

An Indian Experience of Defense Against Blackouts and Restoration Mechanism Followed

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Abstract-- In this paper with the background of evolution of regional electricity grids in India aiming at the formation of National Grid, Indian experience of running the electricity grid with the procedure established to safeguard the system against possible blackouts has been detailed. This has been followed by the restoration measures adopted earlier in the event of such occurrences and as envisaged for future, particularly in the context of four out of five regional grids operating in synchronism and the remaining one connected asynchronously with the rest.

Index Terms-- Black out, black start, fog, islands, load crash, restoration, synchronization.

I. NOMENCLATURE

CIGRE: International Council on Large Electric Systems
ERS: Emergency Restoration System
FGMO: Free Governor Mode Operation
RLDC: Regional Load Dispatch Center
SPM: Suspended Particulate Matter
SPS: System Protection Schemes
SVC: Synchronous Var Compensator
TCSC: Thyristor Controlled Series Compensator
UFR: Under Frequency Relay
UVLS: Under Voltage Load Shedding

II. INTRODUCTION

POWER system in India developed from distributed small systems to state grids. In order to derive benefits of interconnections, the state grids were interconnected to form regional grids. In sixties five regional grids were planned for the country based on various operational, technical, geographical and political considerations aiming for at least regional self-sufficiency. However, soon need arose for to and fro exchange of power under contingencies between the self-sufficient regional grids. Fulfilling such a requirement without bringing much change in operational, technical and commercial principles of regional grids, the asynchronous HVDC back-to-back interconnections were put in place

starting with Vindhyachal HVDC back-to-back station connecting the Northern and Western grids in 1990. Diversity in terms of time, festivals, weather, availability of resources and thus crop pattern, industrialization effecting ultimately load pattern, brought in focus the issue of optimization of resources at national level and thus the need of a National Grid. Therefore, number of high capacity AC and DC interconnections were planned and executed. The North Eastern and Eastern grids started operating in synchronism since October 1990 followed by East and West grid in March 2003 and North and East grids in August 2006. Therefore presently, India has two synchronously connected large grids namely Northeast-North-East-West or NEW grid of approx 100 GW capacity and south grid of approx 40 GW capacity with asynchronous transmission capacity of 4.5 GW with the NEW grid. The operation of each of these regional grids is coordinated by the Regional Load Dispatch Centers (RLDCs) [1].

III. UNIQUE FEATURES IN THE CONTEXT OF GRID OPERATION IN INDIA

Indian power system is growing at a very fast pace. Such a high growth scenario brings up new and challenging technical, operational, commercial and regulatory issues very often. In this context some of the unique features are named below [2].

- A statutorily permitted floating frequency band of 49.0 to 50.5 Hz
- Non-enforcement of mandated primary response, absence of secondary response by design and inadequate tertiary response.
- Limited market mechanisms to complement reliability and absence of an explicit ancillary services market
- Resource inadequacy leading to high uncertainty in adhering to maintenance schedules
- Pressure to meet demand even in the face of acute shortages
- Freedom to deviate from the schedules
- Operation without adequate operating reserves
- Haulage of power over long distances

All the above features have a bearing on grid operation under normal, alert, emergency as well as under restorative conditions.

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IV. SAFETY NETS

The operational procedures and safety net provided help in safe and secure operation of the grid. The regional system operators, i.e., RLDCs are mandated to keep power system under safe and secure conditions and restore the system after any eventuality. To carry out above responsibility, the system operators are required to develop the "Operating Procedures" and "System Restoration Procedures" and review these documents periodically along with all stakeholders. These documents are available at respective RLDC's website [1]. Major safety nets available are described below.

4.1. Under Frequency Relay (UFR) Load shedding

Flat under frequency, rate of change of frequency load shedding and islanding schemes have been the backbone of defense plans. These plans have also evolved and have been modified as per the requirement. After the formation of NEW grid, the set points for under frequency relays and quantum of load shedding have been modified. The present setting of UFR are given at Fig. 1 below.

