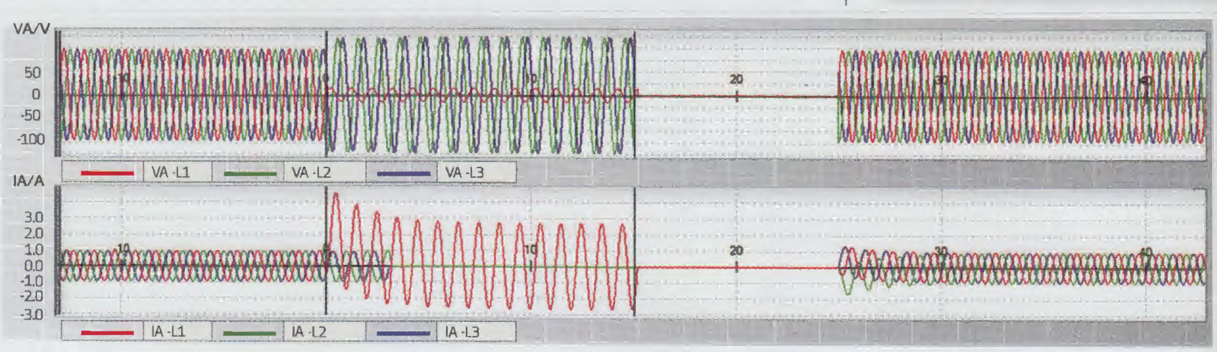

The analysis is aimed at understanding the causes of the events and the consequences related to power system operation.

THE COMPLEXITY OF POWER SYSTEM operation is increasing and automated analysis contributes to more reliable and faster assessment of disturbances and faults, which is critical for improving power system performance. The requirements of automated analysis systems should consider integration of data from many points in the power system and should call for standardization efforts to reduce the cost of future implementations.

An analysis is performed after detection of a possible fault or disturbance in the power system. The analysis objective depends on the user's interest, but in general is aimed at understanding the causes of the events of interest and consequences related to power system operation. This can improve practices through appropriate adjustments in the system operation or through identification of the equipment performance issues. The analysis of faults and disturbances is highly dependent on information that can be obtained from the power system recordings and models (Figure 1).

Automated fault and disturbance analysis is the ability of computers to correlate available data about faults and disturbances, yielding information that is more useful than raw data. The automated analysis is a step beyond automatic data gathering. Typically, data used for automated analysis comes from substation Intelligent Electronic Devices (IEDs) such as Digital Fault Recorders (DFR), Sequence of Event Recorders (SERs), Digital Protective Relays (DPRs), Phasor Measurement Units (PMUs), Power Quality Monitors (PQMs), etc. Data available from the field through Supervisory Control and Data Acquisition (SCADA) Systems, and Energy Management Systems (EMS) is also used. The system configuration (switch positions, line compensation etc.) and system design (current and power limits, transmission lines impedance values etc.) data, as well as data from Lightning Detection Networks or Satellite Images may also be used. A variety of IEEE and IEC standards are used to support gathering of such data.

This report builds on results reported by various CIGRE Working Groups such as B5.03 "*Fault and disturbance data analysis including intelligent systems*" and B5-09 "*Remote On-Line Management for Protection and Automation*" as a background for the basic data recording and analysis requirements.

Why automation?

As power systems' complexity increases under stressed power system operating conditions, the need for analysis of events increases as well. A variety of monitoring, recording and protection equipment may be used to facilitate the results. The complexity comes from ever increasing number of the measurement points of interest introduced by the monitoring equipment, as well as from the need to integrate such data.

