Distribution Substation Automation in Smart Grid

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Substation Automation (SA) can provide integral functions to the distribution grid automation. As more IED devices are installed to the distribution network, the need for IED management, control, and the corresponding advanced application operation is a growing imperative. Moreover, the Smart Grid applications, such as the Integrated Voltage and Var Control (IVVC), Fault Detection Isolation and Restoration (FDIR) in Distribution Automation (DA), and Advanced Metering Infrastructure (AMI), as well as the Demand Response (DR), offer increased operational functionality for distribution substation and feeders. To realize the full benefits of these new applications, a well designed substation automation architecture will provide scaled approach for adding new automation functions, take use of shared communication infrastructure for feeder automation and AMI, and offer provision for updates to the network model.

Traditionally, SA has been focused on automation functions such as monitoring, controlling, and collecting data inside the substation. This narrow scope allows for effective control of automatic devices located within the substation fence, but does not fully take advantage of automated feeder devices. With the arrival of the Smart Grid comes a new level of expectation for distribution automation. Substation Automation is expected to expand dramatically with increased control of relays, capacitor banks, and voltage regulators along the feeders. New applications are expected to incorporate distributed energy resources, AMI and DR functions. This paper discusses the approach to distribution SA incorporating DA, DR and AMI.

1. Overview of Conventional SA

Conventional SA systems are often viewed separately from the protection and control functions within a substation. Although it is deemed important, the SA infrastructure is often considered in isolation for automation purposes.

In North America the transmission substations have often been automated by the installation of Remote Terminal Units (RTU's), connected to a central EMS /SCADA system, with hard wired I/O in the substation and very little automation applications running in the substation to make it more autonomous during adverse conditions. Distribution substations were rarely connected to a central SCADA system, and were not important enough in the scheme of things to be automated. Even utilities that have done Feeder Automation (FA) as part of their DA system have often neglected to automate the distribution substations. Some utilities have started in the past few years to collect data from protection relays where numerical relays were installed and brought that to the central SCADA for visualization and remote control. In the rest of the world, specifically the IEC world, fully integrated SA systems with several smart applications for increased intelligence in the substations have been developed.

In addition, until very recently, the security based on the User Name and Password in SA and other automation systems has been viewed as quite sufficient. Even the different levels of access that can be achieved with this level of protection have not been fully utilized with sharing of log-in information between engineers, technicians and other network operation people in the order of the day. That situation has changed very drastically in the last couple of years with the NERC-CIP dictating amore rigorous review of security requirements and implementation of a proper physical and Cyber security system for critical assets in the electrical infrastructure.

IN THIS NEW ARCHITECTURE THE SA SYSTEM CAN BE SEEN AS A DECENTRALIZED NERVE CENTER

2. Current SA functions in Smart Grid

Upon further evaluation of effective global smart grid architecture, it is clear that the substation should play an expanded role in the 'smartness' of the grid than in the past. The substation has always been important to the operation of the grid, the SA system now can play the same type of role in the intelligence and become the nerve center of the Smart Grid. For this to happen, standards are urgently required, the looseness that was there in the market in the past with utilities drafting their own standards loosely based on regional (IEEE) or global (IEC) standards has to stop in order to embrace the true benefits. A larger acceptance of global standards will also allow the manufacturers of automation equipment the ability to concentrate on the real issues in providing equipment (IED's, Networking equipment, Software applications) and solutions that will enhance the reliability and improve the efficiency of the electrical network. Adoption of standardization in communication protocol and systems e.g. IEC 61850 will be able to focus the R&D money to find advantages in areas of intelligence of the networks to provide a true Smart Grid. The three main groups of components to achieve this goal are:

1) Smart IED's for sensing, measuring and control of network parameters and equipment
2) Interoperable communications networks to tie the different pieces together
3) Software applications at various levels of the network including the Substation system that can manage the other pieces of the automation system

In this new architecture the SA system can be seen as a decentralized nerve center, enabling the network to be more efficient and more reliable locally while still connected to a higher level of intelligence with a wider perspective, e.g. SCDA/EMS/DMS systems. By keeping the local decision on these aspects local, with substation and feeder automation equipment working in concert, the higher level systems and the communication infrastructure connecting them are freed up to make the higher level determinations for optimization to achieve the eventual goals of improving the network operation, reduce the losses and the impacts that energy transmission and distribution have on the environment.

