IEEE/PES PSRC Report on Design and Testing of Selected System Integrity Protection Schemes

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***Abstract*—This paper is a summary of an IEEE/PES Power System Relaying Committee (PSRC) report [2] on the design and testing of selected System Integrity Protection Schemes (SIPS). The report includes high level general considerations in SIPS design and testing, and the industry practice in design and testing of the following selected SIPS with example implemented schemes: (1) Generator rejection; (2) Load rejection; (3) Adaptive load mitigation; (4) Dynamic braking; and (5) System separation.**

***Index Terms*—System Integrity Protection Scheme, Remedial Action Scheme, System Protection System, Generator Rejection, Load Rejection, Adaptive Load Mitigation, Dynamic Braking, System Separation**

I. Introduction

An IEEE transaction paper, "IEEE PSRC Report on Global Industry Experiences with System Integrity Protection Schemes (SIPS)" [1], has shown wide application of various types of system integrity protection schemes (SIPS) in the global power industry. Unlike conventional protection systems that are applied to protect a specific power system element, such as a generator, a transformer, a line, and so on, SIPS are applied to protect the integrity of the power system or strategic portions of the system. SIPS encompass Special Protection Schemes (SPS), Remedial Action Schemes (RAS) and varieties of other safety nets. These schemes provide reasonable countermeasures to prevent, slowdown and/or stop cascading outages caused by several levels of contingencies.

According to the survey results of the paper [1], SIPS in use today include

- Generator Rejection
- Load Rejection
- Under-Frequency Load Shedding
- Under-Voltage Load Shedding
- Adaptive Load Mitigation
- Out-of-Step Tripping
- Voltage Instability Advance Warning Scheme
- Angular Stability Advance Warning Scheme
- Overload Mitigation
- Congestion Mitigation
- System Separation
- Shunt Capacitor Switching
- Tap-Changer Control
- SVC/STATCOM Control
- Turbine Valve Control
- HVDC Controls
- Power System Stabilizer Control
- Discrete Excitation
- Dynamic Braking
- Generator Runback
- Bypassing Series Capacitor
- Black-Start or Gas-Turbine Start-Up
- AGC Actions
- Busbar Splitting

SIPS often are the last line of defense for preventing the protected power system or portions of the system from cascading outages. The proper design, documentation, and testing of SIPS is the basis for reliable and accurate operation of such schemes. For some SIPS, their design and/or testing have been studied extensively over the years, such as the under-frequency load shedding scheme [3], out-of-step tripping [4], etc., while other SIPS (e.g. generator rejection, load rejection, etc.), which are also in wide use in power systems [1], are less studied.

This IEEE/PES PSRC report, "Design and Testing of Selected System Integrity Protection Schemes", was developed to provide practical design examples for five widely used SIPS: (1) Generator rejection; (2) Load rejection; (3) Adaptive load mitigation; (4) Dynamic braking; and (5) System separation.

The report includes information in two main areas: the high level general considerations in SIPS design and testing, and more detailed specific design considerations and the testing for the selected five SIPS design and application examples.

II. General considerations in SIPS design and testing

Although SIPS are typically different from each other because their applications are specific to special requirements, there are some considerations in their design and testing that are generally common to them all. The report has included the following general considerations in SIPS design and testing:

Power system hierarchy

The specific hierarchy of the electric power system needs to be considered in the design and implementation of SIPS. Today's electric power system is very complex, consisting of a large number of generation power plants that generate electric power for delivery to the loads through highly interconnected transmission systems and distribution networks. The growing number of distributed generation units, renewable generation resources, and micro-grids further increases the complexity of the modern power systems.

The electric power system is operated with energy management systems to maintain generation-load balance of the system typically with sufficient security margin to withstand certain system disturbances and contingencies, such as loss of a transmission line and/or a generating unit.

When the power system cannot be operated securely against such contingencies or when multiple contingencies occurring within a very short time period which may result in system instability or overloaded elements, a SIPS should be considered. The action of the SIPS may decelerate the system, reestablish the balance between load and generation, isolate the unstable parts of the system, or unload the overloaded elements. These SIPS actions highly depend on the hierarchy of the part of the power system where they are applied and must be properly considered and addressed in the SIPS design.

