Deployment of System Protection Schemes for Enhancing Reliability of Power System

Operational experience of Wide Area SPS in Northern Regional Power System in India

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Abstract—**System Protection Schemes (SPS) are widely accepted as an effective tool for increasing the utilization of power networks by enhancing the resilience of the power system towards rare contingencies. These schemes are considered as 2nd generation protection philosophy after the unit protection philosophy. In the last few years several SPS have been designed and implemented successfully in the Indian Power System. This paper discusses the need for SPS in Indian power system and provides a brief description of the major System Protection Schemes deployed in the Northern Regional Power System in India. The performance of these SPS post-commissioning has also been analyzed briefly. In the end the paper highlights the major issues associated with the deployment of SPS in the Indian context and also suggests the future scope of work in this area.**

Keywords-Reliability; Planning Criteria; Safety net; Rare contingency; System Protection Scheme; Smart Grid

I. Introduction

The power system of India is demarcated into five regional grids namely, Northern Region (NR), North Eastern Region (NER), Eastern Region (ER), Western Region (WR) and Southern Region (SR). The first four are synchronously interconnected and are also known as the NEW grid. The SR is connected to the NEW grid through asynchronous DC ties. As mandated in the Electricity Act 2003 and the Indian Electricity Grid Code, the Central Electricity Authority (CEA) and the Central Transmission Utility (CTU) in coordination with the State Transmission Utilities (STUs) are responsible for long term planning (for network expansion) in an integrated manner. Operational planning in the other time horizons and operation in real time is taken care of by the National/Regional/State Load Dispatch Centres. Further there are coordination committees at the regional level to facilitate discussion on technical and commercial issues related to grid operation, protection, energy settlement, data acquisition and communication [1, 2, and 3].

The Northern Regional (NR) grid is one of the largest among the five regional grids in India. NR is spread over more than 1 million square kilometers (31% of India) and serves a population exceeding 368 million people (30 % of India). It has an installed generation capacity of 47 GW (27 % of All India capacity). In the year 2010-11 the peak demand met of NR was 34 GW (30 % of All India peak demand met) while the annual energy consumption was 239 BU (30 % of All India annual energy consumption). The highest operating voltage in NR grid is 400 kV in AC transmission and ± 500 kV in DC transmission.

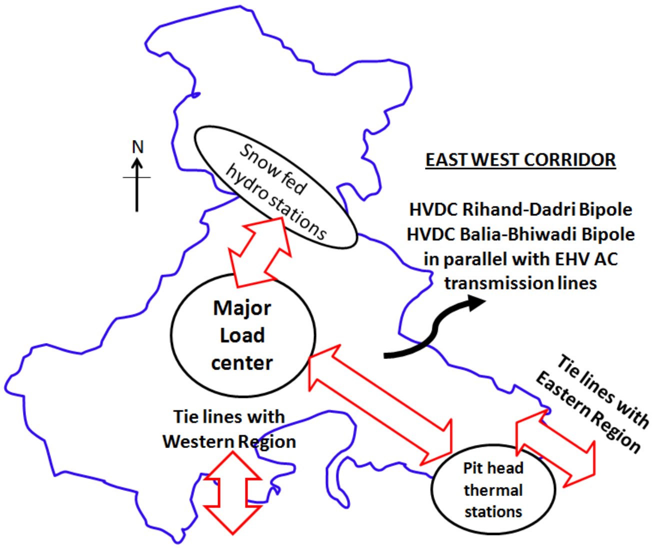

Figure 1: Northern Regional Power System

Within the NR grid the major coal pithead thermal power stations are located in the extreme South-eastern part while the snow fed hydro power stations are located in the Himalayas in the North western part of the grid . However, the major load centres are located in the central and western part of the grid. The parallel EHV transmission lines connecting the generation pockets in the South-eastern part with the major load centres in the western part (separated by a geographical distance of ~800-900 kilometers) comprise the East-West flow-gate/corridor within the Northern Region [refer figure 1].