The SA functions can introduce considerable benefits to the utilities as follows:

Operational

Interoperability, distributed intelligence, integrated communications and systems for greater efficiency and reliability of the equipment, network and energy supply.

Financial

Reduced losses have direct financial benefits. Each KWH that does not have to be generated or transmitted directly reduces the cost of supply. Utilizing the networks more efficiently allow a longer life of equipment and an increased throughput of useful energy, allowing the utility to delay network upgrades. Using the intelligence in the network applications and automation the systems in the substation peak loads can be manipulated and reduced. This reduction has direct benefits for reduced purchase of the more expensive peaking power from less efficient power plants, thereby reducing the utilities cost of operations.

Non-Financial

Non-Financial benefits of the improved substation and feeder automation systems are:

- Reduction of Green House Gas Emissions
- Improved customer satisfaction through higher reliability and reduced outages.
- More efficient utilization of scarce highly skilled resources
- Coordinated training courses and material to increase the pool of resources available to the industry.

3. Applications of DA, DR and AMI in SA

In the extended SA systems, some of the advanced applications in DA, DR and AMI can be incorporated/implemented for enhanced operation performance and capability.

3.1 DA Applications – IVVC, FDIR

Refer to Appendix 1. The net result is that directional relaying is only required where the DG is large enough to trip the devices on an adjacent feeder for faults on that feeder. Tripping devices on the same feeder has no impact on reliability.

DA is not only a key module in distribution grid operation but also a hub connecting other important modules and applications in Smart Grid, such as the Demand Response Management System (DRMS), Advanced Metering Infrastructure (AMI) and Outage Management System (OMS). In general, a DA system comprises of various advanced applications, such as Topology Processor (TP), Distribution Power Flow (DPF), Fault Detection, Isolation and Restoration (FDIR), Integrated Voltage/Var Control (IVVC), Optimal Feeder Reconfiguration (OFR), Distribution Contingency Analysis (DCA), Distribution State Estimation (DSE), Distribution Load Forecasting and Estimation (DLF/DLE), etc. Among them, FDIR and IVVC are the key applications in real time operation and, therefore, are considered as the typical DA applications in the distributed approach while being incorporated into the SA solution.

IVVC is designed for improved distribution system operation efficiency, offering the following basic objectives:

1) Reducing feeder network losses by controlling the feeder capacitor banks' on/off status

2) Maintaining healthy voltage profile in normal operation condition

3) Reducing peak load through feeder voltage regulation by controlling the transformer tap positions in substations and voltage regulators in feeder sections.

IVVC optimally coordinates the controls of capacitor banks, voltage regulators and transformer tap positions installed at the feeder circuits and substations. Because the Var output of a capacitor bank is tightly coupled with the voltage in nature, a control action on a capacitor bank for adjusted Var output or on a voltage regulator for a different voltage level can result in significant impacts to each other. Advanced optimization algorithms are necessary for coordinated controls in IVVC for optimal benefits to both healthy voltage profile and feeder efficiency.

On the other hand, FDIR is designed to improve the distribution system reliability by detecting faults occurred at feeder sections based on the remote measurements from the feeder RTUs (i.e., FTUs), quickly isolating the fault by opening the adjacent switches and then restoring the service for the healthy sections affected by the fault. It can reduce the service restoration time from several hours down to 30 seconds or less, considerably improving the distribution system reliability and service quality in terms of the distribution reliability indices of CAIDI, SAIFI SAIDI, etc.

In addition to FDIR and IVVC, the topology processing function of TP plays an important role in supporting the two key applications in real time operation. TP is a background processor that traces the distribution network to track the topology connectivity for internal data processing for the applications and display colorization. TP can also provide service for intelligent alarm processing to suppress unnecessary alarms associated to topology changes.

Another key application in DA is DPF, which is the core function of almost every DA application, especially for FDIR and IVVC. It is designed to solve the three phase unbalanced load flow for either meshed and radial operation scenarios of the distribution network for evaluation or analytic purposes.