Northern & Western grids	Stage	Initiating Frequency	Time Delay	Load Relief (MW)	
		(Hz)		NR	WR
	1st	48.8	Instantaneous	800	960
	2nd	48.6	Instantaneous	1000	960
	3rd	48.2	Instantaneous	1250	1280

Eastern grid	Stage	Initiating Frequency	Time Delay	Load Relief (MW)
		(Hz)		ER
	1st	48.5	Instantaneous	300
	2nd	48.2	Instantaneous	300
	3rd	48.0	Instantaneous	410

Fig.1. Present UFR settings.

4.2. Rate of change of frequency $[df/dt]$

The relays based on rate of change of frequency change give early indication of the event. However, careful planning is done to correctly set the rate of frequency change. After synchronous operation of 4 grids in India, stiffness has increased and thus rate of change of frequency fall is not very sharp (less than 0.1 Hz/sec in most of the cases). This safety net is also important when islands are formed and stiffness of the island reduces. Therefore, different rate settings for different block of loads are essential.

Synchronization of the regional grids has brought about a paradigm shift in selecting the UFR relay and df/dt relay locations in order to avoid the secondary problems such as enhanced line loadings in some pockets due to UFR action.

4.3 Under Voltage Load Shedding (UVLS)

Though not extensively used currently, stakeholders are being encouraged to have these relays installed so as to make the entire grid secure in case of any contingency.

4.4. Islanding Schemes

Earlier philosophy of islanding system in smaller islands during contingencies has not worked well due to smaller stiffness of the small islanded systems and non availability of free governor mode of operation (primary response). Therefore, most of the islanding schemes have been dispensed with except those with sensitive loads such as large metro cities and or very sensitive generation such as with nuclear power stations.

4.5. System Protection Schemes (SPS)

The System Protection Schemes have been provided at few places. These are to take into account credible contingencies leading to outage of more than a single element. Schemes to take care of outage of load center based power station leading to loss of more than 800 MW are in progress. Scattered ownership of such generators spread across several utilities poses a great challenge as far as installing and commissioning of SPS is considered. The need for including such schemes at the planning stage itself for high capacity transmission lines and mega power stations has been highlighted by the system operator.

4.6. Static Devices

Static devices such as Synchronous Var Compensators (SVCs), Thyristor Controlled Series Compensators (TCSCs) and HVDC controllers have also been employed in Indian system. However, no phase shifters are employed in the Indian grids so far.

V. RESTORATION

Fortunately, in India due to efforts of grid operators and support from all stake holders including regulators, planners and Government, major black outs have not been experienced in the last 5 years. However, minor burnouts and emergency or restorative situations have arisen many a times due to number of factors. Some of such events and consequent challenges faced are being discussed in subsequent sections.

5.1 Philosophy of revival

Both 'Top down' and 'bottom up', 'Sequential' and 'Simultaneous' philosophies of restoration are being used. These have been elaborated in 'System Restoration Procedures' of each regional grid in India [1, 3].

5.2 Priorities

The guiding principles of priorities for extending supply are on account of human safety, equipment safety, minimization of restoration time after black starting and / or getting supply from healthy islands. Major priorities of restoration have been given in [3]. However, there are few regional peculiarities which affect human safety. These are given top priority, such as supply to collieries in eastern grid, railways and hospitals etc. These have also been well documented in the CIGRE

working group report [4]. Emergency supply is also restored on priority to nuclear power stations from safety considerations as these would be depending on only the local back-up from the diesel generating sets. Apart from these, the next priority is to thermal power stations which can be revived quickly and ramped up.

VI. SPECIAL EVENTS AND OPERATING CONDITIONS

Some of exceptional events are discussed below.

6.1 Extreme weather conditions

6.1.1 Fog in northern part of India

Every year northern part of India is severely affected by dense fog along with biting cold weather during the months of December / January. The pollution deposited over insulator strings coupled with fog becomes killer smog for the transmission lines which start auto-reclosing due to flash over. Repeated flash over can result into insulator puncture and line break down. Such incidents have been on the rise due to high Suspended Particulate Matter (SPM) levels and the number of days that the electricity grid was adversely affected is illustrated graphically at Fig. 2. A sample of tripping that occurred on the night of December 22/23, 2005 is indicated in Fig. 3. Part of the systems had separated and collapsed on December 23, 2005. Fig 4 indicates such tripping for January 27, 2007.

