Data Integration and Information Exchange for Enhanced Control and Protection of Power Systems

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Abstract

One issue that did not get adequate attention regarding control and protection of power systems in the past is the data integration and information exchange. The traditional approaches assume that each function such as protection, control, monitoring, and maintenance are supported by a separate infrastructure of recording instruments and/or controllers for obtaining and processing data. With introduction of the new computer-based equipment for control and protection in the mid eighties, the integration of data and information exchange were possible, but not explored. This paper indicates what are the improvements and benefits that can be obtained by integrating the data and exchanging information among control and protection as well as system-wide monitoring and control functions.

1. Introduction

The traditional approach to data acquisition and processing for the control and protection assumes that the needs are served by independent instrumentation and controller infrastructures. Protective relays are connected directly to the switchyard via dedicated wiring typically terminated in the substation control house where the relays are installed. The Energy Management System (EMS), responsible for the overall power system control, is connected to the power system via a Supervisory Control and data Acquisition (SCADA) System . The SCADA system acquires and processes field data through Remote Terminal Units (RTUs) that are wired to the substation switchyard and located in the control house. In today's practice, the local substation relaying and control solutions are quite independent from the EMS and SCADA systems, and there is no data integration or information exchange across the respective equipment [1]. In addition, a variety of monitoring systems are installed at the substation level for the purpose of acquiring and processing substation field data. The monitoring equipment is quite independent from the data acquisition and processing infrastructure for system control and protection, and it is used to assess the performance of either the power apparatus or the local control and relaying devices. As a result, the substation field data is acquired and processed by a variety of different instruments/controllers and there is very limited data integration and information exchange implemented across the solutions [2].

This paper discusses the opportunities for providing the integration of data and exchange of information across the mentioned systems. The approaches for doing that range from the retrofitting solutions enabling "opening" of the legacy systems to the use of advanced substation automation solutions that are designed to support open communication architectures. The consequences of the data integration and information exchange are discussed as they related to the improvements in the relaying, substation control, EMS control, and system-wide equipment monitoring. The benefits are discussed from different utility prospective: planning, operation, engineering, and maintenance. The trends in the solutions for data integration and information exchange are presented bearing in mind new possibilities for coordinating the interaction between the control and protection functions in the future.

2. Existing recording instrumentation and controller infrastructure

In the substations, the recording equipment can be quite versatile [3]. This may depend on many factors including the history of the substation construction and upgrades, utility operating practices, strategic importance of the substation, etc. In any case, the following are different recording equipment types that are typically used in modern substations (see Figure 1):

- Digital protective relays (DPRs)
- Digital fault recorders (DFRs)
- Sequence of event recorders (SERs)
- Remote terminal units (RTUs) of a SCADA system
- Intelligent Electronic Devices (IEDs) used for variety of monitoring and control applications
- Fault locators (FLs) developed for stand alone high accuracy fault locating

Digital protective relays (DPRs). The modern DPRs today represent a complex recording and measurement instrument equipped with a decision making control logic and multitude of monitoring functions [4]. It is important to note that modern DPRs also have a variety of settings (both user selectable and internal) as well as a number of internally computed measurement and logic signals that may be accessed by the user. Due to a relatively low sampling rate of some of the earlier DPRs their waveform recording function provides only a limited frequency representation of the waveforms. This may impair the ability to perform a detailed waveform analysis based on the recordings.