Conventionally, SA is defined as the automation system inside the substation fence, completely isolated from the DA functions. In Smart Grid, however, the conventional SA system can be effectively expanded to incorporating DA functions by including the feeder automation functions in the region served by the substation. This expands the service territory of the conventional SA to the area of the feeder circuits in its service territory, effectively combining the SA with the FA functions in a distributed manner.

3.2 DR - Aggregation and Disaggregation

Demand Response is relatively a new function in Smart Grid. It is designed to directly manage the individual customer loads with two-way communication. The potentially dispatchable portion of the individual loads can be aggregated to participate in the system wide economic dispatch for reduced peak demand and minimum energy cost. On the other hand, the dispatched amount of load management can be distributed to the individual loads through disaggregation. The processes of aggregation and disaggregation require an effective coordination with the DA system for optimal grid operation subject to the constraints on voltage and loading limits. The similar process is needed in the recovery stage while returning to the normal operations for the individual customers. The DA functions in SA can also be designed to play the role properly, similar to the centralized DMS system.

AMI DATA FROM THE INDIVIDUAL CUSTOMERS CAN ALSO BE USED TO ENHANCE THE DISTRIBUTION SYSTEM OPERATION AND MANAGEMENT

3.3 AMI – End of Line Measurements

AMI system is receiving more and more attention in the context of the Smart Grid. In addition to the conventional roles in accounting and customer billing, the AMI data from the individual customers can also be used to enhance the distribution system operation and management, including the historical load profiles for more accurate load forecasting and estimation, as well as the real time information at the end points of feeders to feed DA functions.

5. Approaches to Incorporating DA, DR, AMI in SA

Conventionally, the service territory of a SA is limited to inside the substation fence. While extending the automation scope to include the feeders served by the substation, the service scope of SA is expanded to the distribution feeder circuits. Because the feeders may have open ties to other feeders that are served by other substations, the DA system in a substation has to have the capability to support interoperability with the neighboring substations, becoming the real challenge to the distributed DA systems in SA.

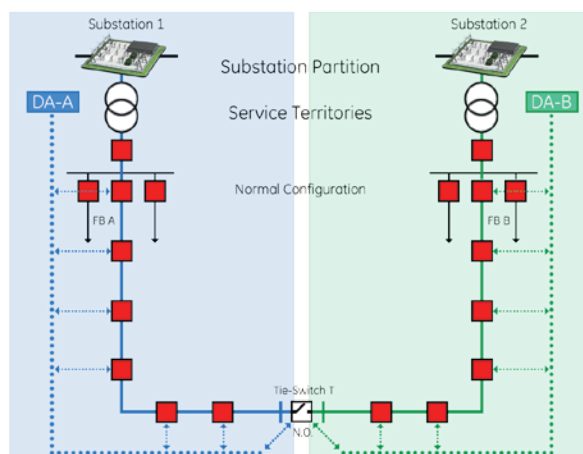

Figure 1.

As described previously, the integration of DA, DR and AMI through data and information exchange can effectively enhance the operation performance of the distribution systems. This advantage can apply to the distributed DA systems too. However, a distributed DA system in a SA can only cover the pre-configured feeders for the substation, a small part of the entire distribution network. The entire distribution network may involve many distributed DA systems in SAs, each covering one or more substations (a logical or virtual substation). In order to implement the automation for a partial or the entire distribution system with the distributed DA systems, an advanced self-coordinating mechanism is required for the individual DA systems to work properly in a well coordinated way through peer-to-peer communications, as schematically shown in Figure 1.

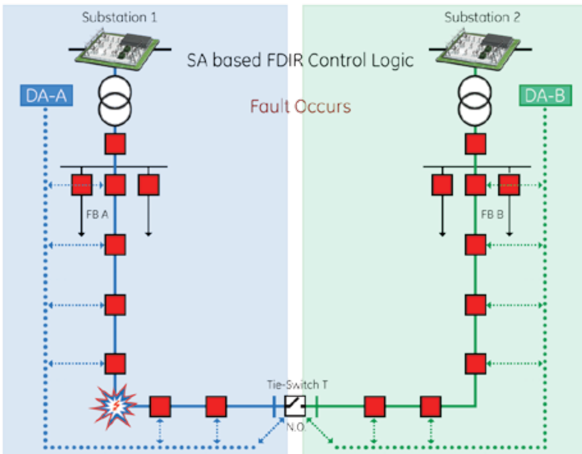

Figure 2a.