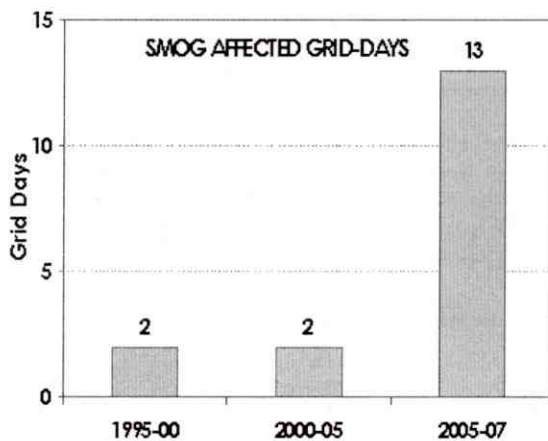


Fig. 2. Major fog affected days.

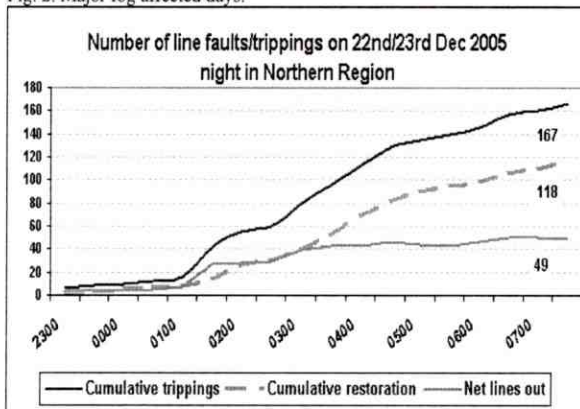


Fig. 3. Line tripping on December 22/23, 2005 due to fog / smog.

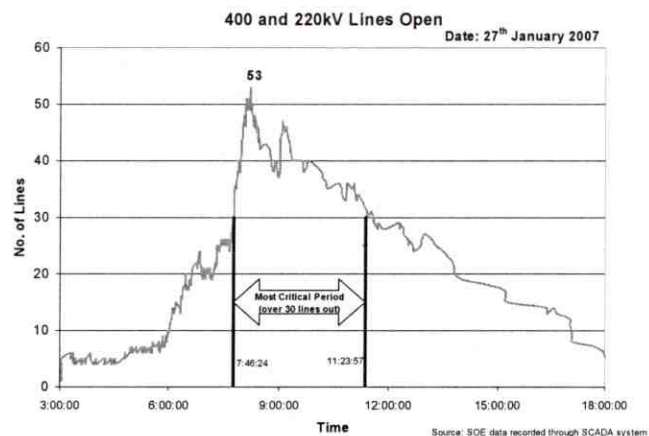


Fig. 4. Line tripping on January 27, 2007.

Under these circumstances, keeping the system interconnected remains the greatest challenge as transmission corridors get depleted. The system separation under such situations would invariably result into collapse of the smaller island. Reviving the island would have its own problem and has to be revived as per island approach or sequential approach based on the collapsed area and availability of black starting units in the area. As the problem occurs during winter when hydro generation is low, delay in synchronizing the system might result in a setback to the restoration process as the hydro generation would get depleted.

Black start of hydro stations and islanded operation of station poses a major challenge as power stations are not familiar with operating their units on primary response (FGMO). Frequency excursions of Salal hydro station during islanded mode of operation after the tripping on December 23, 2005 is depicted in Fig. 5. It is clear from above that FGMO operation is completely off and therefore, unit was not able to operate in islanded mode.

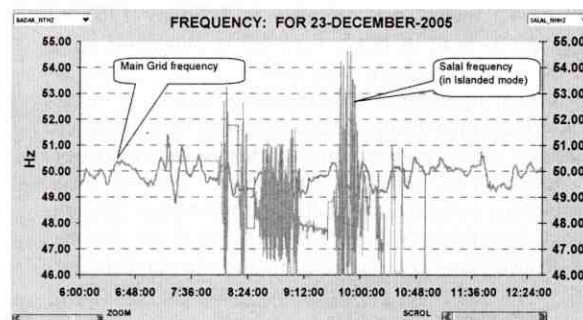


Fig. 5. Islanded operation Salal unit on December 23, 2005.

