SPECIAL SYSTEM PROTECTION SCHEMES IN SOUTHERN REGION POWER SYSTEM- A CASE STUDY

(S.K. SOONEE) (P.R. RAGHURAM) (S.P. KUMAR) (D.K. GURU)
POWER GRID CORPORATION OF INDIA LTD.
SOUTHERN REGIONAL LOAD DESPATCH CENTRE. BANGALORE

ABSTRACT:

The Electric Power System in India is undergoing major structural changes. The growth of power system is high in India when compared to the developed countries. Implementation of a scientific settlement system (Availability Based Tariff) introduction of Open Access in transmission and increased inter regional capacity has resulted in merit-order based generation dispatch causing economy across the entire country. Transmission additions are lumpy in nature. Generating units of higher capacities (1000 MW) and HVDC interconnections of large transfer capability (2000MW) are being added to the grid.

Outage of such higher capacity elements is not totally avoidable and endangers the normal operation of the power system and may lead to a blackout if automatic fast suitable corrective action is not taken. With the increased complexity of the power system and reduced margin, Special Protection Schemes (SPS) are to be designed and implemented to combat such eventuality. Classical protection schemes protect the power system element from damage but may not help preventing total system collapse for which SPS are essential. SPS in India are in their infancy and are yet to be recognized formally as an important faculty.

Key Words: Power System Operation-Special Protection Schemes-Southern Regional Grid.

Introduction

The power system in India has grown from a small stand-alone system (individual self sufficient units along with matching load of area like palace, towns etc) to a large integrated and complex combination of generating units and transmission network covering larger geographical areas beyond national boundaries. It is no wonder that power system has been rated as the greatest invention of the previous millennium. Integration of power system with hundreds of generators and thousands of kilometers of lines into a single operating system with split-second synchronization has been one of the greatest scientific achievements of mankind in the last millennium. The impact of a prolonged interruption in the electric power supply would be much larger than the economic loss to the energy sector alone. The dependency on new technologies has increased the dependency on power. Any disruption of power supply will increase the cost of outage and hardship to the common man. It is not possible to totally eliminate loss of power to the end users. However power system engineers always try to mitigate the chance of failures and endeavor to restore the system back to normal at the earliest. Electric supply industry all over the world is under tremendous pressure to provide quality power supply at least cost and the industry is metamorphosing from monopolist, monolithic, integrated companies to competitive smaller and restructured companies. This has brought in competition and better service to the end-user. However this has endangered normal power system operation. This has pushed asset utilisation to the maximum extent reducing security margins and demanding more surveillance and quick remedial action in shortest possible time. Such level of surveillance demands a fast customisable protection system. Utilities in India are using Special Protection Scheme (SPS) in one form or other and a wealth of experience is available in this field. A humble attempt is made in this paper to explain the SPS adopted in Southern region.
Following are some of the reasons why a special scheme is required in Indian Power system. Some of these reasons are due to the way the grid is operated

- The standard protection schemes available are rightly designed to protect men and the individual elements from damage. Sometimes such operations may result in widespread disturbance. To reduce the impact of power failure and ensure early restoration, protection schemes are required to sense the danger in the system and take corrective action.
- The modern trend in power system is to achieve economy, through economy of scale by installing high capacity Generating Units, constructing pit-head power plants and having HVDC interconnection of large transfer capability. Outage of such high capacity units endangers the stability of the grid
- Introduction of new commercial settlement in India (Availability Based Tariff Mechanism) has brought in overall economy in the whole country. This has resulted in skewed generation and load pattern, which were not what the grid was designed for.
- With unbundling of state utility and advent of open access, competition will increase, put pressure on transfer margins in a transmission system and overall cost of power will come down
- Generators coming up earlier than its planned evacuation results in a security threat till the planned systems are fully commissioned
- The system planners tend to utilize the existing network causing the network to be over-utilized
- The cyclic nature of generation and loads causes overloading to be seasonal and transmission lines get over loaded during some seasons This may not justify putting new lines
- The staggering and rostering of loads which is a common phenomena in India also causes over loading of corridors during particular hours of the day.
- At many places environmental problems do not allow more transmission corridors to be built for power evacuation

Due to the above mentioned reasons a conservative system operator tries to work with more margins to take care of contingencies resulting in uneconomic operation. Special Protection Schemes give confidence to the system operator and empowers him to enhance the power flow through the system and work with less margins.

