Design and Implementation Of Wide Area Special Protection Schemes

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Abstract - Power system protection brings to mind schemes designed to isolate faults in a given piece of equipment or line, either in the immediate area and/or in areas adjacent to the faulty system component. The size and complexity of the power grid, however, makes the electrical system vulnerable and subject to collapse under situations such as congestion, over/under frequency, over/under voltage, system load adjustment, power swings, etc.

To detect and take preventive/protective actions for these conditions, a class of protection schemes known as Special Protection Systems (SPS), also referred to as Remedial Action Schemes (RAS), are developed to address system wide operating conditions. A Special Protection System is typically different in concept and implementation from a conventional protection scheme/system in that the schemes are generally intended to provide a safety net for the electrical grid during unplanned contingency conditions or when system or operating constraints could not allow meeting the power demand.

Implementation of such schemes involve many factors including:

- Comprehensive knowledge of the wide area system to which the scheme will be applied
- Well-developed system planning criteria defining:
  - The intent - including whether thermal or stability limits apply
  - The undesired yet possible contingency conditions
  - The real-time monitoring parameters and arming conditions
  - The overall system performance criteria and the throughput timing based on system studies
- Detailed design and implementation for operation and restoration
- Reliable telecommunication system
- A well prepared set of operating and maintenance manuals along with visual aid tools
- Levels and types of redundancy
- Detailed test plans for scheduled system wide testing

This paper will discuss the drivers for implementing SPSs, the functional requirements of such systems including the interface and coordination with existing protection and control equipment, and the resulting design considerations such as system architecture, Human Machine Interface (HMI), communication system robustness, performance monitoring, and system test (including commissioning, manual, and automatic test modes).

1. Introduction

Blackout prevention / mitigation and power system security are the order of the day. Managing congestion, balancing load and on-line generation, maintaining spinning reserve capacity margins, and managing reactive power support through reliable real-time data are some of the key elements of successful power system operation.

Recent newsworthy wide-area electrical disturbances have raised many questions about the causes and cures for such occurrences and have demonstrated the vulnerability of the interconnected power system when operated outside its intended design limits. The exposure of the power system to wide area collapse has increased in recent years as the system has been pushed to its operating limits - often resulting in violation of NERC operating policies and planning standards [2][3].

One of the U.S. Department of Energy (DOE) and the Canadian Natural Resources (NRCAN)'s top priorities are modernizing North America's electricity infrastructure. This effort focuses, amongst others, on the application of technology to enhance the reliability and efficiency of the entire energy delivery system.

Electric reliability and efficiency are affected by four segments of the electricity value chain: generation, transmission, distribution, and end-use. Satisfactory system performance requires investments in all these segments of the system. Increasing supply without improving transmission and distribution infrastructure, for example, may actually lead to more serious reliability issues.

The Transmission Reliability Program is developing advanced technologies, including information technologies, software programs, and reliability/ analysis tools, to support grid reliability and efficient markets during this critical transition.

The National Transmission Grid Study [1] has made it clear that without dramatic improvements and upgrades over the next decade our nation's transmission system will fall short of the reliability standards our economy requires, and will result in higher costs to consumers.

The Transmission program's mission specifically is to develop technologies and policy options that will contribute to maintaining and enhancing the reliability of the nation's electric power delivery system during the transition to competitive power markets.

There are often many issues to address reliable system operation, however, the primary issue is typically the heavily loaded transmission system (with subsequent high reactive power losses/requirements). This overloading is often at the root of system instability problems. The understanding of this issue is not lost on legislators and regulatory bodies who have expressed their concerns about potential blackout scenarios. Reactive power flow analysis, including mitigation of voltage instability, should become an integral part of planning and operating studies and have been mandated in the recent NERC recommendations for prevention and mitigation of future NE blackout scenarios [2]

It should be noted that the issues faced, in many cases, are not easily overcome. Transmission owners are faced with challenges when placement of new generation is justified by factors such as market forces, permit availability, sighting opportunities, and strict environmental constraints as opposed to system studies. Under these scenarios, load centers often end up connected far from generation resources and through heavily loaded weak transmission systems. Subsequently, deregulation and the high cost of building new transmission infrastructures have placed the transmission owners under increasing pressure to maximize asset utilization. Transmission operators note that they have credible contingency situations that can result in voltage collapse or system instability challenges imposed by insufficient levels of reactive compensation. The potential risk of voltage instability, especially during contingent conditions has been evident without the continued dynamic reactive support.

2. Solution Space

As mentioned above, one of the issues to address is lack of reactive power sources. The North American Electric Reliability Council (NERC) Planning Standard specifies that:

> "Proper control of reactive power supply and provision of adequate reactive power supply reserve on the transmission system are required to maintain stability limits and reliable system performance. Entities should plan for coordinated use of voltage control equipment to maintain transmission voltages at reactive power margin at sufficient levels to ensure system stability with operating range of electrical equipment." [4]

Dynamic VAR support is often needed to maintain the desired operating voltage levels and mitigate voltage instability from unscheduled generation and transmission contingencies during high load conditions. As such, one piece of the solution space is addition of Var sources on the system. Some of the reactive compensation alternative includ

- Static VAR Compensator (SVC)
- Synchronous condensers
- Unified power flow monitoring and control
- Flexible AC Transmission Systems (FACTS)
- Switched shunt capacitors

In addition to reactive compensation, power flow regulation devices such as series capacitors, Thyristor Controlled Series Capacitors (TCSC), and DC lines can be installed on a system. In the total stability solution space, these technologies may be required, however, they tend to have long lead times and are capital intensive.

