

A photograph of the Golden Gate Bridge in San Francisco, California. The bridge's iconic red-orange towers and suspension cables are the central focus, extending across the frame. The bridge spans a body of water, with a hilly, green landscape visible in the background under a clear blue sky. The text 'Wide Area' is overlaid in large white font across the upper portion of the image.

# Wide Area

SIPS - The Bridge to Secure Electric Power Systems



# Special Protection Schemes

## Design & Implementation

● Blackout prevention / mitigation and power system security are the order of the day. Managing congestion, balancing load and on-line generation, maintaining 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.

These widespread outages have demonstrated the vulnerability of the interconnected power systems worldwide when operated outside intended design limits. The exposure of the power system to wide area collapse have increased in recent years as the power systems have been pushed to their operating limits - often resulting in violation of operating policies and planning standards.

One of the U.S. Department of Energy (DOE) and the Canadian Natural Resources (NRCAN)'s top priorities is 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 technology, software programs, and reliability/ analysis tools, to support grid reliability and efficient markets during this critical transition.

The National Transmission Grid Study has stated that without dramatic improvements and upgrades over the next decade our nation's transmission system

The trend in power system planning has become tight operating margins, with less redundancy. It is also apparent that the present trend of load growth outstripping transmission will continue for the foreseeable future.

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 in terms of 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 the reactive margin requirements 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 industry recommendations for prevention and mitigation of future blackout scenarios.

The Union for the Coordination of Electricity Transmission (UCTE) report lists 14 observations for the September 28, 2003 outage, that are very similar to those identified for the outages in North America and in Europe.

It should be noted that the issues faced, in many cases, are not easily overcome. Even when new generation is justified, transmission owners are faced with challenges 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.

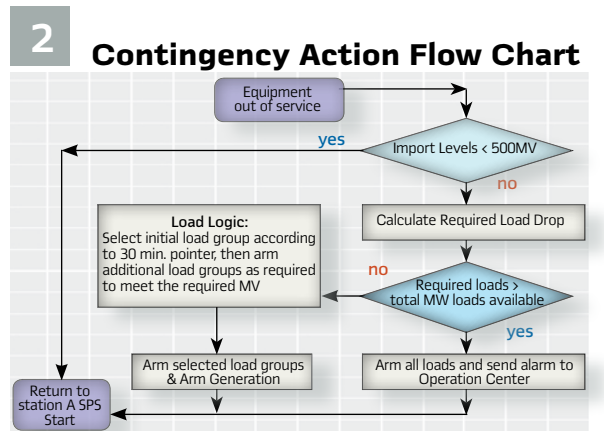
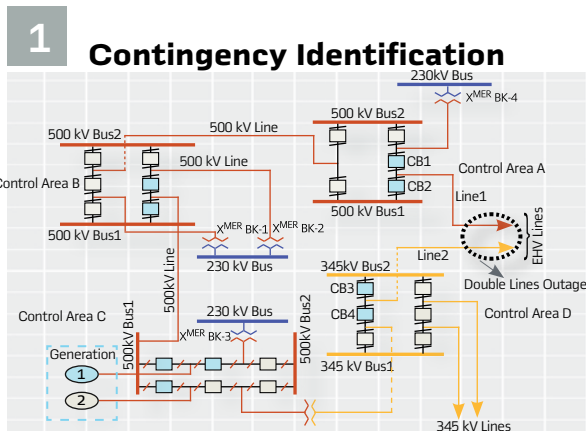
**Solution Space**

As mentioned above, one of the issues to address is lack of reactive power sources. In the case of the 2003 North East outage in North America for example, the 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 sufficient levels to ensure system stability with operating range of electrical equipment."

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.

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.

**SPS Design Process**

In this article, 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.

**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 quantities, locations and set points – overload conditions, undervoltage, underfrequency, phasor measurement
- 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
- 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.

**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 figure depicts outages (breakers open are filled inside) 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 near Control Area B and C of the system and an overload on two other lines

**The fundamental changes in the design and operation of the electric power system require that system-wide protection solutions be implemented.**

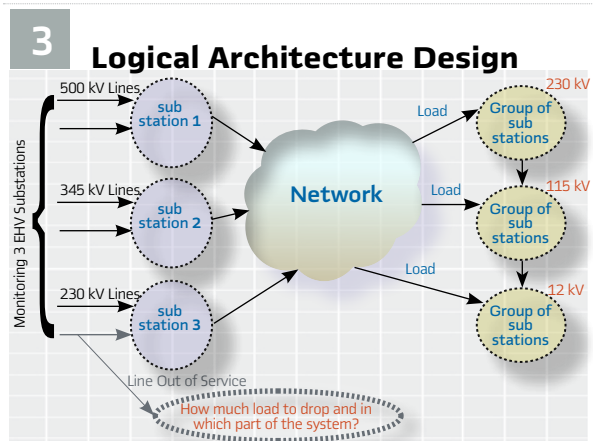
near Control Area A and B of the system will create a potential voltage collapse or generation/load imbalance scenario.