**What is Special Protection System (SPS)**

According to P.M. Anderson [2] SPS is defined 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".

**Characteristic of SPS**

P.M. Anderson [3] has clearly brought out various characteristics of SPS

1. These protections are also known by other names depending on the originator like
   - Special stability controls
   - Dynamic security controls
   - Contingency arming schemes
   - Remedial action schemes
   - Adaptive protection schemes
   - Corrective action schemes
   - Security enhancement schemes

2. In these schemes, depending on the type of the problem, action such as tripping of generators, intentional islanding of the system at predetermined locations, tripping of loads will be taken.
3. SPS has to be designed with the highest possible degree of reliability and it has to be properly coordinated with the existing protection systems, mainly of the local nature.

4. SPS are dynamic security control systems and are designed to control power system stability in case where the uncontrolled response is likely to be more damaging than the controlled response.

5. SPS are devised by off-line analysis as opposed to on-line real time control. The reason behind being power system response is too fast to allow sequential control system logic. Involvement of a grid operator (human intervention for corrective action) should be kept to minimum contrary to SCADA/EMS (i.e. dispatchers’ actions and maintenance effort).

6. SPS are designed to take special action in response to the event disturbances detailed below either individually or in combination:
   - Transmission faults
   - Cascading outage of lines
   - Generator outages
   - Sudden large load changeovers
   - HVDC pole blocking

The above disturbance may cause the following problems in power systems. The solutions for the same are also detailed below (1):

- Frequency Instability – The power system frequency going beyond operating limits
  - Tripping of generators
  - Fast generation reduction through fast-valving or water diversion
  - HVDC power transfer control
  - Load shedding
  - Controlled opening of interconnection to neighboring systems to prevent spreading of disturbance
  - Controlled islanding of local system into separate areas with matching generation and load

- Voltage Instability - Inability of the power system to maintain steady acceptable voltages at all buses in the system
  - Change of the generator voltage set point
  - Automatic shunt switching
  - Control of series compensation
  - Blocking of Tap Changer of transformers
  - Under voltage load shedding

- Transient Angular Instability - Inability of the system to maintain synchronism
  - Braking resistor, FACTS devices etc.
  - Reducing the mechanical power driving the generator
  - Fast-valving, disconnection of the generator etc.

Ways of recognizing possible conditions requiring remedial action are (5):

- The condition may have actually occurred.
- Review of actual data after the occurrence of some contingency or line outage may indicate a near unstable swing, voltage collapse or other system problem. Useful data includes line power flows, transformer loading, system voltages, frequency, generation response, oscillographs, relay targets, and/or logic output, and sequence of events outputs.
- Load flow, planning, and stability studies for new transmission lines or new generators may indicate possible problems.

Survey about the installed SPS carried out by CIGRE and IEEE (2) indicate the following:

- The degree of complexity is rapidly increasing and the schemes are becoming more and more sophisticated.
- SPS are system specific and unique.
- All installed SPS are either fully or in major part designed and installed by utilities.
• SPS should be armed all the time as the cost of the false trips is generally much lower than the cost of failure of the SPS to operate when required. This implies that even with the risk of malfunction, SPS installation is economically beneficial/profitable.

The four main design criteria, which should be used for SPS, are [1]:

• **Dependability** – The certainty that the SPS operates when required, that is, in all cases where emergency controls are required to avoid a collapse.

• **Security** – The certainty that the SPS will not operate when not required, does not apply emergency controls unless they are necessary to avoid a collapse.

• **Selectivity** – The ability to select the correct and minimum amount action to perform the intended function, that is, to avoid using disruptive controls such as load shedding if they are not necessary to avoid a collapse.

• **Robustness** – The ability of the SPS to provide dependability, security and selectivity over the full range of dynamic and steady state operating conditions that it will encounter.

**The Southern Regional Grid – An overview**

Southern Regional grid is a large system comprising of four State systems viz. Andhra Pradesh, Karnataka, Kerala and Tamilnadu systems interconnected with each other through 400 kV grid network and some 220 kV inter-State lines. The Union Territory of Pondicherry is interconnected through 230KV Neyveli-Pondy link. There are two major Central Generating Stations connected to the 400 kV grid viz. Ramagundam Super Thermal Power Station (3x200+3x500 = 2100 MW) in the northern part and Neyveli-II (7x210 = 1470 MW) and Neyveli Expansion (2x 210 MW) in the southern part of the 400 kV system. The 400 kV system not only evacuates the Central generation to the State systems through inter-connected transformers but also plays an important role in the integrated operation of the Southern Regional grid under normal and abnormal conditions. The other Central Generating stations are the Madras Atomic Power Station (MAPS; 2x235 MW de-rated to 390 MW), which is interconnected with the 230 kV system of Tamilnadu and the Kaiga Atomic Power Station (2 x 220 MW) evacuated through 220 kV system at present. The Southern Regional Grid diagram is given in Annex -1.

