



The Substation of the Future: A Feasibility Study

Final Project Report

Power Systems Engineering Research Center

*Empowering Minds to Engineer
the Future Electric Energy System*



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Executive Summary

Digital technologies for data acquisition, automation, and control have been continuously evolving for the last three decades. We propose a revolutionary utilization and integration of existing technologies, including incremental improvements and innovations, for the design of the substation of the future. The proposed approach is based on the concept of equipping each component (i.e., potential transformers, current transformers, breakers, etc.) with a universal GPS-synchronized meter that transmits data to a set of redundant substation computers. The data are processed locally and then transmitted to the control center where it becomes available to all shareholders. This report describes the overall scheme and provides performance metrics for this approach. The report illustrates that it is possible to design the proposed system with existing technology or slightly modified present day technologies.

Section 1 of the report provides a background and an assessment of present day technologies for substation automation and their interfacing to the control center and the enterprise. While the practice varies from utility to utility (i.e., some utilities have invested in automation more than others), this section tries to capture the most advanced practices today. Advanced practices include using numerical relays to perform the functions of SCADA and integrated communications between substations and control centers as well as enterprise communications. This section also discusses the proposed approach for a more integrated and automated acquisition of data and processing as an extension of the present technologies.

Section 2 describes the proposed data acquisition and processing at the substation using the next generation of merging units. Specifically the scheme involves placing merging units at each instrument transformer, providing GPS synchronization and collecting data independently but GPS synchronized with minimal latency. Since communications are confined within the substation for this part, overall time latencies can be easily remain below one millisecond. The use of standardized protocols is discussed. In particular, the IEC 61850 standard is used as the preferred standard for communications and data processing. It is also proposed that at each substation two types of data should reside at two different data buses. First, a process bus that processes time waveform data at the sampling rates of the various merging units. The system supports different data rates as the various merging units may have different rates. Second, a substation bus which accommodates compressed data, such as phasors, magnitudes, power, etc. This data are derived from the data on the process bus and they are computed at much slower rates. The process bus data and the substation bus data can accommodate all foreseen functions in a substation. These functions may include protection, power quality analysis, SCADA functions, state estimation at the substation level, fault disturbance analysis, among other functions.

Section 3 provides a feasibility study of processing the data for validation and calibration. The main tool for this study is a substation level state estimator. The state estimator has been developed under previous projects and is simply utilized in this project. Because of the presence of GPS synchronized measurements, the results of the substation level state estimation are globally valid (i.e. they can be used by any other substation). For example the estimated operational states from each substation are sent to

the control center where the state of the overall system is synthesized by simply combining the estimated states of all substations. This process negates the need for a central state estimator. The end result is that the data are validated, the bad data are rejected, the state of the substation is defined and the accuracy of the states is quantified. The procedures described in this section of the report can be performed at very high rates. For example, the processing of all data in a substation can be performed in less than 20 milliseconds for typical substation sizes. This will allow the validation and filtering of the data at rates more than 30 times per second. An important advantage of this approach is that it is fully scalable. The response times are the same independent of system size because the bulk of the data processing is performed at the substation level.

Section 4 provides an application of the validated data: protection functions. With this application, the protection function is based on all substation data. Thus, the protection algorithm can determine the appropriate protection action with greater dependability and reliability. This section of the report described a feasibility study of the speed by which the protection functions can be achieved using the entire substation state. No appreciable delays are anticipated as compared to the present approach of using dedicated relays trying to determine the protection action using only limited information. As a result, the protection functions can be improved with the proposed approach from reliability and security points of view.

Section 5 describes how the proposed approach can be used to provide power quality analysis for the entire substation. The system that performs power quality analysis uses the data available at the process bus. Since this data can be corrected and validated with the state estimation methods provided in section 3, the power quality analysis based on this data is more reliable than simply using raw data collected with intelligent electronic devices (IEDs). The process can also include disturbance play back by appropriately storing the retrieving process bus data.

Section 6 provides the performance of the proposed approach for wide area monitoring. Wide area monitoring systems are required for a variety of applications such as system protection, visibility of the system, stability and analysis of the system. We describe how the wide area monitoring system of the future can be structured. Since the proposed approach provides the validated substation state at each substation with minimal time latencies, the proposed wide area monitoring system is based on sending the substation state to the central controller. This approach minimizes data rates without loss of information. In addition, the information is validated and its accuracy is quantified. These attributes should be compared with present approaches in which raw data (which may have errors) is used. The data can be fed into various applications for wide area monitoring and control at rates appropriate for the application. By minimizing the amount of data to be transmitted, the time latencies are also minimized.

Section 7 describes the impact on control center operations. First the impact on the state estimator requirements at the control center is beneficial. A two level state estimator at the control center is described and the data flow is analyzed. The overall impact on data base organization and execution times is favorable.

Section 8 describes the impact on company enterprise needs. The distributed communication system coupled with the availability of filtered and validated data results

in the minimum communication traffic since only information is transmitted versus raw data. The quality of the information is superior to present approaches. Databases can be better organized and utilized. Overall, the company enterprise benefits from the filtered and validated data. Response times to request can be faster than traditional systems.

Section 9 provides a discussion on cyber security issues. Again by communicating information only, cyber security approaches can be facilitated.

Summary and Future Research Issues:

The proposed structure of the substation of the future will benefit all aspects of system operation. While present practice in substation design may not be close to the vision presented in this report, it certainly moves towards this direction. Many manufacturers developed and offer merging units with characteristics that will enable the approaches described in this report. It is also apparent that these technologies have the potential of reducing the cost of substation automation while they provide better applications. We are confident that these technologies will continue to evolve and our vision of the substation of the future will materialize in some form. For example this research project has identified certain desirable characteristics of merging units that will enable the functions described in this report. An immediate research project will be to design and develop prototypes of the next generation of merging units.

As discussed in the report, present utility practice indicates that substation technologies include old designs to the latest in substation automation. There is a plethora of substations that represent old-aging infrastructure. The critical and challenging problem is maintenance and upgrading of these facilities as well as managing the planning and execution of aging asset replacement. There are many challenging issues associated with compliance to various standards such as required clearances, commissioning tests, etc. These issues were not addressed in this report and constitute a natural extension of this research project. Since the design of the substation of the future includes a 3-D model of the substation, it can be used to compute any desirable attribute of the substation at any stage of an upgrading plan, such as clearances, transients and insulation coordination.. Demonstration of this capability would be a worthwhile research project since it could lead to a product that can be used in any substation upgrading project.