II. NEED FOR SYSTEM PROTECTION SCHEME IN INDIAN POWER SYSTEM

A. *Ensuring security of the Inter State Transmission System*

As per section 3.5 of the Indian Electricity Grid Code [3], the 'Planning Criteria' is based on the security philosophy on which the Inter State Transmission System (ISTS) in India has been planned. It states that as a general rule, the ISTS shall be capable of withstanding and be secured against a certain credible contingency outages without necessitating load shedding or rescheduling of generation during steady state Operation. This criterion is better known as the N-1 criterion for planning.

The N-1 criterion is used for long term transmission planning in India [4]. However a considerable difference exists between what is a N-1 contingency in planning horizon and a N-1 contingency in operating horizon due to the considerable difference that exist in the network topology and scenario assumed in planning studies and those existing physically during actual operation. This may occur due possible gaps in the forecast assumptions; or network constraints occurring due to non-availability of transmission elements or generators envisaged in that time frame due to disparity in project implementation, mid-course changes; reconfiguration of switching arrangement due to practical constraints such as radial operation, open bus coupler etc. Further in the planning horizon the N-1 contingency implies outage of a single element whereas in the operation horizon N-1 contingency is usually an event involving simultaneous outage of one or more elements [5] which are termed as rare contingencies.

The number of rare contingencies that occurred in Northern Region during last nineteen months (1st January 2010 to 31st July 2011) is given in table 1. It may be seen that the average number of rare contingencies occurring per month in the Northern Regional grid is more than four (4). A similar computation was done for the NEW grid in 2006-07 that revealed that on an average four (4) rare contingencies occur every month [5].

Table 1: Instances of Rare contingencies in NR

S No.	Description	Number of instances
1	Tripping of complete generating station	42
2	Tripping of complete EHV substation	13
3	Tripping of HVDC Bipole/back to back	3
4	Simultaneous outage of multiple transmission lines/ICTs other than those listed above	28
Total (1st Jan-10 to 31st Jul-11)		86
Average per month (1st Jan-10 to 31st Jul-11)		4.53

Thus the rare contingencies can no longer be ignored and suitable measures need to be put in place for securing the system against such contingencies. In fact Charles Concordia, the Power System Guru, in his paper 'Considerations in planning for reliable electric service' [6] has argued that "regardless of how great the planned margins are in system design and operation, there is always the chance that they may be exceeded, either by a highly improbable combination of events, or simply by carelessness or error. Thus, as a final precaution, plans must be made to minimize the magnitude and duration of any resulting service interruption."

B. Utilization of network closer to its physical limits

The Indian grid is evolving with rapid augmentation in the generation, transmission and distribution capacity. In recent years the demand for electricity has shown double digit growth particularly in Northern Region. The ongoing power sector reforms have resulted in manifold increase in the number of stakeholders in the sector. Non-discriminatory open access in transmission, competition between generators, and increasing difficulty in construction of new transmission lines due to right-of-way issues have significantly increased the pressure to utilize the available margins in the existing power network and increase the transfer capability of the existing network without compromising grid security.

C. Reliability of an Interconnection with large footprint

The Indian grid is one of the Very Large Power Grids in the world. The four regional grids (NEW grid) would soon be synchronously connected with the Southern Grid. Further there has been a significant progress towards formation of the SAARC grid with interconnection of Bhutan and Nepal as well as with the proposed projects for interconnection with Sri Lanka and Bangladesh. There are immense benefits of such interconnections and these must be encouraged. But at the same time suitable systems must be put in place to ensure reliable operation of the interconnection.