Advancements in the real time monitoring of power system parameters and availability of secure high-speed telecommunication networks now provide opportunities for implementing wide area protection and control schemes generically known as Special Protection Schemes. NERC defines SPS as:

> " — an automatic protection system (also known as a Remedial Action Scheme - RAS) designed to detect abnormal or predetermined system conditions, and take corrective actions other than and/or in addition to the isolation of faulted components to maintain system reliability. Such action may include changes in demand, generation (MW and Mvar), or system configuration to maintain system stability, acceptable voltage, or power flows.

3. SPS Design Process

In this paper, the SPS design process is broken down into five steps, namely:

1. System Study
2. Solution Development
3. Design and Implementation
4. Commissioning / Periodic Testing
5. Training & Documentation

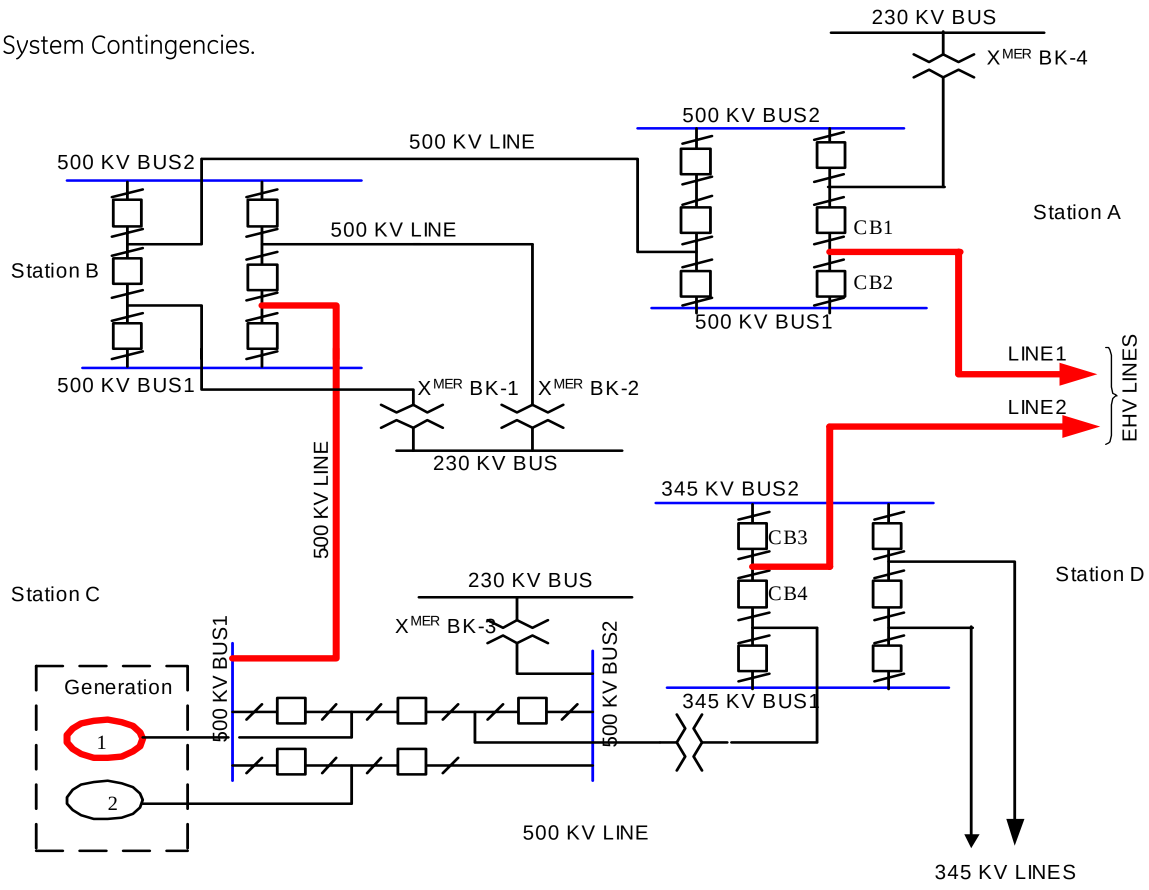
Items to be considered in each of these steps are described in the sections below.

3.1. System Study

In order to design a wide area monitoring and prevention scheme, accurate system studies need to be completed to identify the ensemble of contingency scenarios and to define the parameters required for proper implementation. Some of the critical items include:

- Understanding the requirements and the intent of the application – (different requirements result in different solutions)
- Types of studies to be performed – Planning and Operating studies, followed by on-going system studies including protection coordination studies
- Evaluating multiple solutions – Studying alternatives and performing contingency analysis
- On-going dialog with all entities involved – Internal and external (Regional).
- Identifying monitoring locations and set points – overload conditions, undervoltage, underfrequency, phasor measurement

Fig. 1.
One Set of Identified System Contingencies.