Adoption of automated fault and disturbance analysis is driven by economic and regulatory needs for the following reasons:

- It improves system reliability due to better assessment of system performance
- It enhances staff productivity though reduction of analysis time
- It enables a fast and accurate determination of the fault cause due to automated means
- It helps more efficient handling of data through integration
- It facilitates developing a better knowledge of the system through collection of statistical data
- It meets regulatory requirements concerning capture and explanation of field-recorded data
- It increases the return on

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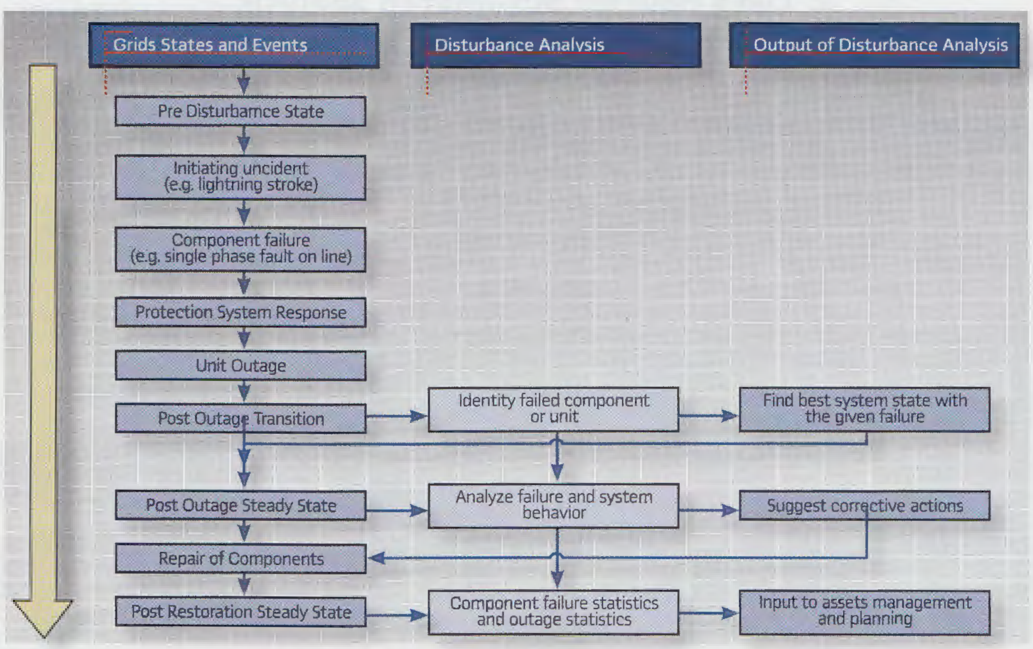
1 Timeline of power system disturbance & related analysis



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investment in recording equipment due to multiple uses of data

- It emphasizes a need for cooperation of different personnel groups for joint uses of the solution

Adoption of such systems comes with costs that must be evaluated against the many benefits (Figure 2).

Improving power system reliability: In general, reliability is the ability of a system to perform and maintain its functions in routine circumstances, as well as in hostile or unexpected circumstances. Also, reliability is defined as the ability of a system or component to perform its required functions under stated conditions for a specified period of time. Reliability in the context of power systems has a wide impact since it affects the reliability of all the processes that use electricity from the power grid. In terms of automated fault analysis, reliability can be improved by proper use of results obtained from the data available from various IEDs.

Fast and accurate detection and location of faults on power system components (transmission lines, power transformers) or control devices (protection relays and breakers) can reduce outage duration and in turn reduce power system vulnerability to other contingencies occurring while the outage remains. As an example, finding fault location on transmission lines quickly, based on specialized algorithms applied to IED data, can benefit system reliability by reducing time to find the faulty section on long lines.

As another example, data coming from various IEDs, including digital fault recorders, digital protective relays, power quality monitors and other with capability to produce oscillography recordings, can be used to improve substation state estimation. The system state estimator can be made more robust and accurate by improved capability to detect incorrect measurements or topology status information in substations. Detailed monitoring of the loading and switching conditions, that are not possible through today's SCADA solutions, can be obtained by using dedicated algorithms applied to IED data.