D. Risk Management

Charles Concordia, the renowned power system guru argued, "a 100 percent availability of electric service can never be attainable, no matter how much time, effort, and money are spent, so it must be conceded that the objective is not 100 percent, but rather the maximum reliability that we can, and should, afford" [6]. Planning with the above philosophy would imply risk management. The North American Electricity Reliability Corporation document titled, 'Reliability Criteria and Operating Limits Concepts' [7], says, "In the context of electric system reliability, risk is the likelihood that an operating event will reduce the reliability of the interconnection and the consequences that are unacceptable. Because we cannot prevent events from happening, we plan and operate the electric system so when they do, their effects are manageable, and the consequences are acceptable. So, one of the keys to providing a reliable interconnection is, managing risks."

Therefore while planning for the reliability of the Indian bulk power supply system one needs to look into its characteristics and the operating philosophy. Few of the distinguishing features of the Indian grid that need to be considered are the haulage of power over long distance, resource inadequacy leading high uncertainty in adhering to maintenance schedules, freedom to deviate from schedule, statutorily mandated floating frequency regime, decentralized set up, absence of primary response from generators, limited mechanism to complement reliability, absence of explicit ancillary market, inadequate safety net and deficiencies in the defense mechanism [5].

All the above factors call for deployment of System Protection Schemes in addition to the other conventional methods for enhancing reliability of the power system. Regulation 5.2 (o) of the Indian Electricity Grid Code (IEGC) also stipulates that all users, STU/SLDC, CTU/RLDC and NLDC shall also facilitate identification, installation and commissioning of SPS (including inter tripping and run-back) in the power system to operate the transmission system closer to their limits and to protect against situations such as voltage collapse and cascade tripping of important corridors/flow gates etc [3].

III. SYSTEM PROTECTION SCHEME

Anderson [8] defines System Protection Schemes (SPS) as “a protection scheme that is designed to detect a particular system condition that is known to cause unusual stress to the power system and to take some type of predetermined action to counteract the observed condition in a controlled manner. In some cases, SPSs are designed to detect a system condition that is known to cause instability, overload, or voltage collapse. The action prescribed may require the opening of one or more lines, tripping of generators, ramping of HVDC power transfers, intentional shedding of load, or other measures that will alleviate the problem of concern. Common types of line or apparatus protection are not in the scope of interest here”. The corrective actions initiated by SPS assist in mitigating the consequence of the abnormal conditions and these actions are other than isolation of faulted element. System Protection Schemes (SPS) are used when focus for the protection is on the power system supply capability rather than on specific equipment. [9-18].

SPS is also used as the acronym for Special Protection Scheme, which has the same meaning as the system protection scheme. IEEE uses the term System Integrity Protection Scheme (SIPS); Remedial Action Scheme (RAS) is used by Bonneville Power Administration (BPA), WECC; others use the term SPS [10].

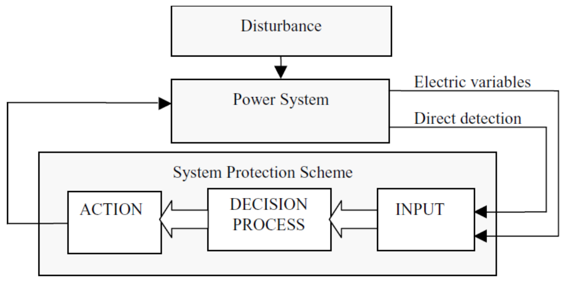

Figure 2: General Structure of a SPS [9]

The general structure of a typical SPS [9] is as shown at figure-3. SPS consists of three main parts i.e., the input which is the level of physical magnitudes & status of circuits breakers, decision making system which initiate some actions based on inputs and output/ action which may be generator tripping/ back down or load tripping. SPS are tailor made schemes & are normally sleeping systems which operate infrequently. The Control actions taken are predetermined & can be armed or disarmed depending upon system conditions [9].