The installed capacity of the Region is 31,316 MW (as on 31st August 2004) with thermal (including Nuclear and Gas) and hydro mix in the ratio of 67:33. The chart in Fig 1 shows the break up in percentages of generation mix available in the region.

![Fig 1](image)

The Southern Regional Grid is connected to Western Region through 400KV Ramagundam-Chandrapur D/C lines; 2 Pole, total 1000MW capacity, HVDC Back to Back terminal at Chandrapur.
The Southern Region is connected to the Eastern Region through two links
- Back to Back HVDC station at Gazuwaka (in north-coastal Andhra Pradesh)- Capacity 500 MW
- A 1250 km long ±500 kV HVDC line from Talcher in Orissa to Kolar in Karnataka, with Converter/inverter stations at Kolar and Talcher – Capacity 2000 MW

The Southern Region has experienced a maximum demand of about 22,000 MW
The Southern Regional grid load is predominantly agricultural in nature. This region faces two monsoons (south-west and north-east), which play important role in the system operation.

**Special Protection Scheme; Southern Region experience**

The first experience and an example of Controlled islanding of local system into separate areas with matching generation

The first special protection scheme was implemented in Southern Region in 1996
The Southern region at that time could be considered as a two-block system (Andhra Pradesh, Karnataka and Tamilnadu, Kerala) connected by two 400kv tie lines viz CUDAPPAMADRAS and SALEM-BANGALORE which were the null points. Load and generation in each block was almost balanced. However about 300MW of power was flowing towards Karnataka from Tamilnadu via SALEM-BANGALORE line and about 300-400 MW of power was flowing from AP to Tamilnadu via CUDAPPAMADRAS line. The diagram of the SR Grid in 1996 is shown below in Fig-2 (last page of this paper)

The Southern Region used to get islanded into two blocks by opening CUDAPPAMADRAS and SALEM-BANGALORE lines. By this Andhra Pradesh, Karnataka and Tamilnadu, Kerala used to form two separate blocks.
Following were the settings of the relays provided at Madras substation and Salem substations for generating the required signals. Two-out-of-three logic was adopted to increase the reliability of the scheme

<table>
<thead>
<tr>
<th>Line Name</th>
<th>Frequency Below (Hz)</th>
<th>POWER FLOW(MW)</th>
<th>Time delay (second)</th>
<th>Type of Relay</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUDAPPAMADRAS</td>
<td>47.8</td>
<td></td>
<td>0.5</td>
<td>UF</td>
</tr>
<tr>
<td>SALEM-BANGALORE</td>
<td>47.8</td>
<td></td>
<td>1</td>
<td>UF</td>
</tr>
<tr>
<td>CUDAPPAMADRAS</td>
<td>48.0</td>
<td>100 MW towards</td>
<td>0.5</td>
<td>RPUF</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CUDAPPAMADRAS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SALEM-BANGALORE</td>
<td>48.0</td>
<td>300 MW towards</td>
<td>1</td>
<td>RPUF</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BANGALORE</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This scheme has prevented Southern Region from total Blackouts. Tamilnadu had further adopted splitting of their system into three islands in case of Load Generation imbalance. But with the augmentation of the grid and increase in number of tie-lines the natural islanding was not feasible any more and was discontinued in 2003.

**Example of Generation backing down**

**SCHEME IMPLEMENTED AT KAIGA ATOMIC POWER STATION**

Generating stations Kaiga, Kadra, Kudasalli, and Nagjhari forming a generating complex of 1565 MW are located in north-western part of Karnataka and are connected to load centers of Hubli and Guttur of Karnataka. The Kaiga APS is connected to the load center via Kaiga – Guttur 400kV D/C lines presently charged at 220kV level. Besides it is connected to the other generating stations of this block via two 220kV lines (FIG 3). Construction of 400kV switchyard is under progress in Kaiga. Further construction of 400kV transmission lines from Kaiga is delayed because of environmental issues. The evacuating lines of this block are passing through thick forest and tripping of lines on fault during rainy season is not avoidable, thus resulting in frequent outage of lines. On number of occasions, Generators at Kaiga have tripped due to tripping of one of evacuating lines of this block resulting in cascade tripping of lines and
generators of this block. Tripping of Kaiga units invariably results in poisoning of reactors and takes minimum of three days to comeback on bars. This also has safety implications. To avoid this, the following SPS has been implemented(7).