Generic SIPS Description Model

Although specific SIPS may have very different architecture and use different components, they can be described using a generic model as shown below (Fig. 1), i.e. all SIPS can be described to have monitoring and detection, communication, decision making, and mitigation measure execution part.

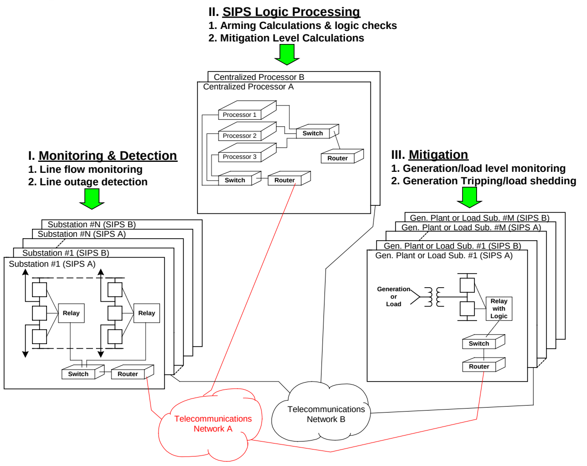

Fig. 1. Generalized SIPS Architecture

Communications Requirements

Communications are used by SIPS to acquire data from distant locations for the central controller where the decision for any action is made. Communications are also used to send SIPS control commands to the field to execute the mitigation action. In order to assure power system stability, SIPS signals transmission requires the communications system that it uses to meet specific speed, security and dependability requirements. The report described typical communication media commonly used in various SIPS and their typical delay values.

Centralized SIPS vs. Distributed SIPS

SIPS could be designed to have either a centralized or a distributed architecture. In centralized SIPS, all logic processing and arming is done at a central site, and only input/output (I/O) interface devices are deployed at the remote sites. In distributed SIPS, the logic processing and arming functionality is distributed across the various stations or hierarchical levels. The logic processor at each station can independently initiate control actions. The design choice should be based on the specific design requirements.

Redundancy Considerations

Failure of the SIPS to operate when required, or its undesired or unintentional operation may have adverse impact on the power system. Therefore, design of the SIPS often involves redundancy or some backup functions. Although simple redundancy or backup systems will improve the dependability of the system it will reduce the security of the overall system. To maintain the security level of a single system and achieve the dependability of a redundant system a two out of three voting system may be needed. Redundant systems also improve operations and maintenance efficiency by minimizing downtime, and the overall life cycle support.

One drawback of redundant systems is increased hardware complexity. Depending on the application philosophy of primary and redundant applications being same or different hardware (component), additional training costs and need for more spare parts may also be considered as drawbacks. However, if product and type of hardware used are common to other (conventional) protection and control applications, then added hardware and training are addressed from a "Program" level at the power company.

Functional and System Testing of SIPS

Functional and system test plays an important role in confirming how well a SIPS satisfies its design requirements at any given time or under any specific conditions. Functional testing is the most widely accepted practice for protection and control systems and is required to ensure that the SIPS and each of its components will operate as designed under different system conditions.

Understanding what has or has not been tested in a complex system is still a major challenge for many organizations. The time commitment required for quality assurance functional testing needs to be one of the highest priorities for ensuring successful operation of the SIPS. It is essential that the functional testing requirements, test cases, test methods and tools are considered and defined as part of all stages of the engineering of the SIPS.

With functional testing the engineering, commissioning and maintenance teams translate functional requirements into executable test cases that confirm how well the SIPS satisfies the requirements at any given time or under any specific conditions. A test plan needs to be developed in order to build a suite of executable tests that define and verify the functionality requirements, providing a fast and objective way to assess the performance of the tested function. It is important to include in this test plan the simulation of common events and conditions for which the SIPS should not operate, particularly when the consequences of false operation are harmful to the system or costly. This process should start together with the design of the SIPS and follow through at each step until the detailed test plan for the SIPS and each of its components is defined. These tests can then be executed regularly to ensure that functional modifications or firmware upgrades do not unintentionally change previously verified functionality.

An effective functional testing practice involves the definition of guidelines for using functional testing technologies effectively (based on the user's protection testing philosophy), and then the implementation and integration of those guidelines into the asset management system.