SPS can comprise of a large number of coordinated actions, in a cascaded manner. One of the vital elements of SPS design is a reliable and secure communication infrastructure for data exchange amongst monitoring, controlling and action 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). [17]

IV. MAJOR SPS DEPLOYED IN INDIAN POWER SYSTEM

The most common SPS are probably automatic load shedding schemes triggered by either under frequency, under voltage, or high rate of change of frequency. These have been deployed extensively in the Indian power system. However, these generally have local measurement, local processing and local actions. The other major wide area SPS operational in the regional grids in India are given in table 2.

Table 2: Major SPS deployed in Indian power system

S No.	Description	Identification / (In service since)
1	Load shedding in SR and generation rejection in ER subsequent to tripping of HVDC Talcher-Kolar Bipole	SPS_01_ER-SR (2006)
2	Load shedding and/or generation rejection within NR subsequent to tripping of HVDC Rihand-Dadri Bipole	SPS_02_NR (2007)
3	Generation rejection at Jhakri HEPS subsequent to tripping of one or more evacuating feeders from 400 kV Jhakri	SPS_03_NR (2010)
4	Load shedding in NR and/or generation rejection within NR as well as in ER subsequent to tripping of HVDC Balia-Bhiwadi Bipole	SPS_04_NR (2011)
5	Generation rejection at Wangtoo HEPS subsequent to tripping of one or more evacuating feeders from 400 kV Jhakri	SPS_05_NR (2011)

The SPS for HVDC Talcher-Kolar (SPS_01_ER-SR) has been designed to simultaneously shed load in Southern Region and reduce generation in Eastern region subsequent to the tripping of HVDC Talcher-Kolar Bipole an asynchronous link between Eastern Region and Southern Region. It has a capacity of 2x1250 MW. The tripping of this link would create a deficit in Southern Region and surplus generation in Eastern Region (part of NEW grid). Details may be referred in [19].

It may be seen that out of the five SPS listed in table 2, three (SPS_01, SPS_02 and SPS_04) are related to the contingency of HVDC Bipole while the remaining two (SPS_03, SPS_05) are related to the contingency of high capacity AC transmission corridor. All the above schemes were designed and executed as a part of operational planning. The schemes have proved their worth by successful operation on several occasions. Several other SPS are under implementation. These include SPS for reliable evacuation of generation under depleted network conditions; condition for high capacity AC corridor; SPS for ICTs; SPS based on under voltage etc.

V. MAJOR SPS DEPLOYED IN NORTHERN REGIONAL POWER SYSTEM IN INDIA

A. SPS for outage of + 500 kV HVDC Rihand-DadriBipole of 1500 MW capacity (SPS_02_NR)

The 2x750 MW HVDC Rihand-Dadri bipole is one of the major high capacity links between the pit head generating stations in south – east part of northern region (NR) and the load centres in the North-western part of NR. It operates in parallel with other AC transmission lines [refer figure-1]. Outage of this link results in overloading of the parallel AC network and low voltage in the Northwestern part of the NR grid. In the past tripping of this link had resulted in system separation within NR. Therefore in order to secure the system under contingency of the HVDC link, an SPS has been designed and implemented to carry out automatic generation rejection at thermal power stations located in South-east NR and load shedding at several locations in Northwest part of the NR grid. The commissioning of this SPS has facilitated higher loading of the East-West corridor within NR. For the purpose of load shedding the loads have been distributed in different groups say group- A, B, C & D in western part of the grid. Details of the corrective action logic for different cases are as explained in table [3].

Table 3: Logic for corrective action in SPS_02_NR

	Contingency	Action 1	And Action 2
Case-1	Tripping of any or both poles resulting in power order reduction by 750 MW and above	Immediately Shed Loads in Groups A, B, C & D.	Reduce generation at Singrauli/Rihand by 500 MW in the fastest possible time, and
Case-2	Tripping of any or both poles resulting in power order reduction above 500 MW but less than 750 MW	Immediately Shed Loads in Groups C & D.	--------

The response of generation reduction due to SPS action during the incident of HVDC bipole tripping carrying 1415 MW on 12th Jan 2011 at 14.27 hrs are shown in figure 3. An SPS similar to the one described above has been designed for contingency of HVDC Balia-Bhiwadi Bipole (SPS_04_NR).