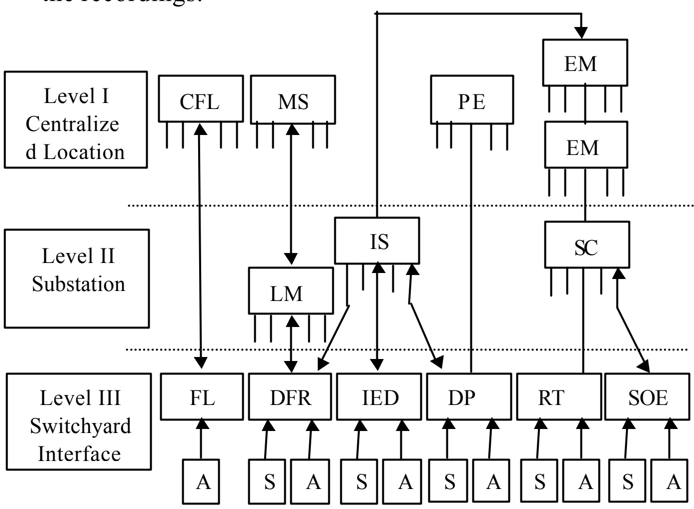

Figure 1. Existing Recording and Control Instrumentation Infrastructure

Digital fault recorders (DFRs). The modern DFRs are highly accurate recording instruments providing sampled waveform and contact data using relatively high sampling rate (typically above 5KHz) [5]. They provide recordings of the waveforms that were also "seen" by the DPRs. Various DFRs provide different triggering mechanisms, and the performance and sensitivity of the triggers may affect the ability to capture relevant waveforms. Some of the newer DFR designs allow the user to program a customized triggering mechanism. It should be noted that DFRs are generally pretty expensive when a unit cost per channel is considered. Due to a large number of input channels typically being required in a substation, an attempt may be made by the field personnel to connect only the crucial monitoring signals for the recording. In that case not all the channels of interest may be available (recorded). DFR data formats may be proprietary not allowing implementation of an "open" data recording system.

Sequence of Event Recorders (SERs). The modern SERs are complex recording instruments implemented today most likely using programmable logic controllers (PLCs) and analogue waveform data acquisition subsystems [6]. The SERs are capable of monitoring changes in the switching equipment status with high precision due to a high data sampling rate. Combined with measurements of analog signals, SERs can record the status change for variety of controllers including the ones that are based on analog set points. Most of SERs can also be set to provide control function through a number of control outputs. Majority of the utilities will have SERs possibly only in larger substations due to an excessive cost. The SERs also present a potential obstacle of not being designed as an "open" system, which in turn may reduce an ability to interface the data recorded by those systems with the data from other sources.

Remote terminal Units (RTUs) of a SCADA system. The modern RTU can be a very sophisticated recording instrument that may have a recording performance of a DFR, and at the same time may be producing a variety of pre-calculated quantities [7]. In addition, some advanced RTUs will provide an extensive SER and some limited DPR functions. Due to the fact that RTUs are a part of the Supervisory Control and Data Acquisition (SCADA) system, the data is readily available at the centralized location through a SCADA database. The "open" system design provision remains an issue with the RTUs as well since they are primarily designed to interface to the EMS SCADA data base using mostly customized communication protocols and database formats. Another potential problem is related to a limited opportunity for the user to access the recorded data locally before it is sent to a centralized location

Intelligent electronic devices (IEDs) used for variety of monitoring and control applications. The modern IEDs are available today for variety of applications ranging from simple stand-alone controllers and dedicated data recording systems to pretty complex integrated devices for monitoring, control and protection of the entire substation bay [7]. The issues with IEDs are the "open" communication architecture and data recording performance. Since the IEDs are not standardized even regarding the functions they perform, it may be very hard to find a standard interfacing approach provided for all the IEDs. Similarly, the recording performance between various IEDs may vary significantly. Not withstanding the limitations, the IEDs are indeed a good addition to the data-recording infrastructure needed for a comprehensive understanding of the substation equipment operation.

Fault locators (FLs) developed for stand-alone high accuracy fault locating. The modern stand alone FLs are designed to provide very accurate fault location, but for that purpose they may have to have a fairly advanced built-in data acquisition system [8]. Because of this, the cost of the stand alone FLs is almost prohibitively high, and only a few companies are using them extensively.

More typically, these instruments will be used occasionally and only on the most critical transmission lines. Further discouragement for the use of stand alone FLs comes from the fact that the fault location function is provided today almost free of charge on most DFRs, DPRs and even RTUs. Hence there may be very little motivation for the additional investment for possibly not too significant increase in the accuracy.