To achieve effective system testing, the user or manufacturer must not only have a defined practice for its use, but that practice must be implemented and integrated into the engineering process so that it can be used consistently and regularly across the organization. The definition of the functional tests will be part of the design and testing documentation of the SIPS. At the time when the functionality of every single element of the SIPS is designed, it must be specified how it is going to be tested.

Utility Documents

The design and testing of SIPS may need to follow the requirements of reliability coordination authorities in addition to utility's own guidelines. Individual utilities have also developed whitepapers and internal guidelines about the SIPS for their own use. These documents should be consulted and the requirements should be followed in the SIPS design, documentation, and testing guidelines to ensure compliance where they are implemented.

III. Practical Examples of Selected SIPS

The report included practical design examples for five widely used SIPS: (1) Generator rejection; (2) Load rejection; (3) Adaptive load mitigation; (4) Dynamic braking; and (5) System separation.

Generator rejection

Generation rejection schemes involve tripping of one or more generating units. The practice of generator tripping is used on all kinds of units but especially on hydro-generator units. Generation rejection improves transient stability by reducing the accelerating torque on the machines that remain in service after a disturbance. Generation rejection can also be used to reduce power transfers on certain parts of a transmission system and thus solve overload or voltage stability problems.

The generator rejection design example provided in this report is for a four unit coal-fired electrical generating plant (the Plant) located in the western United States. The plant has the capacity of a net output of 2120 MW, and it is remote from the load and connected to a transmission network by three long 345 kV and two 230 kV transmission lines. When the transmission path is being operated at the path load transfer limit and a transmission line in the path is lost, the generation at the Plant must be reduced to maintain the transient stability of the power grid. To arrest the transient power swing following the clearing of the line fault from dropping the voltage below 0.3 per unit, a SIPS that trips generating units at the Plant is deployed.

Load rejection

Load rejection is a protection system designed to trip load following an event or disturbance that causes supply-load unbalances that may lead to a wide area disturbance. Load rejection SIPS typically are designed to keep a system or sub-system in parallel with the remaining parts of the system in case of the loss of a major supply to the affected power system area. Load rejection differs from the automatic under-frequency load shedding, since one of SIPS main goals is to prevent the separation of an area of the system before the change of frequency can result in the operation of the under-frequency relays.

The load rejection SIPS design example provided in this report is for a transmission system in northern Chile. The load reject scheme is used to maximize the use of the transfer capability of the power flow between station A-B and B-C as shown in Fig. 2. The scheme disconnects loads automatically in order to adjust to the remaining operating line capacity (using adjusted n-1 safety criterion).

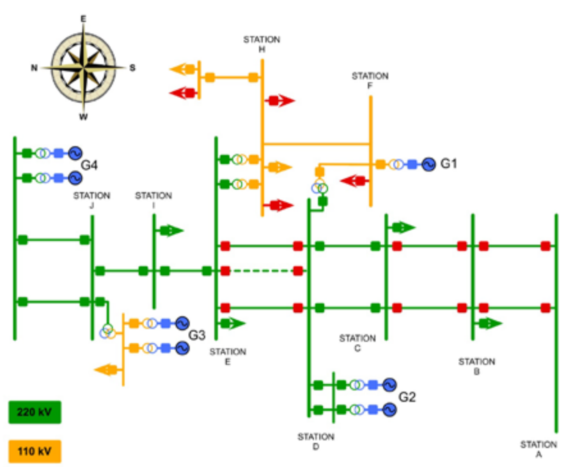

Fig. 2. One-line diagram for northern Chile

Adaptive load mitigation

: Adaptive load mitigation schemes typically take an initial action then monitor the effect of that action before evaluating and executing further actions. For such adaptive schemes, additional corrective actions continue to be executed until the congestion is mitigated and system is relieved. The arming of such schemes determines the mode of operation and whether the system adjustments need to be immediate or the conditions support more gradual balancing of load and system capability, including generation.

The adaptive load mitigation SIPS design example provided in the report is for an area in Western US that is served by five 115 kV transmission lines (Fig. 3). Generation station N is substantially less economic to operate than other available generation sources for the area, but is a designated as a must-run station for minimizing risks of operating the area.