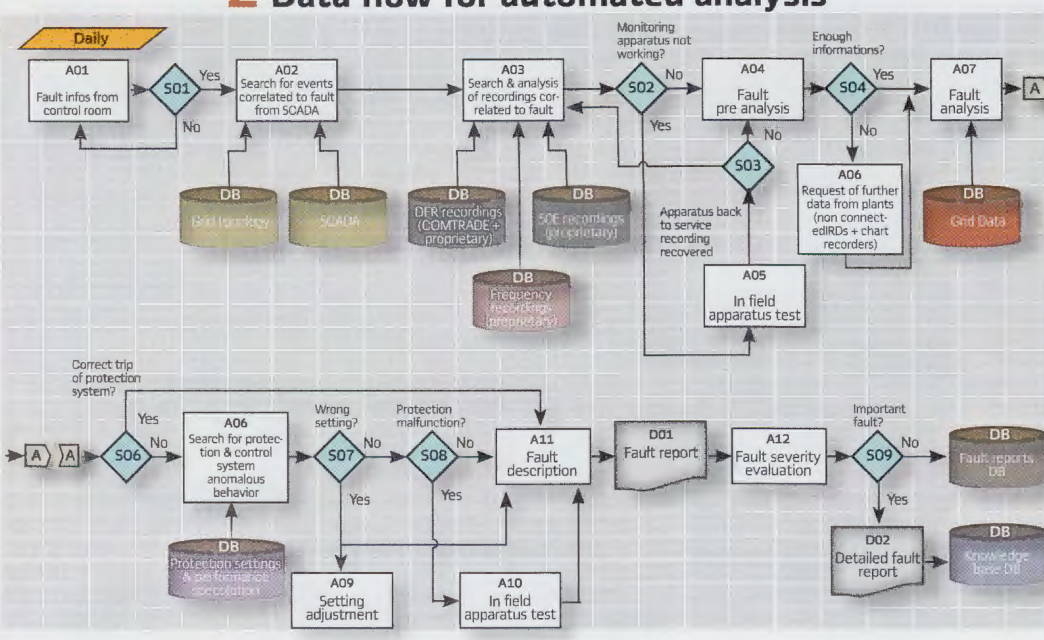
As the complexity of the power system grows, it gets increasingly

Consequences of not analyzing an event

involved to keep track manually of all malfunctions in protective relays, potential transformers (PTs), current transformers (CTs) and other devices in a fast and accurate manner. Such difficulty may create a situation where a major fault occurs at the same time when relay malfunctions (for example, due to defective transducers), and all of this occurs during peak load times leading to many serious consequences. Automatic checking of the health of the IEDs based on available data could pinpoint many device malfunctions before they coincide with a power system fault. During the first months after the commissioning of a controller, some problems like phase permutation, loose contacts in measurement channels and polarity inversion in PTs and CTs can also be detected by automated analysis systems.

System operators would, in the past, take all decisions based on SCADA data. Nowadays more elaborate conclusions are needed, and more complex EMS systems are being developed and implemented to meet such needs. The general idea is to take advantage not only of operational data collected through SCADA data but also of non-operational data from other IEDs. Synchrophasor measurements are a promising new technology that can yield valuable information if used, for example, in system state estimators. DFRs can generate information about distances to transmission line faults and, also, they can help in verifying the correctness of SCADA measurements. Quality monitors, if used online, can detect incipient

2 Data flow for automated analysis



quality problems evolving in some part of the grid, enabling operators to pinpoint the source and take proper actions before a line needs to be disconnected. Some of the equipment does not store and transmit data on a regular basis such as remote terminal units (RTUs) of SCADA and modern IEDs do, but in a great number of cases, they can generate data fast enough to make a difference in system operation. Integration of different sources of data is facilitated nowadays by a number of standards applied to each kind of data being dealt with and by the use of data sampling synchronization through Global Positioning System of Satellites (GPS) systems.

Enhancing personnel productivity: When fault and disturbance analysis is carried out, a large amount of information may have to be accessed to reach the final conclusions. This work involves not only a high degree of smart thinking, but also a lot of repetitive work, like retrieving files, converting file formats and making simple calculations. With the advances in the areas of monitoring, communications and computers, a large amount of data, which can be obtained in near real time, can be used to help accomplish this aim. The large size of many power grids added to the fact that the number of disturbances increases as the power system gets more and more stressed, creates an overwhelming situation for the personnel involved in such a job (Figure 3).