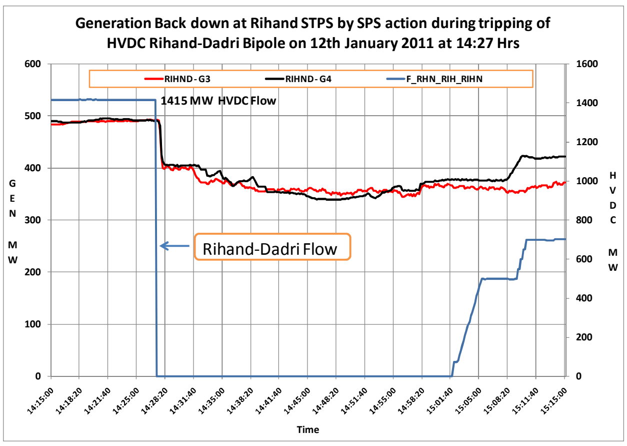

Figure 3: Generation backing down at Rihand on 12th January 2011

B. SPS for reliable evacuation of 6x250 MW of Jhakri HEP + 3x100 MW of Baspa (SPS_03_NR)

Jhakri-Baspa generation complex is located on the Sutlej river basin in Himachal Pradesh. The total installed capacity of Jhakri and Baspa prior to the commissioning of Karcham Wangtoo HEPS was 1800 MW. Out of the four evacuating feeders that are in operation, two are towards 400 kV Nalagarh (144 km each) and two are towards 400 kV Abdullapur (180 km each) [refer figure-4]. All four circuits are triple snowbird conductors and they are adequate for evacuating complete generation from Jhakri and Baspa. On 19-November 2009, 400 kV Jhakri-Abdullapur-I went under forced outage due to failure of GIS breaker of this line at Jhakri end. Jhakri HEP generating station is a Gas Insulated (GIS) substation with double bus and single breaker scheme. The damaged circuit breaker associated with 400 kV Jhakri-Abdullapur-I required import of components from abroad, that resulted in long outage of one out of four lines evacuating generation from this hydro complex. In the meantime, with only three circuits in service, the evacuation of full generation (1800 MW) from this area was highly unreliable and it was not fulfilling the 'N-1' criteria. Therefore in order to avoid spillage of water and to ensure secure evacuation of generation from the Baspa-Jhakri complex during peak hydro season, SPS_04_NR was designed as a contingency measure. The SPS envisaged automatic rejection of generation at Jhakri HEPS subsequent to the tripping of circuits downstream of 400 kV Jhakri. The scheme was commissioned before the beginning of the peak hydro period in 2010 and it gave a lot of confidence to the operators and it also helped in avoiding spillage at Jhakri/Baspa. 400 kV Jhakri-Abdullapur-I was restored on 06th April 2011.

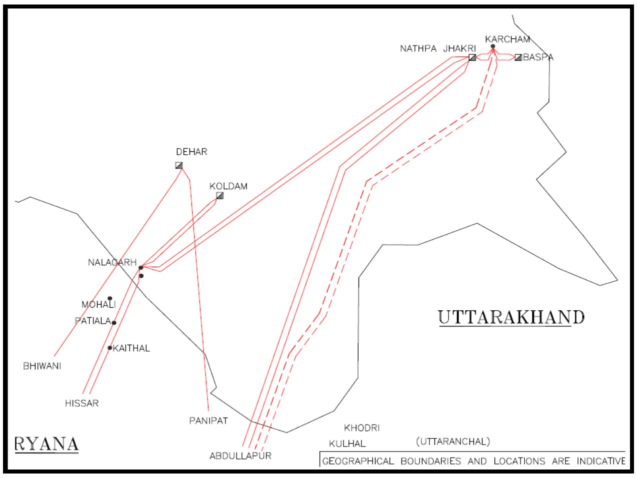

Figure 4: Evacuation system for Jhakri-Baspa-Karcham complex

C. SPS for reliable evacuation of 2x250 MW of Karcham Wangtoo HEP through the existing evacuation system of Jhakri-Baspa HEP (SPS_05_NR)