3. Differences in the recording performance

Possibly the least understood issue regarding the infrastructure given in Figure 1 is the recording performance of the various monitoring, control and protection equipment. As much as the basic recording function of all the equipment may be the same in that the same signals may be recorded, the type of the recorded data and performance of the recording function may be quite different. The following are some typical recording approaches that are found in different equipment, which in turn make the difference in the performance of the data recording function [3]:

- Synchronized data sampling vs. scanning
- Continuous recording (after triggering) vs. reporting by exception
- Local synchronizing of sampling vs. system-wide synchronizing
- Low precision (10 bit) vs. high precision (16 bit) A/D conversion
- Low sampling rate (16 s/c) vs. high sampling rate (64 s/c)
- Recording of pre-calculated values vs. recording of samples
- Pre-filtering of data (beyond just the antialiasing filtering needs) vs. only the antialiasing filtering

Table I, given at the end of this section, summarizes the recording properties of the typical substation equipment.

Synchronized data sampling vs. scanning. It is well known that some recording instruments perform synchronized data sampling on all the channels connected to the instrument. In this case a sample and hold (S/H) circuit is provided on each input channel, and all of them are strobe at the same time via a common sampling clock signal. The basic techniques for deriving and synchronizing the sampling clock may be implemented by using either an independent external clock or utilizing a phase lock loop tuned to the frequency of the analog signal being sampled. The signal samples obtained this way can be used to recover not only the basic properties of the signal, but also to establish a phase difference between the signals presented at different inputs. On the other hand, some instruments use the data scanning techniques where the samples are taken from each channel with one and the same S/H circuit. This is typically implemented using a multiplexer that switches the sample and hold circuit among various channels. The time of switching is calculated to accommodate the time required for A/D conversion so that each next channel sample is taken only after the previous channel sample has been converted. Using this technique the samples are taken at different time points on each of the channels hence prohibiting an easy way of establishing the actual phase difference among signals connected to various channels. DPRs, DFRs, FLs, some SERs and some IEDs typically perform synchronized data sampling, while RTUs, and some other types of SERs and IEDs would typically use data scanning techniques.

Continuous recording (after triggering) vs. reporting by exception. Some of the recording instruments are set up to perform continuous recording where a certain length of a data buffer is continuously upgraded with new samples while the old ones are discarded. This technique is called a “circular buffer” recording. After the instrument is triggered by an event or disturbance, the recording is continued beyond the circular buffer length, while the circular buffer data is preserved. The length of the recording may be as long as there is the memory available, and the recording appears to be “continuous” after tripping, beyond the “circular” buffer length. On the other hand, the recording may also be initiated by a command or a trigger asserted by an operator. In this case there may not be a pre-history available, and the history starts with the trigger initiation of the recording. Another similar approach is taken by setting a threshold for a measured value (RMS for example), and each time the threshold is exceeded, the value is recorded and reported. DFRs typically maintain several cycles of pre-fault data, while DPRs do the same but the length of the pre-fault data may vary depending on the fault detection technique implemented.

Local synchronizing of sampling vs. system-wide synchronizing. The data sampling techniques require a synchronizing clock signal to be available and its synchronization to be maintained over a period of time. The two typical implementation approaches are: local synchronization and system-wide synchronization. The local approach assumes that there is a local clock, which is fairly stable, and hopefully re-synchronized from a more accurate centralized clock. In some instances the re-synchronization is done manually, and the drifts in the local clock may be significant. On the other hand, the synchronization may be done using “continuous” synchronizing to a system-wide accurate clock. Such an example is the case of the use of the Global Positioning System (GPS) of satellites [9]. In this case each of the recording devices needs to be equipped with a GPS receiver, and synchronization accuracy achieved is within several microseconds. The type of sampling synchronization is directly tied to an attempt to establish either a phasor or data sample correlation at two adjacent substations or within a given substation between different recording instruments. It should be understood that the phasors or data samples may also be synchronized using software techniques, but the process may be more complex and may require additional processing time. Very few instruments in the use today provide GPS receiver for synchronization, but in the future this feature may become standard.