Detection of tripping of the evacuating lines of this block at other locations is sensed at Kaiga by increase of power flow on Kaiga – Kodashalli and Kaiga – Kadra circuits. If power-flow on these circuits is more than 600 Amps for 1sec OR is more than 900 Amps for 300 msec, these lines are tripped and prevent tripping of Kaiga Guttur lines on over-load. This prevents tripping of Kaiga generators as they have an evacuation path. Hydel machines of this block can be brought back as and when required. Whenever, one circuit of Kaiga – Guttur is not available and power flow on the other circuit is more than 850 Amps – One generating unit at Kaiga goes to house load to prevent tripping of available Kaiga-Guttur line and subsequent tripping of both the generators.

House loading of units during extreme frequency variation

Whenever this block gets separated from rest of the grid it faces very high frequencies. Similarly, whenever Karnataka system gets separated from rest of the grid Kaiga station experiences under frequency. To avoid damage to the plants generating units at Kaiga go to house load at the following settings

- Frequency more than 51.5 Hz for 500 msec
- Frequency less than 47.5Hz for 500 msec
- Frequency less than 47.7 Hz for 4 secs,

The evacuation arrangement of Kaiga Atomic Power Plant is at Fig 3.

Example of fast load relief -Inter trip scheme at Kolar

Talcher – Kolar is a 2000 MW HVDC link between Eastern and Southern regions. At present this link is normally carrying about 1500MW of power and it is likely to increase to full capacity in near future. The outage of Talcher – Kolar causes wide fluctuations in transmission between Karnataka and AndraPradesh system (Cuddapa-Kolar). Frequency of southern grid will dip more than 1Hz and may result in further disturbance. To prevent this in the event of tripping of Talcher – Kolar HVDC lines or loss of more than 400 MW power, loads are shed in the following near-by substations of AndraPradesh, Karnataka, and Tamilnadu.

- Yeraguntala
- Kolar
- Hosur
- Salem
- Sriperambadur
- Hoody
- Somanahalli

Loss/reduction of power is sensed at Kolar and signals are sent through PLCC to these substations. Through this scheme, a load relief of about 500MW to 600 MW is obtained. A Grid Map of Southern Region with the trip-signal plotted is at Figure-4 below.

INTER-TRIP AT KOLAR: The different power flows on which inter trip signal is generated:

<table>
<thead>
<tr>
<th>MODE OF OPERATION</th>
<th>POWER LEVEL FOR GENERATING INTERTRIP SIGNAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>MONO POLAR</td>
<td>&gt;400 MW AND THE POLE TRIPS</td>
</tr>
<tr>
<td>BI-POLAR</td>
<td>IF BOTH POLE ARE CARRYING &gt; 800 MW EACH AND ONE POLE TRIPS</td>
</tr>
<tr>
<td>BI-POLAR</td>
<td>IF POWER FLOW ON EACH &gt; 200 MW AND BOTH POLE TRIP</td>
</tr>
</tbody>
</table>

Automatic tripping of loads during overloading of Transformers

In Southern region, to prevent cascade tripping of 400KV/220KV parallel Transformers during tripping of other transformers the overload trip relay was wired only to alarm circuit and depending on available CT ratio directional over current relays have been set to trip the transformer at 125-150% of load. On some occasion it has been observed that immediate action is not forthcoming for reduction of the loads putting transformer safety in jeopardy. To overcome this a trip signal is automatically generated when the
transformer is overloaded beyond 110% and sent to adjacent substation to trip radial loads to give immediate relief. This scheme is working satisfactorily at 400kv Somanahalli, Hoody, Nelamangala substations of Bangalore.

Under frequency and DF/DT protection

Elaborate under-frequency load relief scheme is in operation in Southern region. In addition, to overcome the sudden outage of units and frequency going below 49Hz, dF/dT relays are provided and setting adopted is 49.5 Hz and freq drop of more than 0.3.HZ per sec.