- Arming conditions and levels – Determining whether the scheme arming should be power system condition based or outage/contingency based
- Contingency identification
- Identify islanding points if applicable
- Voltage or phase angle stability
- System restoration process; Cold Load Pickup considerations [9].
- Wide area monitoring and intelligent dispatch
- Reliability and dependability levels – Redundancy, Voting, Fail safe, etc.

System studies identify limitations or restrictions. The limitations may be thermal, voltage, or angular instability related limits wherein the latter items are of significantly more concern than thermal capacity limits. It should be noted, however, that relaxing non-thermal limits in a cost-effective fashion can be very challenging in a deregulated environment.

3.2. Solution Development

Once the system studies are completed, the solution space must be analyzed and specific recommendations must be made. Figure 1 shows an example area that might have been modeled in a system study. The **Highlighted** items depict outages and/or overloads on particular pieces of equipment. Of note in this example is the fact that a generator outage in one area of the system coupled with the outage of one line in the "western" portion (near stations B and C) of the system and an overload on two other lines in the "eastern" portion (near stations A and B) of the system will create a potential voltage collapse or generation/load imbalance scenario.

Given the defined contingencies, a method of conveying the actions for a given contingency is required. One technique is to migrate the monitored quantities and subsequent state transitions in a flowchart. Figure 2 illustrates such a flow-chart for a situation where remedial action is required for a particular piece of equipment being out of service. Once the outage is detected, updated power flow measurements are used to determine whether any arming is needed. If the measured line flows are less than the value from the study (500MW in this example), stable system operation can be expected. However, when line flows exceed the limits identified by system studies, the system is automatically armed for a pre-calculated load-shed upon detection of the next defined contingency. In this example, the amount of load shed needed is compared against that available and then an optimal load-shed decision is selected.

3.3. Implementation Solutions

Once the design and application planning aspects of the SPS have been defined, many questions arise regarding the implementation such as:

- Identification of the functional and technical requirements (evaluation of monitoring, isolation of transmission equipment, breaker failure application, redundancy, etc.)

- Selection of the technology to meet the functional requirements of the SPS technically and economically, such as high speed secure communication between the SPS devices and programmable solutions to protect the system against severe contingencies
- Identification of the areas that may need new technology developments
- System diagnostics.
- Flexibility/Upgradeability to meet the future expansions or requirements of designed SPS
- Description of scheme operation and well prepared Maintenance plans / Intelligent or Automatic Maintenance Testing
- Communication system design and failure detection systems. For example, routing of primary system communication failure on the alternate communication medium when dual schemes are applied.
- Simplicity of the implemented solution over the life cycle of the project and as new operators, maintenance specialists, and engineers take responsibility for expansion or operation.
- Cost effectiveness for implementation.
- Provisions for alternate location for manual arming
- Breaker failure operation and automatic restoration – Should breaker failure be incorporated as part of the design and whether automatic restoration should be considered for parts of the scheme operation

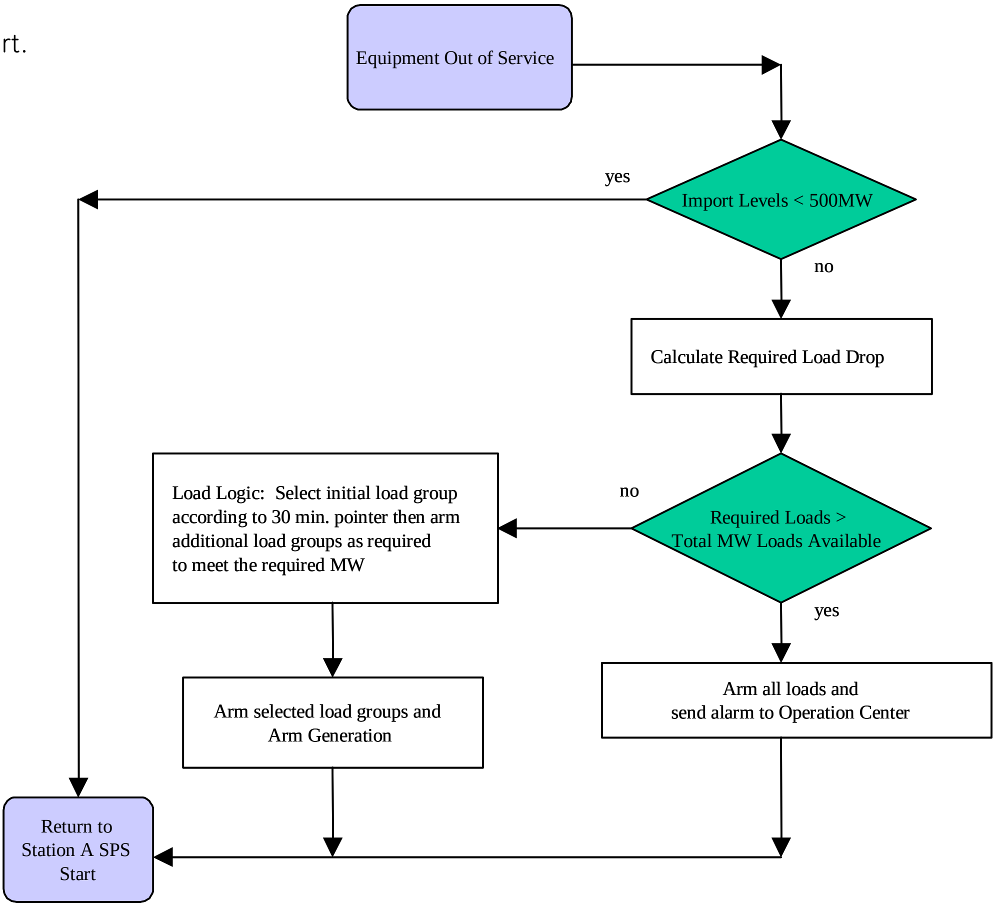
Knowledge of the answers to these questions bring us to the next steps of the implementation solutions, which are as follows:

- o Developing a test plan
- o Established procedures for continual or rotational training

Selection of equipment for such schemes should provide real time data to enable:

- Validation of contingency models to improve simulation and analysis of power system stability
- Advanced monitoring and warning indication as the power system approaches thermal limitations and / or system instability
- Flexibility to adapt to changes in power system conditions
- Expedited restoration coupled by recommended restoration alternatives [5]
- On-line operator or dispatch training opportunities for responsive and coordinated restoration; with cold load pickup considerations
- Accurate and timely analysis of disturbances
- Automated data gathering system for sequence of event listing based on absolute synchronized information
- Simplified data analysis to assist with investigations and root cause determination or faulty equipment performance
- On-line monitoring to provide both internal (IED failure) and external (communication failure) condition monitoring
- Device synchronization

Fig. 2.
Contingency Action Flow Chart.



The implementation solutions should also involve the following steps:

- Identification of the project team including manufacturers where needed
- Equipment selection and application process that would involve various groups responsible for the maintenance and operation of the system
- Implementation of automated and intelligent system testing as well as a well developed test plans for such system-wide tests

The selection and application process will assist the project team to identify the functional and technical requirements of the SPS such as the location of system controllers, monitoring points, the transmission equipment to isolate for various contingency conditions, methods of compensation for the deficiency in a given network, typical Protection and Control functions, type, speed, and security of communication options, communication broadcast options to share significant information such as telemetry, status, maintenance switching, and outage information with considerations for network congestions. The key focus here is to choose the right technology followed by proper implementation.

Another significant factor is different practices and familiarity amongst maintenance and engineering personnel in different companies with different types of equipment and communication interfaces. Established maintenance priority agreements are recommended - different systems or entities may have different maintenance priorities

3.3.1 Functional Evaluations

The intention of this step is to look into the detailed functional requirements such as number of monitored transmission / distribution equipment points, bus configurations, selection of secure communications, automatic restoration provisions, inputs / outputs, programming needs, throughput timing considerations, etc.

In the implementation, a separation of tradition protection and control devices and SPS devices is recommended. Reasons for maintaining such separation include:

- Different maintenance and operating needs and failure response times for the two types of applications
- Need for different set points and the types of setting elements used for conventional protection vs. those needed for SPS applications
- Device setting changes and potential impact to other schemes
- Different clearance requirements
- Availability of the SPS devices for routine automated system testing (Isolation or unavailability of the SPS devices may not cause system limitations while may not be acceptable from the equipment protection prospective)
- Need for different test and isolation points
- Potential confusion from operating and maintenance prospective
- Communication network, interfaces, and routing are different between SPS devices and those used for conventional equipment protection

Ultimately, each application would need to be evaluated on a case-by-case basis. The complexity of the scheme, its purpose, space availability, and other factors may drive some of these decisions. Ultimately, the pluses and minuses of each option must be quantified in order to make the optimal decision. It is recommended that the cost of the project be evaluated over its total life cycle (which includes ease of test and maintenance).

3.3.2 Technology Evaluation

Evaluation alternatives should involve in-depth knowledge of the existing practices, operating constraints, and Regional, Provincial, or Governmental Reliability requirements, and cost effectiveness of the solutions. When the technology does not meet the functional requirements of the SPS such as reliable out of step detection methods, load shedding, islanding, restoration, etc. in the best possible ways, then look for opportunities to develop solutions to fulfill the requirements, or present the challenge to manufacturers for developing the technology.

Another key component of technology evaluation is field upgradeability. Considering the future changes in the generation and transmission network of the power system, it is expected that the SPS schemes will require modification over their installed life. Upgradeability should be evaluated from both a hardware and software perspective.

3.3.3 Communication Options and Algorithms

One of the vital elements of SPS or RAS design is a reliable and secure communication infrastructure for data exchange amongst monitoring and controlling devices. These devices are often required to send, receive, filter and process status and / or analog measurements.