Low precision (10 bit) vs. high precision (16 bit) A/D conversion. This discussion is related to the recording of analog waveforms. The "vertical" A/D converter resolution vs. "horizontal" resolution is the issue, which affects accuracy of the signal measurement vs. signal representation respectively. The horizontal resolution is determined by the sampling rate and will be discussed in the next paragraph. The vertical resolution is associated with the dynamic range of the signal. The larger the dynamic range, the higher the need for a more precise A/D converter. For example, to capture the dynamic behavior of the current signal before and after the fault, the data conversion using a 16 bit A/D converter may very well be needed. On the other hand, the dynamic change in the voltage signal may be measured rather accurately using a 12 bit A/D converter due to a smaller dynamic range. If the analysis requires very accurate representation of a wide dynamic range of the signals, a high precision A/D converter may have to be used. It is worth mentioning that only the latest products for substation recording may be equipped with a 16 bit A/D (which is the desirable accuracy in most application cases), while most of the older products have either a 10 bit or 12 bit A/D converters. Another point to be understood is the signal scaling technique used in some recording devices to adjust signal dynamic range before the A/D conversion is applied. The scaling technique may have to be known in advance to be able to interpret the recorded waveforms and perform the analysis correctly.

Low sampling rate (16s/c) vs. high sampling rate (64 s/c). The issue of the sampling rate used in a recording instrument may be quite important for at least two reasons: the antialiasing filter selection and accuracy of signal representation. The antialiasing filter selection is associated with the requirements that the sampling rate be at least twice the highest frequency to be represented in the sampled signal. This requirement comes from the well-known sampling theorem, and is selected based on the application at hand. Since some of the recording instruments have other applications implemented on the same device as well (DPRs are a good example), it becomes very important to understand the constraints placed by the main application when an auxiliary application is being defined based on the data coming from the same instrument. The accuracy of signal representation is also dependent on the selection of the sampling rate. In general, the higher the sampling rate, the better the representation. As well known, the higher sampling rate may not contribute to a better measurement accuracy unless the selection of the A/D converter meets the dynamic range requirement. In addition, the antialiasing requirement may be satisfied with a lower sampling rate, but a better signal representation may be achieved by increasing the sampling rate. If one is observing given measurements that represent pre-calculated quantities, one should note that some of the calculated quantities may be optimized if a given sampling rate is selected (some techniques for phasor measurements, for example). In some other measurement approaches there is no clear guidance for the optimal selection of the sampling rate (measurements based on the differential equation solution). The selection of the sampling rate is a multifaceted issues and needs clear understanding when various applications are considered.

Recording of pre-calculated values vs. recording of samples. Specific applications may require that some values are already pre-calculated by the recording device using samples. This poses an interesting question as to what is available from a given device: samples, pre-calculated values, or both. The instruments that are designed to perform only the recording function (DFRs for example), would provide the samples. Dedicated instruments such as Power Quality (PQ) meters or RTUs may provide only pre-calculated values. The DPRs may be able to provide both. In some applications it may be important to understand the exact signal processing that has taken place in the recording device when the data was acquired. This information may not necessarily be available to the end user, and the application may have to be simplified if such information is not available.

Pre-filtering of data (beyond just the antialiasing filtering needs) vs. only the antialising filtering. This issue is important in understanding the signal processing undertaken by any recording device. If the details are known, the original input signals may be reconstructed more faithfully, and this in turn may lead to better and more appropriate uses of data. The pre-filtering process in some of the recording devices (DPRs in particular) may be quite involved and data difficult to reconstruct unless full design information for the data acquisition subsystem is provided. Typical example is the use of the different techniques for filtering of the DC offset and " undesirable" harmonics. Some of the DPRs have the filtering part separated from the part that reconstructs a measured quantity, while some DPRs have both function implemented in one and the same digital filter. Being able to distinguish the differences may be an important part of an application, but the level of detail in an application may be the driving factor for wanting (or not wanting) to know the design details of the recording equipment. The recording equipment that uses only the antialiasing filters of a simple design may be doing the least of pre-processing and hence reconstructing the signal may be the simplest.