The other two “source” 115 kV lines (D and E) connect the area to more economical generation and stronger transmission sources. Loss of line E, by itself, does not result in system performance outside acceptable limits. However, various contingency conditions (e.g. loss of line D, outages on 230 kV system, etc.) could result in an overload of line E by as much as 60% above its thermal rating. Without additional transmission line capability the only solution is load shedding in the area. The amount of load that must be shed varies as a function of the actual load at the time of the critical outage, hence an adaptive load mitigation scheme is used.

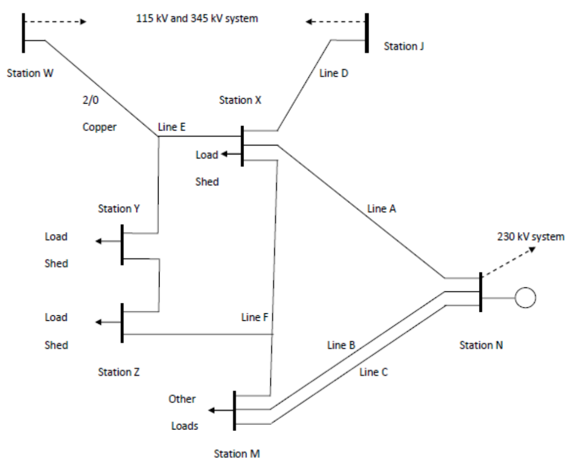

Fig. 3. One-line diagram of the 115 kV system

Dynamic braking

A dynamic brake is a resistive shunt type load that is switched onto the power system briefly to help maintain transient stability once a disturbance has occurred. For the design example in this report, application of a dynamic brake is used to enhance transient angular stability between adjacent systems allowing one system to benefit from the other systems’ remotely located renewable power sources [5]. When first installed, availability of this three-phase 1400 MW braking scheme was thought to increase power transfer capability by 900 MW.

The dynamic braking scheme is applied to a system which also has several other SIPS schemes in operation at any time. Using dynamic braking scheme avoids the need for equivalent generation reduction amounts using a gen rejection scheme when the system is in export mode. The brake is applied at a single location adjacent to large hydroelectric generation units as part of a wide area protection scheme. The control is open loop type, with fixed duration of application.

System separation

The system separation scheme design example included in this report serves as the primary means for maintaining system angular stability and maintain reliability within regulator planning requirements such as NERC TPL-003 (or category C – double contingency events). It will trip breakers at substation B, line 8 and 9 (Fig. 4) for unstable power swings separating the system in two islands and block system separation for stable power swings.

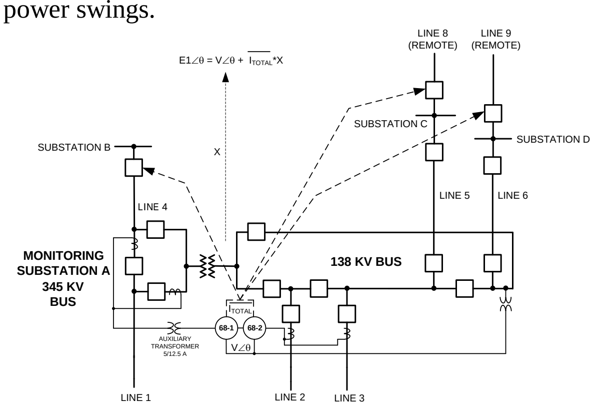

Fig. 4. Example system one-line diagram

The report provides more detailed description of design considerations, the design details and the testing of these examples.

IV. Conclusions

The SIPS included in this PSRC report demonstrated that design and testing of SIPS are highly system dependent. Specific system and grid conditions, such as grid topology, generation levels, load levels, load flow patterns, etc., greatly influence the types of SIPS being selected. However, the design and testing of a specific scheme of the same type of SIPS should still take specific power system and grid conditions into account.

SIPS can be very diverse in design. This requires owners and the region to perform detailed and sometimes extensive studies and apply the appropriate standards and oversight to ensure the design meets acceptable performance requirements. The examples in this report are intended to provide a reference of design and testing techniques used to meet a specific application and are not intended to apply without any change to every SIPS of the same type.

V. Acknowledgment

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VI. References

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Biographies

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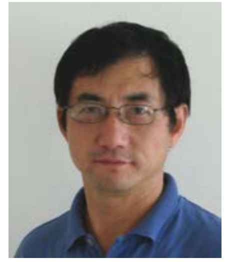

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