Some SPS communication requirements/solutions include the following:

- Communication architecture to support redundancy and data integrity
- Sufficient bandwidth to meet the communication time constraints
- Communication system diagnostics/alarms

Standards that meet the requirements include:

- IEEE C37.94 (N x 64 kbps communication)
- IEC-61850 for Peer-to-peer communications interfaces (10/100MB Ethernet based)

3.3.4 Complexity Vs Simplicity

In general, the wide area special protection scheme implementation is a multi-disciplinary process involving experts in automation, telecommunication, planning, operations, protection, and maintenance.

The selection of various equipment needed to implement such schemes, identification of monitoring points, types of alarms and priority classification, various contingencies associated with equipment abnormal conditions, types and availability of real time data, considerations for various categories of inputs and output tests, development of the test scenarios, coupled by provisions for automated testing make such schemes very complex. Furthermore, wide area protection schemes may involve many different entities with different background and practices.

It is therefore paramount to make application of such systems user friendly, and the functional performance relatively easy to understand, as equipment selection and application are considered and as the design phase progresses. Such applications are intended to perform for unlikely events and thus may not be exercised as frequently as some of the conventional equipment protection schemes.

3.3.5 Communication System

Considering the significance of the information passed over the communication channels, a robust communication channel is required. Today's technology allows robust communication network which offer:

- Low error-rate communication channel
- Low latency
- High Availability
- High security
- Deterministic

Low error rate communications can be achieved through fiber channels or low-noise copper channels. At a minimum, a copper communication channel with a Bit Error Rate (BER) of less that 10^{-4} is required. With a BER of 10^{-4} and a communication pack size of 200 bits, the probability of a lost packet is 1 out of 50. The probability of getting two bad packets in a row is 1/2500 that would delay operation of the system by 16ms.

More important than low noise is high data security, that is, if there is an error in a packet of data, the device must have a high probability of being able to detect bit errors in the message. This function is typically accomplished through the addition of a Cyclical Redundancy Code (CRC) – an error detecting methodology - along with the message. The probability of the CRC to detect an error is a function of its size. A 16-bit CRC is capable of detecting all bit error combinations up to 4 bits.

Although the probability of getting 5 errors in one message at a bit error rate of 10^{-4} is about once every 200 years, the real issue is related to burst errors. A burst error is when many bits (more than 6) are changed due to some event on the communication system. With a 16-bit CRC, the probability of NOT detecting a burst error is 1 out of 65,536. Although these are good odds, the communication industry tends to err on the conservative side and pushes the size of the CRC to 32 bits. With a 32-bit CRC (as used on all Ethernet communications), the probability of NOT detecting a burst error is 1 out of 4,294,967,296 – somewhat better odds.

Desirable in a communication system is the ability to monitor not only lost packets but also the rate of lost packets. When high rate of errors are detected, maintenance crews can quickly be dispatched to search out the source of the communication errors. In conjunction with error detection is the need to detect lost communications in general. The end users could also benefit from cost effective test tools that would help validate noise / error detection and system response during lab and commission testing.

Another desirable feature is the ability of the communication link to provide end to end timing – that is, how long it takes a message to travel from "Station A" to "Station B". Detection of communication delays outside the expected ranges again allows for quick crew dispatch, identification, and solution of the problem.

3.3.6 Restoration

As application of wide area monitoring often involves extreme contingencies, such schemes are not expected to operate frequently. Therefore, significant importance should be placed on effective and fast power system restoration after major disturbances Power system restoration needs to be executed with well-defined procedures that require overall coordination within the restoring area, as well as with the neighboring electrical networks [5].

Intelligent restoration recommendations could also be provided to the operating personnel as the frequency and/or voltage recover.

3.3.7 Central Controller

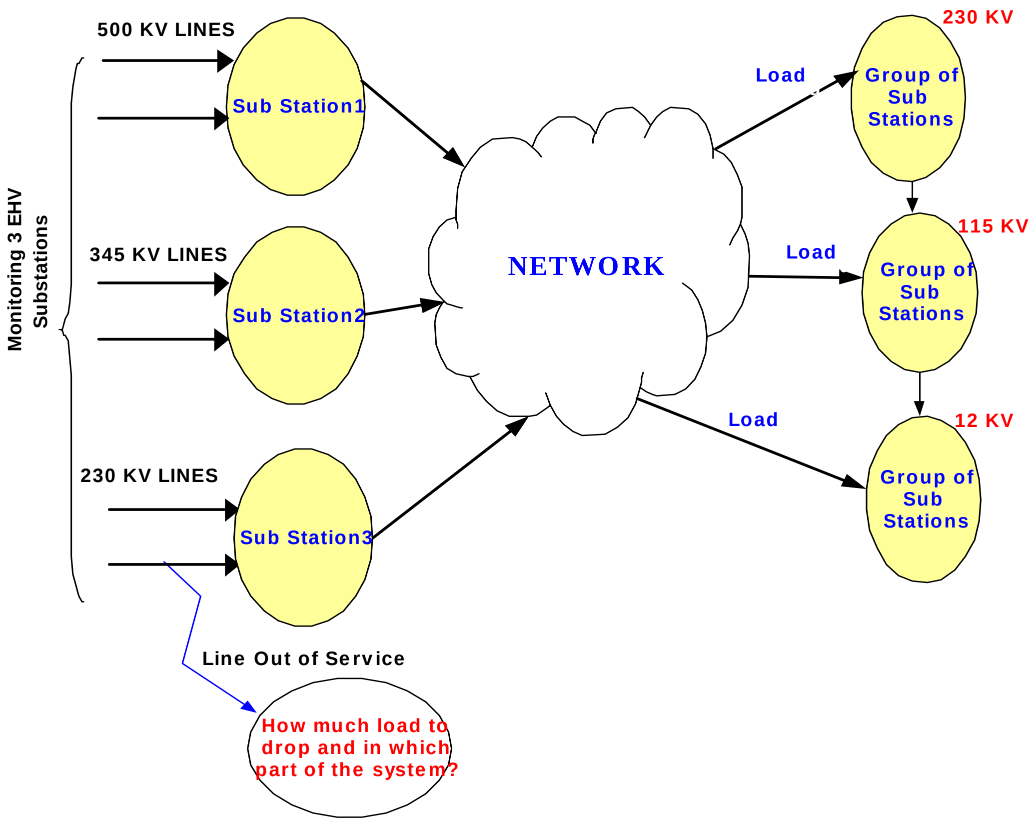
In many SPS applications, a Central Controller may be utilized. The expected performance may require the controller to consist of multiple parallel busses running in tandem with status and telemetry information exchanges taking place amongst the parallel processing busses. The controller design may also allow for "hit swapping" in case of component failures, also referred to as triple redundant controllers. The specification of the system controller should factor the overall functionality of the scheme.