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 (500 MW 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. 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,



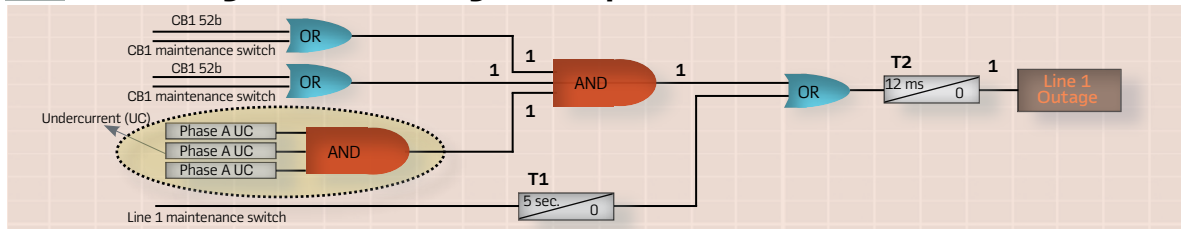
**Vahid Madani** - IEEE Fellow, is the primary architect and developer of standards in protection & control integration applications and substation modernization at Pacific Gas and Electric Co. (PG&E). He is a Tau Beta Pi member, and a registered Electrical Engineer with more than 25 years of academic and utility experience, and recipient of many honorary and distinguished citations. For a decade, he served as Chair of the WECC RAS Reliability Subcommittee and received the best Chair Person award for his leadership twice. He Chairs the Performance Standards Task Team within the North American Synchrophasor Initiative (NASPI). Mr. Madani is the author of more than 60 publications, the co-editor of the 2006 McGraw Hill year book of science technology, and the 2008 Edition of International Journal of Reliability and Safety (IJRS) for InderScience Publishing.



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### 4 Line Outage Detection Logic Example



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
- Communication system design and failure detection systems. For example, routing of primary system communication failure onto the alternate communication medium when dual schemes are applied

■ Simplicity of the implemented solution over the life cycle of the project

- Cost effectiveness for implementation
- Provisions for alternate locations for manual arming
- Breaker failure operation and automatic restoration

The implementation solutions should also involve the 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 and 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.

#### 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.

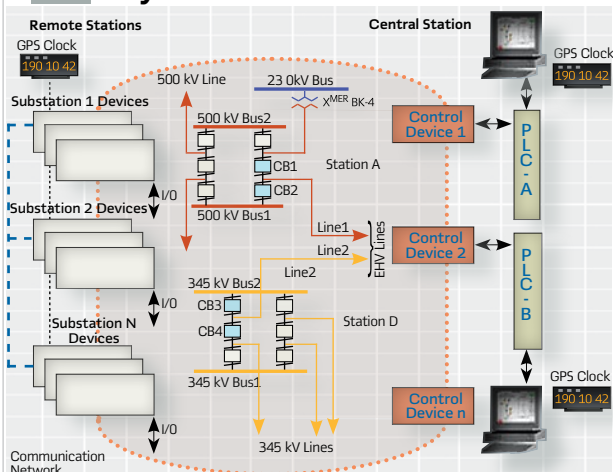
Lab testing is designed to validate the overall scheme in a controlled environment. Lab tests permit controlled inputs from numerous sources with frequent checks of the output at every stage of the testing process. The lab tests ensure that the desired results are accomplished in the lab environment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

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.

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, CT DC decay quantities when the line current goes to zero need to be tested thoroughly in the field before putting the scheme into service.

A critical consideration in implementing wide area

### 5 Physical Architecture





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

A proper test plan to simulate line outages 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 integrity of the wiring, contingency plans and as a learning curve for the better understanding of the SPS. The overall design needs to incorporate the capability of isolating the trip signal but yet validating that it was issued. Devices such as latching and lockout relays can be installed for this purpose.

#### 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.

#### Future Trends

As power system loading continues to outstrip transmission development, more complex system contingencies will develop and need to be addressed. 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:

#### 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 specifies relatively new functions such as priority and Virtual LAN allowing for more deterministic Ethernet packet delivery.

IEC 61850 defines GOOSE (Generic Object Oriented Substation Event) messages that enable 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 have evolved to provide mathematical manipulation functions which 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.

#### 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 MB and 1GB Ethernet options

## A set of technologies exist to meet the needs for today and new developments are bringing more sophisticated tools.

on a system wide basis. End to end delivery of Ethernet data packets has been demonstrated in as little as 6ms over a 100 mi path.

#### 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.

#### 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. Applications explored to date include state measurement (in contrast to state estimation), on-line voltage security, inter-area oscillation damping, system-wide voltage regulation, and real-time security control. Applicability of the advanced analytical techniques using modern technology are described in many publications. Overview of traditional scheme requirements leading to the SIPS of the future are also discussed. A new joint IEEE / CIGRE survey provides valuable information about power industry trends and experiences in SIPS.

#### 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 in 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. ■

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SIPS can be used to prevent disturbance propagation if integrated to complement conventional solutions that protect the grid against vulnerabilities.