4x250 MW Karcham Wangtoo HEPS is a new hydro station that has been envisaged on the upstream of Jhakri HEPS on the same river basin. For evacuating generation from Karcham Wangtoo, an additional double circuit quad conductor line from 400 kV Karcham to Abdullapur along with loop in loop out of 400 kV Baspa-Jhakri HEPS at 400 kV Karcham was planned. The LILO was completed in May 2011 and the 2x250 MW units of Karcham were also ready for synchronization in May/June 2011. However the commissioning of the new circuits from 400 kV Karcham to 400 kV Abdullapur was delayed due to various reasons. Therefore, there was no evacuation for Karcham Wangtoo HPS (KWHPS) except through the existing transmission system of Jhakri/Baspa complex as shown in figure 4.

Two alternatives emerged under the given circumstances. One was to hold up generation at Wangtoo HEPS till the commissioning of 400 kV Karcham-Abdullapur D/C while the second was to evacuate the generation at Wangtoo along with the generation at Jhakri and Baspa HEPS. In order to avoid a bottling of hydro generation at the time of peak inflows and at the time when the demand was at peak in the grid and also to ensure reliability and security of the grid, another SPS in addition to the existing SPS for Jhakri and Baspa, was implemented as a contingency arrangement. The scheme was designed for immediate dropping of generation at Karcham - Wangtoo HPS in case of tripping of any one of the downstream circuits emanating from Jhakri. The generation rejection at Karcham Wangtoo would also be carried out whenever the total evacuation from the complex exceeds 1800 MW with only three out of four outgoing circuits in service from 400 kV Jhakri.

VI. ANALYSIS AND LEARNING FROM SPS OPERATIONS

Summary of SPS Operation events in Northern Region is shown in table 4. These events have also been segregated into three categories. The events under category C1 are successful SPS operations i.e. events where SPS operated as designed and the desired actions were also achieved. The events under the category C2 are misoperations of SPS. The misoperations include events where either the SPS operated but the desired actions could not be achieved; or the SPS operated when it was not envisaged; or the SPS did not operate when it should have operated. The misoperations were either due to inadequacy of logic or issues in implementation.

Table 4: SPS operation in Northern Region

S No.	Date, Time	SPS that operated	Category
1	14-12-2007, 07:49	SPS_02_NR_Rihand	C1
2	12-02-2008, 14:30	SPS_02_NR_Rihand	C2
3	26-04-2008. 12:37	SPS_02_NR_Rihand	C2
4	28-08-2008, 09:50	SPS_02_NR_Rihand	C2
5	15-09-2008, 14:56	SPS_02_NR_Rihand	C1
6	22-09-2008, 02:01	SPS_02_NR_Rihand	C1
7	22-10-2008, 13:26	SPS_02_NR_Rihand	C2
8	22-10-2008, 14:06	SPS_02_NR_Rihand	C2
9	17-11-2008, 12:03	SPS_02_NR_Rihand	C2
10	20-11-2008, 04:00	SPS_02_NR_Rihand	C2
11	22-11-2008, 15:30	SPS_02_NR_Rihand	C2
12	28-12-2008, 00:00	SPS_02_NR_Rihand	C2
13	28-12-2008, 10:02	SPS_02_NR_Rihand	C2
14	29-04-2009, 11:22	SPS_02_NR_Rihand	C2
15	29-04-2009, 12:30	SPS_02_NR_Rihand	C2
16	15-08-2009, 21:16	SPS_02_NR_Rihand	C2
17	23-11-2009, 04:19	SPS_02_NR_Rihand	C1
18	01-04-2010, 01:12	SPS_02_NR_Rihand	C1
19	08-09-2010, 06:52	SPS_03_NR_NJPC	C1
20	12-01-2011, 06:28	SPS_02_NR_Rihand	C1
21	06-06-2011, 19:11	SPS_05_NR_Karcham	C1
22	09-06-2011, 15:59	SPS_05_NR_Karcham	C1
23	16-07-2011, 04:29	SPS_05_NR_Karcham	C1
24	16-07-2011, 15:02	SPS_05_NR_Karcham	C1