3.3.8 Overall Functionality

The overall functionality of the scheme depends on the successful operation of various components either at the substation level or at the Central Control and Monitoring stations.

The overall functionality of the SPSs should be validated against the system studies. The total throughput of the system

Fig. 3.
Logical Architecture Design.



during commissioning and scenario testing stages, should measure significantly less than the throughput time identified in systems studies to allow for system changes and in case other stringent contingencies are identified in the future.

3.3.9 Logical Architecture

Given the various pieces of the solution, a next step is the development of the logical architecture. The logical architecture allows the designer to depict the data flows and logic locations of the complete system. This then helps the designer in the identification of gaps and seams in the design. Figure 3 shows a logical architecture for a three substation monitoring arrangement for an EHV system with the logical grouping of substation data as is required in the performance of the SPS logic (shown on the right hand side). Also shown is base `logic asking questions about line loss and possible resultant actions.

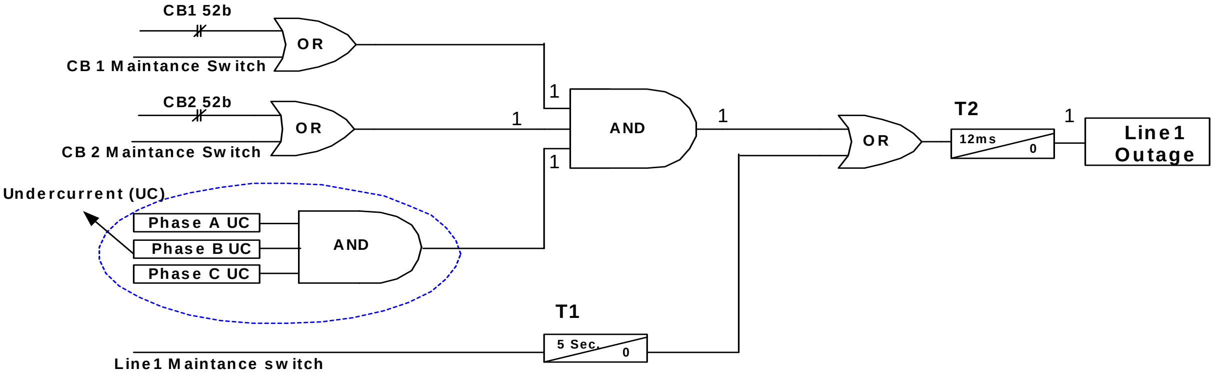
3.3.10 Logic Development

The next step in the process is the specific logic development. Depending on the solution determined by the system studies, the specific logic needs to be developed. In the example shown in figure 4, logic is shown for line outage detection logic for the 500 KV Line 1 shown in Figure 1 (breaker and half arrangement). The function is defined as a combination of undercurrent (UC) detection on all 3 phases of Line 1 and the breaker open condition (CB1 and CB2), or breaker maintenance switch set. In addition to this, The Line 1 maintenance switch can also create a line outage condition. An appropriate time delay (T2) can be applied to this logic, which avoids the rare but possible DC surge situation causing fictitious Line Outage.

3.3.11 Physical Architecture

Having done the engineering analysis as to the device inputs and outputs, communication requirements, and system controller requirements, the final step in the implementation

Fig. 4.
Line Outage Logic Example.



process is the development of the physical architecture. This drawing shows the number of devices required per substation, I/O requirements, communication channels and redundancy, system and device redundancies, time synchronization, controller locations, HMI facilities, etc. This physical architecture allows for one final review before sending the system out for final design. In addition, the physical architecture provides a mechanism for future explanation and operator training.

3.4. Testing

The ultimate success of the implementation solution depends on a proper testing plan. A proper test plan should include the lab testing, field-testing, study validation, and automatic and manual periodic testing.