Although there are situations that only human expertise will understand, automated analysis can make a big difference when one consider dealing with processing a large amount of data to extract information. An important role of automated fault analysis is to help the personnel responsible for disturbance analysis in getting focused in the most important events by not spending excessive time in accessing relevant data and performing repetitive tasks. Other benefits are coming from receiving results, like fault location along transmission lines, automatically.

Another example is in automated power quality analysis. It demands the gathering and processing of a huge amount of data, identifying phenomena like voltage sags and swells, which is a repetitive and intensive data handling task. Automation greatly enhances the efficiency of this task.

The automation has economic impact, not only in the productivity of the involved personnel but also in better overall performance of the system. This is due to correct actions resulting from better and faster diagnostic of the fault and disturbance causes being done automatically, which are less prone to mistakes caused by human errors in performing repetitive tasks.

Providing faster response time: In general, adopting automated fault and disturbance analysis helps determining fault causes, location and characteristics faster and more accurately. This happens because most of the work of correlating information is done automatically. The automation is limited only by communication networks and computer speed, which are becoming less restrictive as the technology develops further. Also, automated fault and disturbance analysis systems can help in discovering an incipient equipment failure before it can lead to a fault.

This change in the time frame creates a competitive advantage that results in a direct benefit for the customer since automation reduces the power system interruption time. With the increasing dependability of our society on electrical energy, a fast recovery after a fault can change positively the public perception about the companies' responsibilities for power system operation, particularly at the time when we are witnessing an increasing number of large scale blackouts. During such events, attention to the utility response during emergencies is more intensive, and not using automated disturbance and fault analysis systems may make the company look less responsive to the public needs and concerns.

Nowadays more elaborate conclusions are needed and more complex EMS systems are being developed.

Enabling efficiency in handling data: In order to put an automatic disturbance and fault analysis system into operation, better organization of related data is needed. This in general may require a change in business process, as explained next.

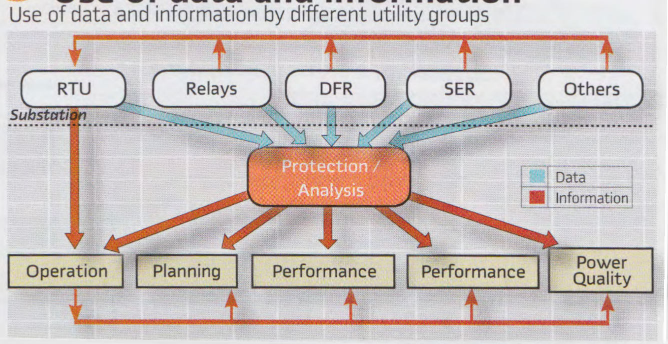
One of the characteristics of human beings is the capacity to perform their tasks using implicit knowledge, i.e., using some knowledge available to them but not explicitly stated in the data. As an example a file name may identify a set of data because it is known, by someone or by some persons, that such name relates to a specific source of data. Novice users of the same data would get lost unless they become aware of that knowledge!

When shifting to an automated analysis system, all the data has to be well organized; every file or database has to indicate clearly the origin and the characteristics of the data it contains. This knowledge is a key feature for data correlation and an imperative task if automated analysis systems are

Figure 3: When fault and disturbance analysis is carried out, a large amount of information may have to be accessed to reach the final conclusions faults.

3 Use of data and information

Use of data and information by different utility groups



to be used. This also facilitates retrieving data in an automated way substituting manual process used in the past such as retrieval of data from digital fault recorders. Other data that has to be put into explicit electronic format relates to the system configuration (switch positions, relay settings, amount of line compensation etc.) and system design (current and power limits, transmission lines impedance values etc.). Generally, when organizing this data, a lot of mistakes are corrected and the capacity for understanding faults increases.

A consequence of adopting automation systems for disturbance and fault analysis is the change in business process since the system operation tasks and cooperation among personnel in different areas gets better defined. For example, if fault location is automated, protection engineers can be relieved from the task of collecting DFR files and running fault distance algorithms in short time periods.