Table I. Properties of substation recording equipment

Equipment	Sampling Synchron.	A/D res. (in bits)	Sampling Rate(kHz)	Signal Coverage
DFR	Synchron.	10-12	3- 5	Substation
DPR	Synchron.	12-16	1- 3	Line
SER	Synchron.	N/A	1- 3	Substation
FL	Synchron.	12-16	1-20	Line
RTU	Scanning	8-12	1- 3	Substation

4. Approaches to data integration and information exchange

The following approaches are possible today but need further investigation before a full justification for an implementation is defined:

- Integration of the Protective Relaying system
- Integrated Substation Automation (SA) Systems
- EMS Systems Integrated with SA Systems
- Total System Integration

Integration of the protective relaying system. The relaying system consists of individual relays that are mostly microprocessor-based today. For the sake of the discussion we will assume that the old electromechanical and solid-state relays are substituted with digital protective relays (DPRs), which makes the whole integration issue appear as the issue of linking different computers in a distributed processing application. The integration may be performed at the level the protected element (unit protection), the level of an individual substation and at the overall power system level. To better appreciate the amount and type of recorded data becoming available through the recording function of the relays, one should envision thousands and thousands of these devices being scattered around substations and feeders measuring almost all the analog and contact signals available. As mentioned earlier, the recording properties of the relays may vary from one solution to the other, so the data integration has to be properly implemented to account for inconsistencies related to the sampling rates, A/D conversion accuracy, and number of channels available per a given relay. The most important obstacle with today's solution is the lack of sampling synchronization among the relays. This can be easily overcome by providing unified front end for data acquisition with an over sampling technique utilized to obtain the data with high sampling frequency, and then using various decimation approaches to "reduce" the sampling rate to the levels desired for a particular relaying application. Providing a synchronization interface to the GPS receiver will enable relays to collect the data simultaneously allowing for far better information processing capabilities than what is available today. At the level of issuing command to circuit breakers and other switching equipment, each individual relay has that capability today regarding the equipment that it controls for the relaying purposes. By integrating all the relays in a system-wide solution, the traditional SCADA function may be easily implemented using relays as distributed RTUs.

Integrated Substation Automation (SA) Systems. The trend of integrating all digital substation devices for monitoring control and protection is very real today where several utilities are already pursuing this approach. To facilitate the process, a very elaborate standardization activity is under way to develop a world-wide standard for open system architecture for substation and system-wide applications [10]. The integration allows inter-operability of the equipment since equipment from different vendors may be interchangeably used at the substation level. As much as this approach provides a unique opportunity for data integration and information exchange at the substation level, it should be recognized that some important issues for practical use of such systems are not yet resolved. As examples, at least the following two issues need to be mentioned: front-end sampling and database organization. The front-end sampling has already been discussed in detail in the previous section where it was noted that signal recording capabilities of various monitoring, control and protection devices are quite different. This is still the case in the integrated substation systems since the standardization efforts do not include any provisions for a change in the recording performance. Similarly, the standard does not impose any of the requirements on the substation database design. While the integration of the equipment at the communication level is very important, it has to be recognized that data integration and information exchange do require certain consistency in the sampling front-end and database organization.

EMS Systems Integrated with SA Systems. This approach is quite feasible today but is not extensively pursued at the moment for several reasons. The main reason is the lack of substation automation systems readily available for the integration. The other reasons may include the lack of understanding of the benefits for such a design change as well as the reluctance to change the EMS system philosophy due to a very complex operator-training requirement that may result from such a move. The most important observation is that such an integration will bring several functions into one infrastructure, and yet it may not be quite clear how the functions would be coordinated and executed. The example is the coordination between protection and control. Presently, there is virtually no real-time coordination between the two. Protective relaying is now designed off-line through a planning study, and when implemented it executes in an autonomous mode. The control functions are mostly operator initiated and executed in an open-loop mode. The time response of protective relaying is in the millisecond range and all the relaying functions are executed automatically. The control functions are not as demanding in terms of the time response and are executed by the operators over several seconds, minutes or even hours.

Total System Integration. This approach is an idea for the future that has to wait for all the other approaches to be well understood and widely implemented. An architecture of such a solution is given in Figure 2. Several envisioned properties of such a solution are shown on the figure: availability of the GPC synchronization at each substation, capability of performing a local analysis and control, suitability of the mobile agent application system-wide analysis and control and, possibility of using of variety interfacing techniques for achieving better exchange of data via internet, intranet, wide-area networks, etc. The GPS synchronization together with a redesign of the front-end sampling system would bring the consistency in the substation database, which a crucial provision for an efficient extraction of information. The local processing for the analysis and control purposes will enable development of new monitoring, control and protection strategies that will capitalize on the new information exchange concept. The use of mobile agents will allow for the required flexibility in exchanging the information through an exchange of application programs. The use of the standard computer communication facilities is essential for the system-wide information exchange to be implemented using the integrated data.