The incident highlights the requirements of technological solutions for fighting the 'killer smog'. A committee of experts has decided for hotline washing of insulators and change of insulators based on pollution level [5]. Fog forecasting and assessment of the impact of environmental conditions on the performance of power system would also

Similar load crashes take place whenever there are dust storms or thundershowers in the region and the intriguing part of these load crashes is that the load bounces back to normal level within a few hours. The only plausible explanation for this phenomenon could be the traditional practice of manual switching of distribution feeders by the distribution companies to avoid collateral damage. This puts a lot of pressure on the system because the boxed up generating units take a long time to revive and hence the practice of opening distribution feeders at the slightest hint of rains/ dust storms needs to be revisited at the state utility level.

6.3 Extreme Contingencies

Power system operator has to tackle a number of grid emergencies during real time operation. Northern Region has seen several instances of complete power station trip and entire 400/220 kV substation trip since December 2004. Apart from these there have been several system-threatening multiple contingencies. However, most of them could be managed due to the robustness of the grid and the swift actions by the power system operators while a few resulted into interruption of power supply from the EHV level. Each incident is unique and interesting with its twists and turns but the incident that occurred on July 6, 2005 needs special mention (Fig. 9).

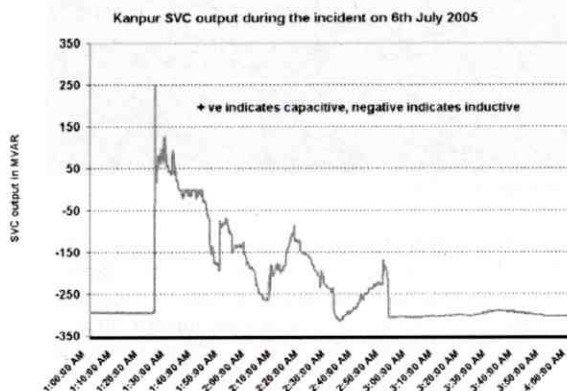


Fig. 9. Output of SVC at Kanpur during the fault.

At 01-23 hours Northern Grid was subjected to a stress test of the worst kind. Simultaneous outage of vital transmission elements in the interconnected grid resulted into wild fluctuations in the grid parameters, like, frequency, power flow on trunk lines interconnecting major subsystems and voltages at several nodes for more than an hour. Rapid corrective actions were taken by the power system operators to prevent the system from degenerating and as a result the grid was held together.

A thorough investigation following the event revealed that a fault occurred on a single 400 kV transmission element, which was not isolated from one end leading to failure of other elements in its vicinity. The unhealthy section remained firmly connected to healthy system (as it was beyond 3rd zone reach of any distance relay and many utilities did not have a

back-up earth fault protection in 400 kV system) causing an unprecedented assault on the physical network. The fault was fed for nearly 63 minutes before it got cleared through manual opening of a circuit breaker on the adjacent section. Such a situation was unprecedented and the system operator could get only the following clues that something was amiss.

- SCADA data from 400 kV Agra (UP) substation was not getting updated. The fault on 400 kV Agra-Muradnagar line was cleared from that end but not from the other end.
- Negative sequence alarm appeared at some power stations.
- One coal fired station at Dadri (4 x 210 MW) which tripped due to back up protection on the Generator Transformers (GTs) found it extremely difficult to start their auxiliaries during this 63-minute interval when there was an un-cleared fault.
- Mal-operation of a protective system led to tripping of one 400 kV bus at Dadri which further confused the system operator as he had to wait for a confirmation from the power station that it was indeed a mal-operation before carrying out any switching operation.
- The operator could see MW values intermittently on 400 kV Agra-Muradnagar line at Muradnagar end which led to the assumption that the line was in service.

To prevent recurrence of such events in future greater emphasis is required in protection systems. The voice communication between the operators of adjacent stations and between the field and the load dispatch centers is crucial for improving situational awareness. Subsequent to this event, the visual displays at the Control Center were modified to indicate a bus outage at any 400 kV substation to draw quick attention of the operator.

6.4 Social recreation such as kite flying

The independence day being a public holiday, traditionally people enjoy the day by engaging in activities, like, kite flying in and around Delhi. Thicker metallic thread / string used now-a-days for better strength plays havoc on electrical power system by resulting in transient faults (Fig. 10).