3.4.1 Lab testing

Lab testing is designed to validate the overall scheme in a controlled environment. Lab tests permit controlled inputs from numerous sources with frequent checks of the output at every stage of the testing process. The lab tests ensure that the desired results are accomplished in the lab environment in contrast to costly and time-consuming field debugging.

For example, in a group of three SPS devices, a lab test could be simulated to check wide area communications (fiber/copper), average message delivery and return time, unreturned messages count and CRC failure count (under simulated noise conditions), and back-up communication switching timings.

It is advisable to create a detailed test plan as part of the overall implementation. A combination of the Logical Architecture, Logic Design, and the Physical Architecture could be used in preparation of the test plan.

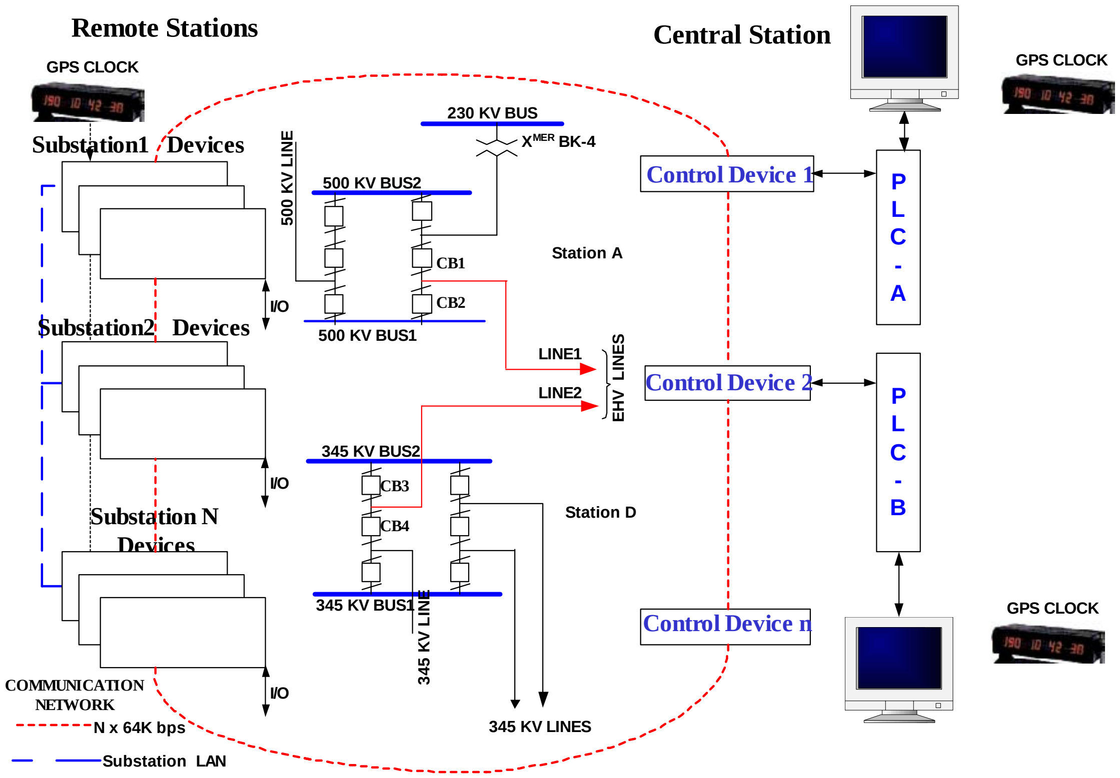
3.4.2 Field Commissioning Tests

Field commissioning tests should be carried out to check the performance of the special protection scheme against the real world abnormal system conditions. The telemetry data and the dynamics of various power system configurations such as breaker close and bypass contacts, changing the selectivity of the current transformer inputs, the total trip timing over the implemented communications between devices and the central control station, and the possible scenarios of unavailability of devices at the time of execution of a command signal in a given station all need to be tested. In general, every input point and every logic condition needs to be validated against expected results. Additionally, the effect of DC transients on Line Outage need to be tested thoroughly in the field before putting the scheme into service.

3.4.3 Validation through State Estimation

A critical consideration in implementing wide area monitoring and control schemes is the development of automated test scenarios. Such test cases could be prepared based on the type and the intended application of the scheme, and should

Fig. 5.
Physical Architecture



include provisions for ease of updating case studies as system conditions change.

For schemes that involve transmission constraints and stability limits, data from the state estimator can be used to determine different pre-outage flows within the power grid. The pre-outage flows are loaded into the controller as pre-contingency conditions. The controller, or simulator portion of the controller, would then be programmed for various outage, underfrequency, and / or undervoltage status scenarios to perform overall system performance evaluation.

State Estimator data could also be used to develop case scenarios representing future flows and load patterns for further system performance evaluations or to make adjustments where necessary.

3.4.4 Periodic Testing (Input/Output)

A proper test plan to simulate line outage on the monitored transmission/distribution lines in the respective substations and tripping of the lines should be conducted on a periodic basis to test the contingency plans and as a learning curve for the better understanding of the SPS

This test should be conducted without stopping any inputs – only actual trip outputs. For example, while simulating, a line outage, the monitored station should generate a trip output for the required load shed. The overall design need to incorporate the capability of isolating the trip signal but yet validating that it was issues. Devices such as latching and lockout relays can be installed for this purpose.