The most important result of the more efficient process is that taking the decisions automatically offers more timely and reliable actions while avoiding human errors.

Building better knowledge from statistics of historical data: A complete knowledge of power system operation includes defining, obtaining and keeping an up-to-date set of statistical data derived from historical data. Automated fault and disturbances analysis systems can obtain such data as a by-product.

An example is the statistics used for strategic or long term fault analysis, where data from each event is aggregated over time to draw a picture of system fragilities (like transmission lines sections more prone to faults) or equipment degradation (like I^2t calculations in circuit breakers). Such planning is needed to perform preventive maintenance, timely equipment replacement and plan for system expansion. Statistics are also important in power quality assessment. Statistics about the time and frequency of interruptions are used for calculation of reliability indices like SAIDI and SAIFI.

Also, statistics can be used in operation planning to keep system reliability at acceptable levels. For example, an area where ground fires are frequent in the dry periods may be detected by observing an elevated number of transmission line faults. Predicting a possibility of losing certain transmission lines based on past statistics may be helping improve planning for generation dispatch, power exchange among

The report ends with a set of conclusions and list of references.

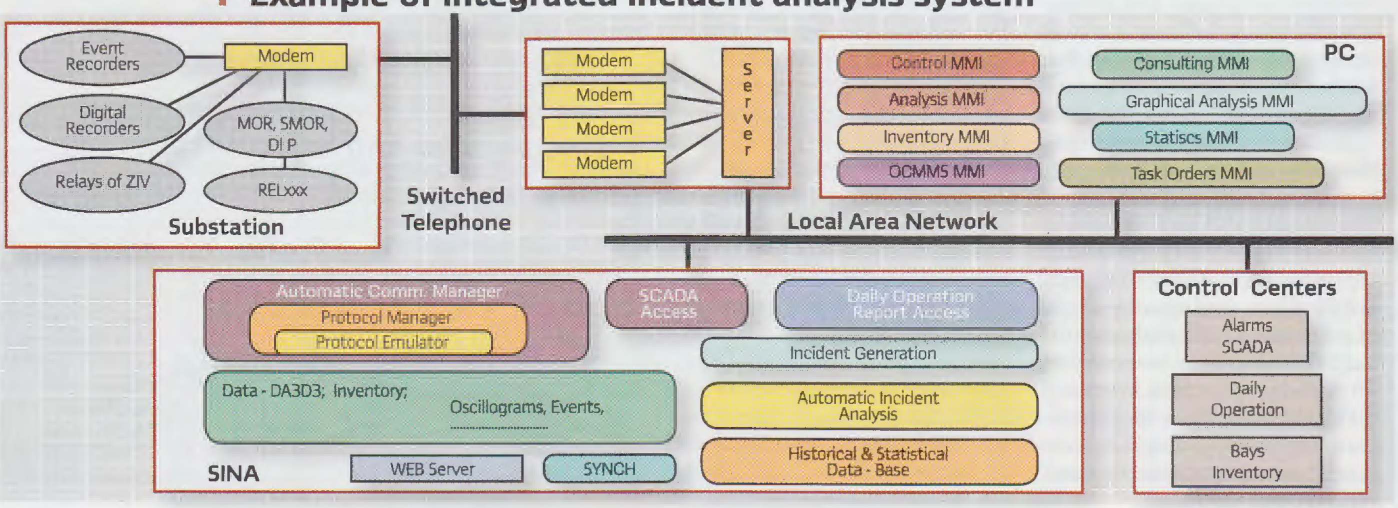
involved areas and equipment maintenance. In addition, equipment maintenance and replacement can be better planned if fault information is organized to reflect equipment stresses and aging.

Meeting regulatory requirements: Regulator demands for information from utilities are increasing. It is almost impossible to deliver all the requested information manually. Automated fault analysis can not only help in making data available, but it can also help in creating elaborated results while reducing the time of human involvement.

For example, some regulators ask for DFR files from utilities when major faults or disturbances occur. For larger utilities the number of files can be enormous, and some kind of smart filtering is needed before the files that should be sent can be identified. Smart filtering can separate recordings related to major faults from those generated by errors or events unrelated to faults.