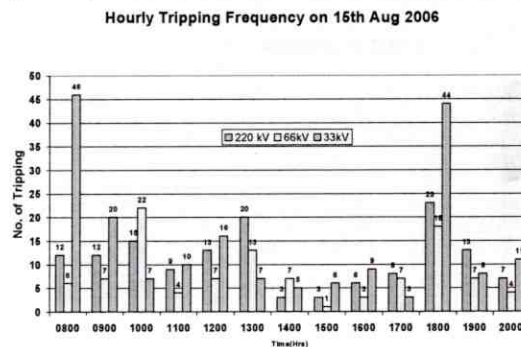


Fig. 10. Tripping in Delhi system on August 15, 2006 due to kite flying.

An extensive awareness drive launched through print / visual media prevented any such happening in August 2007.

6.5 Hydro generation reduction due to high silt content

Northern Grid experiences maximum demand during the period from June to August due to irrigation requirement of the paddy crop. Of course hydro generation also goes high during this period on account of high rainfall and water inflows. However high silt content in the Himalayan rivers such as Sutlej results in frequent outage of the power station and the system has to handle such contingencies. An example of Jhakri hydro power station generating 1,500 MW going out frequently whenever the silt content exceeds 5000 ppm is indicated in Fig. 11 below.

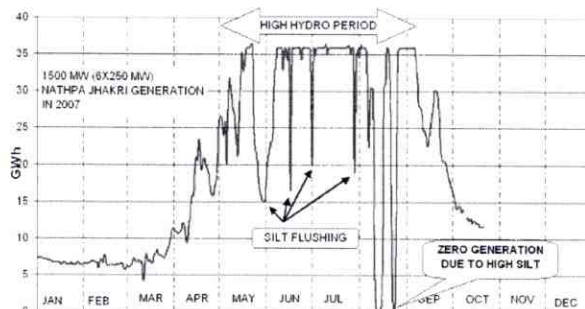


Fig. 11. Outage of Jhakri HEP during high hydro conditions.

VII. IMPROVEMENTS INITIATED

Normal and abnormal events faced in power system are learning opportunities. The Indian electricity grids faced several major disturbances in the past (Fig. 12). The reduction however has a flip side that while earlier operators were frequently trained in real life system restoration, the same had to be now done in a simulated set-up. In this context it is worthwhile to refer to the saying of power system guru Charles Concordia that 'a weaker system that has a well tested plan for emergency procedures and for restoration may be more reliable than a stronger system with no such plan' [6].

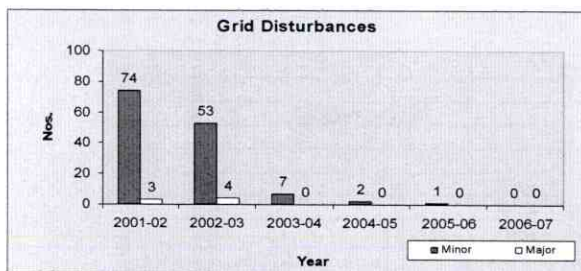


Fig. 12. Reduction in grid disturbances

Improvements initiated to minimize disturbances are as under:

7.1 Visualization and Situational Awareness

Visualization and situational awareness are the most important factors during contingencies and restorations and greatly help on comprehending the problem and decision

making. The following has been put to use in control centers [7].

7.1.1 Displays

In tabular, geographical, summary, graphical displays, the concept of layers is being utilized to access relevant information with ease and in time. In order to avoid mixing of supplies and extent of energizing, de-energizing, indicator such as color changing, width changing, flashers and style (dotted, firm), etc. is being used extensively (Fig. 13).

