Mock Blackstart Drills – An Excellent Learning Experience for Power System Operators

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Abstract

Blackouts are the most dreaded events in any power system. All efforts are made to avoid the occurrence of blackout and in case they occur efforts are made for restoring the system within minimum possible time. Mock black start drills and learning sessions on the subject familiarize the operators with the system recovery procedures, build their confidence to respond to contingencies and provide them an opportunity to address systemic deficiencies detected during the exercise. These efforts ultimately reduce the time taken during actual system restoration and also help in improving the coordination between various agencies. This paper describes the general philosophy adopted during mock black start drills. It also discusses few of the mock black start exercises conducted in the northern region; the challenges faced especially those related to protection system and the learning derived from those drills. Few of the mock black start drills have been simulated on the Despatcher's Training Simulator (DTS) located at NRLDC for imparting training to the operators. The paper also deliberates on such DTS sessions.

Keywords

Blackout, Black start drill, Despatcher's Training Simulator, Disaster Management

1. Introduction

A blackout can be understood as a total power failure in an area usually caused by the failure of generating equipment or transmission facilities [1]. The impact of a blackout increases exponentially with the duration of the blackout while the chances of quick restoration of the system substantially improve if the start-up power sources are readily available [2]. As the blackout may spread over the entire grid or in a particular pocket the restoration strategies depend on the nature and scale of the blackout [3]. While building up a system after blackout in general there can be two distinct strategies- 'top-down' strategy and 'bottom-up' strategy. Under the 'top down' strategy the grid supply from the neighbouring area is extended up to the affected area and power supply is restored while in the bottom up strategy generating unit is self started, the subsystem is built or expanded and synchronized with the grid. During a mock black start drill attempt is made to simulate both the scenarios.

2. Simulating scenarios for black start drill

To simulate the 'top-down' approach, a small area comprising of a generator is identified and it is disconnected from the grid to create a blackout in that area. Thereafter the start up supply required by the generator in that area is extended from the grid. The generating units are brought on bar and synchronized with the grid.

The other scenario that is simulated is that of system islanding and re-synchronization. In this case a small subsystem with at least one generating unit along with radial load is identified. All the tie lines connecting this subsystem with the rest of the grid are manually opened and efforts are made to prevent blackout in this subsystem after disconnection from the grid. The subsystem is operated in islanded mode for some time and subsequently the subsystem is re-synchronized with the grid.

To simulate the 'bottom-up' approach a small area is identified exactly as described above. The area is disconnected from the grid and the generation in that area is closed down to create a blackout. One or more generating units in the area are self-started with the help of auxiliary supply from a stand-alone source such as a local diesel generator. The generator transformer and the station bus are energized. Thereafter the tie line is charged to reach up to the nearest load point. The generator is operated with radial load to create a subsystem. This subsystem may be expanded to include more generators and load. Finally the islanded subsystem is then synchronized with the rest of the grid at appropriate location.

3. Coordination from the Load Despatch Centre

Similar to actual system restoration, black start drill requires extensive coordination between the load despatch centre (s), substations and the generating station that is involved in the exercise.

In the planning stage a radial load near to the generating station is identified. The switching diagrams of the substations involved are checked to identify the circuit breaker positions during the various stages of the exercise. Special SCADA diagrams are developed to monitor the digital status and the analogue values. They are also useful for supervising the progress in building up of the system during the exercise. The existing switching arrangements, protection settings, availability of synchronizing facility are also checked. A detailed procedure explaining the various steps in the exercise and the roles and responsibilities of everyone involved are developed. The modus operandi of the entire exercise is communicated and discussed with all the participating operators. The transmission/ distribution substations involved in the black start exercise are informed to ensure that supply from different sources are not mixed by any inadvertent switching operations. This is also done to avoid using alternate source of supply during a planned (simulated) blackout.

During the execution stage, the preparatory activities such as bus splitting and shifting of load on the desired bus are completed. Thereafter the black start drill is conducted and the system parameters are recorded. After completion of the black start drill the entire experience is documented and the success or shortcomings observed during the drill are shared with concerned utilities. Subsequently the shortcomings are addressed in coordination with the concerned utilities. The sections ahead discuss selected black start drills conducted in Northern region.

4. Black start drill with Bhakra HEP

Bhakra Beas Management Board (BBMB) conducts a very elaborate black start drill with Bhakra (Right) bank powerhouse twice every year.