5. Expected improvements and benefits

As a result of the various integration and information exchange approaches mentioned in the previous section, the following areas of improvements and benefits may be expected:

- Equipment monitoring and maintenance
- System-wide protective relaying
- Real-time EMS Control

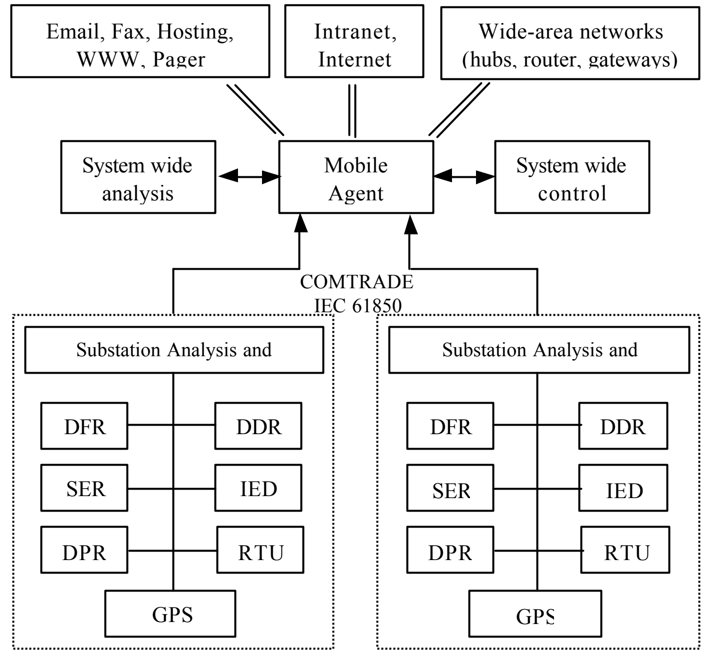

Figure 2. Future Instrumentation infrastructure

Equipment monitoring and maintenance. The benefit that has not been explored in the past is the integration of the substation recordings. The present practice relies on the use of a dedicated instrumentation infrastructure that is used by one technical group only [11]. Good examples are the recordings from digital relays and digital fault recorders that are almost exclusively used by the protection engineers, while the recordings from the transformer and circuits breaker monitoring IEDs are studied by the maintenance personal. Like wise, the supervisory control and data acquisition (SCADA) recordings are utilized by the EMS operators. Having all the substation recordings collected in one data base, most likely hierarchically distributed between substations and control centers, the advantage of redundant recordings can be explored to make the data verification and bad data rejection very efficient. Once the data accuracy, consistency, and validity are confirmed, the information extraction may be improved since many data correlation and historical trends may be utilized to gain better understanding of the behavior of analog signals and contacts. One good example for the mentioned benefits is the improvement in the fault analysis function. Having the recordings from DFRs, DPRs, SERs, and monitoring IEDs can bring a very close insight into the behavior of relays and circuit breakers, which goes well beyond what can be gained by looking at the data acquired just with one instrument. The new approach will allow determining exact inception of the fault, performing accurate fault classification and determining exact fault location by looking at the DFR data, learning a lot about the relay behavior during the tripping and restraining actions by looking at the DPR internal data, assessing the circuit breaker performance in detail looking at the SER and circuit breaker monitoring IED records, and gaining considerable insight into the interlocking and coordinating actions of the overall substation equipment by analyzing the integrated data. Once the data is integrated, and information is extracted, the information exchange may be performed in a new way to serve the diverse interests of different technical groups. The benefits in the new approach to information exchange are associated with the ability to provide more comprehensive data than what was available in the "old" set up. To follow the above example of the fault analysis, the protection, operations, maintenance and planning groups can get additional insight into details of fault occurrence, fault clearance, and circuit breaker performance. Table II summarize the major benefits for each of the mentioned groups coming from the data integration and information exchange related to the fault analysis.