3.5. Training and documentation

The long-term effectiveness of an SPS design depends on how well it is understood by the operating and maintenance staff. The key point here is that proper documentation and training of SPS allows for its functionality to be easily assimilated by anyone. Training avoids human errors and also provides for ongoing feedback for improvement of the SPS.

4. Future Trends

As power system loading continues to outstrip transmission development, more complex system contingencies will develop and need to be addresses. The utility industry, however, is not standing still waiting for these next generation issues to suddenly appear. There are several trends on the horizon – some nearer, some farther out – that will facilitate next generation SPS design. A few of these trends are highlighted herein:

4.1. Emergence of IEC 61850

IEC 61850 – Communication Networks and Systems in Substations – is the next generation IED communication protocol. The protocol is defined on an Ethernet backbone and, as such, provides for very high-speed device-to-device communication. In particular, the standard implements out relatively new Ethernet functions such as priority and Virtual LAN allowing for more deterministic Ethernet packet delivery.

On the relay-to-relay communication front, IEC 61850 defines a Generic Object Oriented Substation Event message that enables the high-speed transmission of analog data messages from one to multiple other devices in the 5ms to 10ms time frame. Given this analog data transfer capability, IEDs will evolve to provide mathematical manipulation functions which will enable the ability of SPS designs to adapt and track historical performance. Logics could then be created to allow adjustments to support system changes as well as to support more precise future performance alternatives.

4.2. High-Speed Utility Intranet Availability

The available and continued installation of fiber throughout the utility enterprise has created, in many instances, wide area high-speed communication paths. Synchronous Optical NETwork (SONET) communication systems are providing 10 and 100 MB Ethernet options on a system wide basis. End to end delivery of Ethernet data packets has been demonstrated in as little as 6ms over a 100mi path.

4.3. Synchronized Phasor Measurement

Synchronized Phasor measurement or Synchrophasor is the simultaneous measurement of the magnitude and phase angle of the positive sequence voltage at multiple points around the electric power grid. Although the technology was defined in the early 1980's, the general availability of Phasor Measurement Units (PMUs) has only recently occurred. Phasor data has proven to be extremely useful in post mortem analysis of system transient events and is now being used to assist state estimation and Power System Stabilization (PSS) systems [6].

4.4. Wide Area Control Systems

Given the high-speed observability of the power system, a new class of power system control functions is being developed which are generally known as Wide Area Control Systems. The basic concept is that if one can observe the dynamic state of the power system, real time control actions can be implemented that, upon detection of a transient condition, can drive the system to a stable state. Application explored to date include state measurement (in contrast to state estimation), on-line voltage security [7], inter-area oscillation damping, system-wide voltage regulation [6], and real-time security control.

4.5. Real-Time Pricing / Direct Load Control

Lastly, a major initiative among many utilities throughout the world is the implementation of Real Time Pricing (RTP) and Direct Load Control (DLC). The recent industry deregulation on supply pricing can, under numerous conditions, result is very high prices for the supply of electricity. RTP enables the utility to directly pass the cost of electricity onto the customer and let the customer choose how much electricity he/she wants to use at a given price.

In the migration path to RTP, communication to the end-users facility will be required. This communication path will enable DLC. By coupling the DLC path with Wide Area Control, real-time closed loop control systems become realizable.

5. Conclusions

It is apparent that the present trend of load growth outstripping transmission will continue for the foreseeable future. In order to maintain power system stability over the ensemble of contingencies introduced by this load/transmission imbalance, protection engineers are challenged to find alternative solutions such as SPS / RAS to fill the gaps. A set of technologies exist to meet the needs for today and developments are progressing that promise to bring more sophisticated tools to affect better control over the massive machine known as the Electric Power Grid.

6. References

1. National Transmission Grid Study; Department of Energy; http://www.eh.doe.gov/ntgs/reports.html

2. August 14, 2003 Blackout - NERC Recommendations to Prevent and Mitigate the Impacts of Future Cascading Blackouts; www.NERC.com

3. Survey of the Voltage Collapse Phenomena, NERC, August 1991

4. NERC/WECC Planning Standards - Table I. Transmission Systems Standards — Normal and Contingency Conditions; www.NERC.com

5. D. Novosel, M. Begovic, V. Madani Shedding Light On Blackouts – IEEE PES Power and Energy, January 2004

6. B. Fardanesh; Future Trends in Power System Control; IEEE Computer Applications in Power; July, 2002.

7. R. Nuqui, A. Phadke, R. Schulz, N. Bhatt; Fast On-Line Voltage Security Monitoring Using Synchronized Phasor Measurements and Decision Trees; IEEE PES Transactions; 0-7803-6672-7/01; 2001.

8. T. Garrity Shaping the Future of Global Energy Delivery – IEEE PES Power and Energy, September 2003

9. V. Madani, J. Law, C. Finn, R. Mansfield Deterministic Model for Cold Load Pickup – IEEE Midwest Power Symposium, October 1985