Statistics about protection systems may also be required and used by regulators to access quality of the

4 Example of integrated incident analysis system



utility's design, operation and maintenance of protection system. Statistics like number of protection misoperations can be obtained by an automated relay operation analysis system if needed. Interchange of data among companies for cooperative tasks may also benefit from analysis automation. Use of automated fault analysis systems may be enforced by regulation in order to guarantee almost real-time availability of data to all interested parties.

Increasing return on investment: After examining the many advantages and opportunities that drive the adoption of automated disturbance and fault analysis systems, it is important to account for the investments needed. If the cost is too high, it may make it impossible to implement or if the desired functionalities may not be met, the expectations to proceed may not be fulfilled.

For example, when using DFRs for monitoring transmission lines the voltages and currents stored show the pre-fault and fault events. They are used mainly to determine fault location and understanding protection behavior during the fault. In this task, data from both line ends is necessary and, in the case of fault location, fast retrieval of data files is expected. The cost for integrating the devices can be summarized as:

- Old devices must be updated or replaced to enable network communication & GPS synchronization
- A fast and reliable network communication must exist between the substation and central office where the files are to be analyzed

The cost for fast retrieval of data can be very high if a company needs to implement a fast network linking its substations and central office just for this application. In this case, data files can be obtained using a dialed phone line connection. If fast determination of fault distance is imperative, sampling rate and length of the recordings must be kept low or local processing must be performed. If the sampling rates are low and files are short, other kinds of analysis will not be possible: harmonic components need a higher sampling rate to be analyzed while protection system behavior (like teleprotection and reclosing) cannot be observed if the recordings are too short. If local processing is performed, it means that a computer must be used for gathering DFR data and sending the fault distance calculated from only one terminal to a higher level. This makes the fault location calculation more prone to errors and does not enable more accurate analysis of fault location using files from two ends of the line.

The final solution will depend on analysis of the real needs against the available budget. The important thing to keep in mind is that even with the simplest approaches, some benefits become readily available.

The shift to automated analysis is not done at once. It follows a phased plan, in which the benefits achieved in each phase are evaluated to decide whether further investments are justified or not. Companies may judge how much automation is desired using different criteria. Phased implementations can benefit from:

- A technology becoming mature and device costs decreasing (*IEDs*)
- Need for replacement of control equipment due to aging (*replacement of old electromechanical relays*) creates new data recording enhancements for fault analysis
- New substation automation facilities being built with new data collection and transmission capabilities (*e.g. substations designed according to IEC 61850 standard*) or old ones being refurbished
- Regulatory needs driving equipment replacement and changing operation procedures may create new opportunities to pursue further fault analysis implementation
- Governmental or internal utility financial resources for modernization get allocated based on the demonstrated need for comprehensive fault analysis

The benefits must be carefully justified when proposing the adoption of an automated system.

Great attention must be taken when preparing the specifications of new devices because sometimes advanced features come at low or no cost in some devices but are difficult to be upgraded in others. A bad choice in the original data recording equipment specification can delay or even prevent automated fault analysis from being used, or future needs from being fulfilled.

As shifting from the traditional to an automated approach may generate savings that justify the investment, the benefits must be carefully justified.

Coordinating multiple utility personnel groups: The automated approach produces results that may be utilized by different utility groups. In the process of specifying the requirements, different groups need to find common means of agreeing on how the solutions are going to meet their individual goals. This results in a need to coordinate group activities and discussions. This interaction is quite useful for setting broader goals of how the investments and returns are viewed from a global company strategic standpoint.

This allows revisiting the business models for dealing with improvements in data utilization across the entire enterprise, a topic that may not be resolved unless different utility groups come together to a common point of view. Since this level of coordination is not a common practice today, one may say that the automation solutions are acting as an incentive for introducing new practice in the group coordination across the entire enterprise. ■

The report contains two appendices, one with definitions of terms usually referred to, and the other detailing three examples of the present use of data for fault analysis.