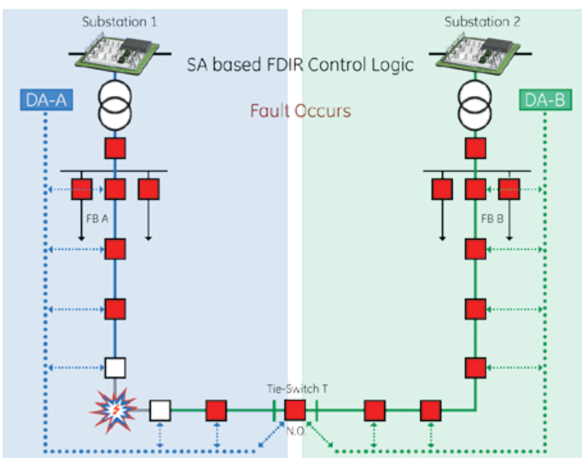

Figure 2b.

The service area of a distributed DA system can include one or more substations. Each area is a part of the connected distribution network that connects to the neighboring areas through the normal open tie-switches. The node at each end of the tie-switch belongs to the area it resides, setting up the boundary of the area. The DA function in each area is fully responsible for the operation of the area. Both parties will exchange or share the boundary information. Figure 2 and Figure 3 illustrate the typical coordination between two areas for FDIR and IVVC operations.

It can be seen from Figure 2 that when a fault is detected by the DA system in Substation A, the FDIR logic isolates the faulted section, restores the service of the upstream sections immediately, then calculates the total load of the downstream sections and checks the loading and voltage limits to figure out the minimum capacity and voltage requirements for substation B to pick up. If substation B is not capable to pick up the load for restoration, alternative approaches will be evaluated, including using multiple sources, transferring loads from one feeder to another in substation B to make more spare capacity, or executing partial restoration to restore service to as much load as possible.

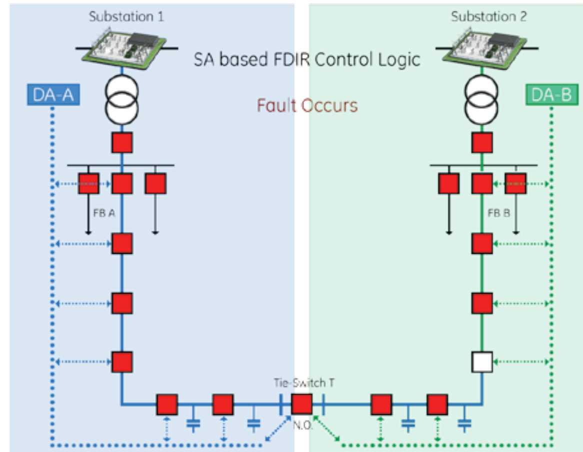

Figure 3.

Figure 3 demonstrates the logic of IVVC operation with the distributed DA system. When a part of the feeder circuit in Substation B is supplied by Substation A through the tie-switch, the IVVC logic of the DA can deal with the case through data exchange between the two substations.

6. Summary

Conventionally, SA has been focused on automation functions such as monitoring, controlling, and collecting data inside the substation. This is a narrow scope to allow for effective control of automatic devices located within the substation fence, but cannot well take advantage of automated feeder devices. In Smart Grid, the SA system in distribution substations can be extended to include the automated feeder devices distribution circuits supplied by the substation. The SA functions in distribution substations can include the key DA functions, such as IVVC and FDIR and can incorporate the AMI and DR data for further enhanced operation performance. An overall review of the conventional SA functions is presented and the extended SA functions in distribution substations are discussed with DA, AMI and DR functions incorporated in Smart Grid operation.

7. Reference

[1] Jiyuan Fan, Xiaoling Zhang, "Feeder Automation within the Scope of Substation", Proceedings of Power Systems Conference and Exposition, 2006 PSCE '06. 2006 IEEE PES, Atlanta, GA, ISBN: 1-4244-0177-1', pp 607 - 612