System-wide protective relaying. As it was originally invented, and then used for a long time, protective relaying concept consists of a number of individual protective relays operating as distributed automata. They are coordinated through relay settings that are coordinated through a system-wide short circuit study. Once the settings are computed, they are entered into the relays, most likely by the technicians, and they remain fixed until there is a reason to perform a new short circuit study to compute new settings. The settings are not changed very often since the overall system conditions do not change too often. Such a relaying concept has performed rather well over the years for the cases of n-1 contingencies. The contingency condition translates to occurrence of a fault that will cause a simple change (switching) in the power system being protected without causing major changes in the system configuration and/or loading at any given time. This concept has not worked satisfactorily in the case when there are multiple fault events occurring in a relatively short period of time causing a cascade of switching operations that, as a result, have cause major change in the system topology, and hence in the system loading. To be able to cope with the system-wide disturbances (fault) causing cascade switching, a different protective relaying infrastructure and approach have to be used. The main approach in the past was to design customized infrastructures that will perform a specific system-wide relaying or switching action aimed at maintaining the system in tact. Those schemes are often called "special protection" or "remedial action" schemes (SPS or RAS) respectively. One typical such scheme is the one that protects the power system from loosing the voltage/frequency balance. In that case an SPS may be designed and implemented to perform high speed generation rejection and load shedding while possibly utilizing reactor switching and static voltage compensation simultaneously. The approach of designing customized solutions may not be the most economical approach since there may be a number of contingencies that will require specialized actions. Instead, the system-wide relaying may be done through the existing protective relaying infrastructure by providing high-speed communications among the relays in a substation, between the relays at adjacent substations and among various relays at scattered locations around the system. The approach may consist of a variety of approaches ranging from adaptive relaying [14] to the relaying that will act in concert with the overall system switching and islanding. As much as the specific solutions for system-wide relaying may still need further development and as such may be unknown, the expected benefits are rather clear: the system-wide relaying should be able to properly act in the case of cascading faults, where the existing relaying concept often fails.

Table II. Benefits from the new approach to fault analysis

Equipment	Benefits to fault analysis
DFR	Coverage of analogs and contacts for the entire substation. Fault location, fault classification, sequence of events, breaker and relay operation
DPR	Coverage of analogs and contacts for one transmission line. Fault location, fault classification, internal relay information, additional information about breaker operation
SER	Coverage of contacts for the entire substation. Detailed sequence of events. Only identification of faulted line, but neither fault location nor classification.
RTU	Coverage of analogs (only by exception) and contacts for the entire substation. Some idea about sequence of events but no information on neither fault location nor fault classification

Real-time EMS Control. The key feature of the new EMS architecture is to include substation automation systems into the EMS design. This assumes that there is an automated local processing function at the substation level that is coordinated with the centralized control executed at the EMS level. The data integration and information exchange may be implemented at both levels and real-time operation may also be executed automatically at both levels. As an example, in the case of a fault, the relaying will automatically disconnect faulted elements in a given substation, or multiple substations. In the new EMS solution, any restorative switching action may also automatically be performed, first by initiating switching actions automatically in the same or unrelated substations through the decision making that is local (substation) executed but centrally (EMS) coordinated. The real-time operation may also include automatic operation related to the maintenance required to achieve a full system restoration. The new EMS solution may be capable of determining the location and cause of the possible failure in fault clearing in real time so that either an automated switching remedial action may be initiated or an automated work order for the maintenance crew may be issued. In addition, the new EMS design will be capable of monitoring the system topology and loading much closer giving an opportunity to the dispatchers to act promptly and with much more knowledge about the system conditions than available through traditional SCADA systems. The data integration and information exchange at the substation level will be providing the necessary details that may then be communicated across the system (to the control center and/or neighboring substations) to allow for real-time coordination and automated execution of condition- or operator-initiated actions.

6. Conclusions

The following conclusions are most important as they lead to a new set of benefits:

- Different substation devices have different recording capabilities, which has to be clearly understood before data integration is performed
- By integrating the data from different IEDs it is possible to get much better "view" of both the substation and system conditions
- By processing the data at the substation level, the information exchange may be facilitated both at the substation and EMS level
- The foreseen benefits of data integration and information exchange are multiple but have to be explored in the future to get the specific solutions and control practices.

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