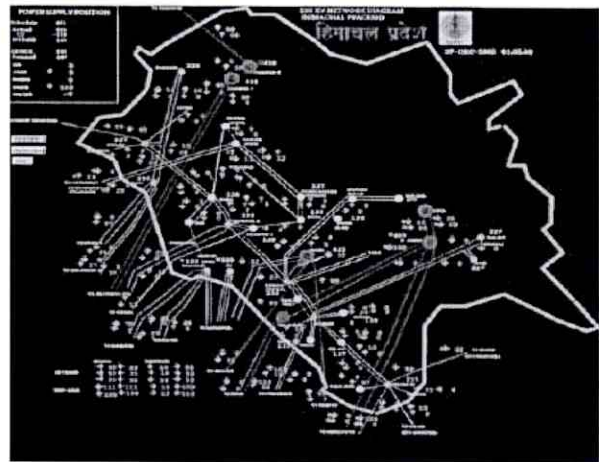


Fig. 13. Geographical display

7.1.2 Angular Measurement

Angular difference calculation and angular measurement is being extensively used in Indian power system to understand the vulnerability of the system. The angular measurement is also being used as a signal for integrated / islanded operation (Fig. 14).

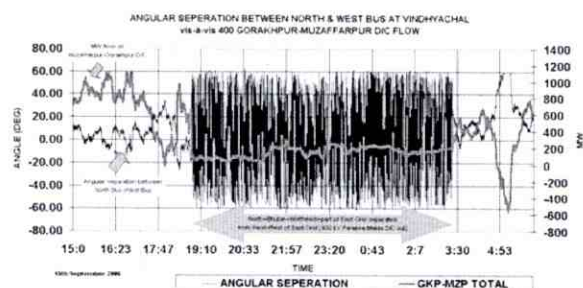


Fig. 14. Angle measurement.

7.2 Mock Drills

Frequent mock exercises for black start of hydro power station and extending supply to local loads, building up the network and synchronization are being done on a regular basis by segregating one 220 kV bus at a couple of substations.

VIII. FUTURE REQUIREMENT

The situations described above pose a great challenge to system operators and further improvements would help in

tackling the situation in future. Some of these are given below [8 - 11].

- Explicit Ancillary Service Market in the form of black start facilities, reactive power support etc.
- Primary response from generating units
- Under Voltage Load Shedding (UVLS)
- More System Protection Schemes (SPS) to correct outages of generation / transmission lines and prevent cascading notwithstanding the number of agencies involved in making such a scheme functional
- Synchronizing facilities at major substations and availability of trained manpower
- Improved situational awareness at Control Centers

IX. CONCLUSIONS

The society is becoming increasingly dependent on electrical power and it expects reliable, uninterrupted, secure and affordable supply. Power system engineers have designed an elaborate system to fulfill that desire. However the real test of any system is its ability to handle emergencies. The issues highlighted above assume greater importance with increasing size of the power system and regional / international interconnections. Any blackout in the Indian power system would have much larger socio-economic and political impact than earlier days when the systems were limited in size and complexity. It is expected that new tools and techniques, requisite training and the right attitude would help the system operators in discharging this onerous responsibility.

X. ACKNOWLEDGMENT

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XII. BIOGRAPHIES



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Sushil K Soonee (M'99, SM'01) born in 1956 and currently heading Northern Regional Load Dispatching Center of Power Grid Corporation of India Ltd. as Executive Director, had his graduation in Electrical Engineering from the Indian Institute of Technology (IIT), Kharagpur, India in 1977. After a brief stint in private sector joined Central Electricity Authority and worked extensively in integration of State Grid to form a Regional Grid in Eastern and North-Eastern Region, carried out Research and Literature Survey in Power System Operation and Control at IIT Kharagpur in 1981, traveled extensively Europe, USA and SAARC countries. He had first hand experience of Power System Operation of Eastern, Southern and Northern Grids, and also on Commercial Settlement, Restoration and entire gamut of Power Pooling and System. Frequency maintenance within permissible limits, voltage control, etc. achieved to a great extent during his tenure in Southern Region. Persuaded constituents to rejuvenate Inter-State Transmission lines, hitherto dormant. Worked for implementation of Availability Based Tariff (ABT) and on implementation, the scheme is recognized not only in India but worldwide. At present implementing the Intra-State ABT scheme also, and Free Governor Mode of Operation. Streamlined Open Access in Inter-State Transmission System. Authored 27 technical articles and presented in various forums, chaired many technical sessions in seminars / workshops, acted as Member of various committees for Regional Power System on disturbance and restoration. He is a Fellow of the Institution of Engineers (India) also.

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