Ramp up and Ramp down of power In HVDC Stations Operation of PDO’s
To reduce the effect of outage of lines /overloading of transmission elements on either side of HVDC stations, automatic reduction of power transfer through HVDC is carried out by operation of Power Demand Override (PDO) Control. Following are the settings of different PDO’s of HVDC stations in southern region.

AT HVDC Gazuwaka

<table>
<thead>
<tr>
<th>SCHEME</th>
<th>POWER REDUCED TO</th>
</tr>
</thead>
<tbody>
<tr>
<td>INDRAVATI-JEYPOR OR JEYPORE ICT TRIPPING</td>
<td>250 MW</td>
</tr>
<tr>
<td>F + DF/DT ON EAST BUS 49.0 Hz and 0.3 Hz/sec</td>
<td>150 MW</td>
</tr>
<tr>
<td>Under Voltage at Jeypore(&lt;320 kV)</td>
<td>250 MW</td>
</tr>
<tr>
<td>110 % Over Loading of Gazuwaka ICT</td>
<td>250 MW</td>
</tr>
</tbody>
</table>

AT HVDC KOLAR

<table>
<thead>
<tr>
<th>SCHEME</th>
<th>POWER REDUCED TO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Only Two evacuating lines available</td>
<td>500MW</td>
</tr>
<tr>
<td>Only Three evacuating lines available</td>
<td>1000MW</td>
</tr>
<tr>
<td>Only Four evacuating lines available</td>
<td>1500MW</td>
</tr>
</tbody>
</table>

Proposed SPS in Southern Region

For loss of 2000MW of power import at Kolar
After commissioning of all units at Talcher (2000 MW) power flow on this link will increase to 2000MW. To take care of the contingency of loss of 2000 MW, effective load relief is planned across a wide area by sending inter-trip signal to the following substations using wide-band communication system.

| Somanahalli | Gooty Switching Station |
| Chinakampalli | Ananthapur |
| Somayajulapally | Kurnool |
| Madurai | Karaikudi |
| Thiruvarur | Trichy230 |
| Ingur | Trichur North |
| Kozhikode | |

From wide-band points, Signals will be relayed to the load points through PLCC

This scheme is under implementation.

Backing down of generation at Raichur

Raichur Thermal PowerStation is connected to Bangalore (load center) through two 400kv paths viz Raichur- NagarjunaSagar- Gooty-Hoody and Raichur-Guttur-Hirur-Nelamangala-Hoody
In the past four years there have been six major disturbances affecting most parts of Karnataka due to breaking of the loops and non- availability or tripping of feeders. Occurrence of second contingency causes reversal of power and power swings. Sensing of opening of the loop is to be detected by Reversal of power flow on Raichur- NagarjunaSagar feeder at Raichur and if it exceeds by 700Mw, one unit at Raichur is tripped or generation is reduced by about 200 MW. This will save Karnataka system from total collapse
Conclusion

In this paper a case study of SPS adopted in Southern Region Power System of India, the need of SPS, evolution of SPS, present position and future SPS planned for the Southern Region power system are deliberated from the system operator’s point of view. With the adoption of SPS’s explained above spreading of disturbance has been contained and localised.

SPS’s adopted is discrete open loop control. This method holds good as long as we have few long lines connecting the generators and the load centers. Indian power system is a growing system As the power system matures and the complexity of the network increases, identifying the occurrences of the events by change in line-flows etc becomes difficult. The use of GPS technology for computation of Synchronised Phasor Measurement is fast developing due to low cost of communication and computation. We may have to adopt wide area protection and control based on Phasor measurement to over-come the problem of increased complexity of the Network and to provide a continuous smooth control for efficient and stable Power system Operation.

Acknowledgement Authors acknowledge the support given by POWERGRID to publish this paper. The opinions expressed here is that of authors only and not necessarily of that of POWERGRID.

References

5. WSCC Relay workgroup Guide for Remedial Action Schemes WSCC website
6. Extract from FAILSAFE The Electronic Journal Of The forum for environmental law science engineering and finance FALL.2003
8. Consequence and Impact of electric Utility Industry Restructuring on Transient Stability and small signal Stability Analysis Vijay Vittal Power System Engineering Research Center Web site
10. System Blackout causes and cures Damir Novosel www.energypulse.net Energy pulse
KOLAR INTER-TRIP SCHEME

FIG:-3

FIG:-4

HVDC BI-POLE
400 KV DC LINE
TRIP SIGNAL