It may be seen from table 4 that several misoperations were observed during the initial period of SPS implementation for HVDC Rihand- Dadri. These misoperations were investigated and it was found that spurious tripping command was getting generated due to 'bit error' in the data communication channel of the multiplexer. These were overcome by introducing 'destination addresses' in the control signals initiated by SPS logic. Few loose connections were also found at the data interface tag block. These were replaced with terminal blocks having firm grip on the connecting cables. After carrying out the above modifications it was observed that misoperations were curbed after the modifications.

VII. TESTING OF SPS IN NORTHERN REGION

Besides routine testing during commissioning of the scheme, mock testing of the SPS in operation in Northern Region was carried out to check the healthiness of the SPS [refer Table 5]. These tests involved meticulous co-ordination with multiple agencies. Detailed plan was prepared and circulated to all stakeholders well in advance. During the mock testing the control signals for load shedding and/or generation rejection were disabled and high alert was maintained. During the mock tests it was found that the SPS were generally in order. The stray deficiencies revealed during these exercised were taken up for rectification.

Table 5: Mock test of SPS in NR

S No.	Mock test date	SPS tested
1	08-August-2008	SPS_02_NR
2	15-August-2009	SPS_02_NR
3	24-May-2011	SPS_02_NR and SPS_04_NR
4	29-July-2011	SPS_05_NR

VIII. CHALLENGES IN SPS IMPLEMENTATION

The major challenges experienced in implementation of SPS in Northern Region are listed below:

a) Convincing the stakeholders
b) Development of SPS design and its testing
c) Identification of interruptible loads
d) Coordination during implementation
e) Availability of reliable and high speed communication system
f) Mock test and monitoring of SPS operation
g) Achieving the desired actions from SPS within a reasonable operational time

IX. CONCLUSION AND SCOPE FOR FUTURE WORK

In a large interconnected system the risks and stakes are very high. It is difficult to plan and secure the system for all contingencies that are experienced in real time. The operational experience with the System Protection Schemes has been encouraging as they have been found to be effective in mitigating the security threats to a large extent. However SPS should not be conceived as a substitute for adequacy in transmission.

Unit protection system is generally considered as first generation protection philosophy and the SPS are 2nd generation protection system. The SPS try to automate what otherwise would have been implemented through a series of manual operator actions. It assists in maintaining system stability by cutting down on the time taken between a contingency and corrective actions. Thus the total operating time of the SPS is of vital importance. Suitable care must therefore be taken to avoid undesirable delays in SPS operation. The reduction in SPS operation time would enhance the stability of the system and facilitate larger power transfer.

The misoperations in SPS need to be minimized to sustain the stakeholders' faith and confidence on the SPS. The inadequacy of high speed dedicated communication network is emerging to the biggest infrastructural bottleneck during execution of the SPS. Attention is also required for creating in capacity building for simulation of SPS logic and its impact on the system.

Synchrophasors have now been deployed in Indian Grid for real time monitoring of network, disturbance analysis and model validation. Efforts are now required to achieve wide area monitoring control (WAMCS) through SPS action based on data from synchrophasors [20].

DISCLAIMER

The views expressed in the paper are the opinion of the authors and may or may not be that of the organization to which they belong.

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