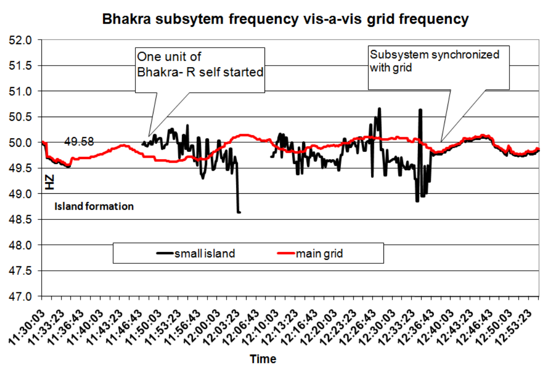

Fig 1: Bhakra subsystem frequency vis-à-vis grid frequency

It involves three generating units at Bhakra right bank powerhouse and 220 kV substations of Jamalpur, Ganguwal, Panipat and Dhulkote. Bhakra-Right bank (157 MW) unit # 9 is self started and voltage is built up by DC field flashing. This provides the unit auxiliary supply for Bhakra right bank unit # 10, which is also self-started. 220 kV supply is extended to Jamalpur through 220 kV Bhakra-Jamalpur-I. At Jamalpur one of the 100 MVA, 220/132 kV transformers is energized and load of about 60-70 MW is fed through 132 kV Jamalpur-Moga-I & II and Jamalpur-Ghulal I & II feeders.

After stabilization of the above subsystem, 220 kV supply is extended to 220 kV Ganguwal and 220 kV Dhulkote via one circuit of 220 kV Bhakra-Ganguwal and 220 kV Ganguwal-Dhulkote. At Dhulkote, a load of about 40 MW is fed by closing 66 kV Dhulkote-Chandigarh and 66 kV Dhulkote-Ambala feeders. In case the subsystem load exceeds 75 MW third unit of Bhakra Right is also taken into service. 220 kV supply is then extended to Panipat via one circuit of 220 kV Dhulkote-Panipat and around 20-25 MW load is built up at 33 kV level. The subsystem is operated for sometime and then it is synchronized with the grid either through bus sectionalizer at Bhakra Right bank or at 220 kV Panipat. The above exercise is carried out in coordination with Bhakra Power house, Punjab, Haryana, SLDC BBMB and NRLDC.

5. Black start drill with Chamera HEP

Black start exercise was conducted successfully with Chamera-1 HEP (NHPC) in April 2006. During this exercise two units of Chamera-I (180 MW) were self started. Thereafter 400 kV Bus-I at Chamera-I, 400 kV Chamera-Jallundhar line (153 km), 400 kV bus-I at Jallundhar, 220 kV Bus-I at Jallundhar (POWERGRID), 220 kV Jallundhar-Kartarpur and 220 kV Jallundhar-Kotlijunga line were energized. A subsystem was formed with approximately 20 MW load at Kartarpur (Punjab) and Kotlajunga (Punjab). After islanded operation of the Chamera-1 subsystem for 37 minutes the subsystem was synchronized with the grid at 400/220 kV Jallundhar at 400 kV level.

In the above exercise, two units of Chamera-I had been taken on bar in order to have additional capacity for MVAr absorption and voltage control in the subsystem particularly during charging of 400 kV Chamera-Jallundhar line (153 km). This change in strategy was done based on learning from past black start exercise.

While planning this exercise, it transpired that Chamera-1 (GIS) has a 400 kV double bus single breaker arrangement and the practice was to keep all the feeders and generators on one bus and to keep other bus out of service. It was suggested that feeders and generators should be distributed on both the 400 kV buses so that minimum elements are lost in case of a bus fault (although the possibility of bus fault in GIS is remote). The suggestion was successfully tested during the mock exercise.

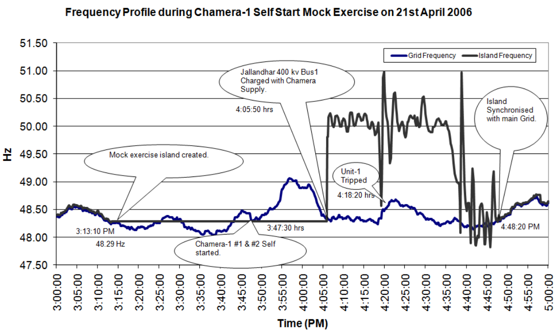

Fig 2: Chamera subsystem frequency vis-a-vis grid frequency

6. Black start drill with Bairasiul HEP

Black start drill was successfully carried out at Bairasiul HEP (NHPC) in June 2006 in association with Pong powerhouse (BBMB) and loads at 66 kV Sansarpur (HPSEB) & 66 kV Talwara (PSEB). The exercise involved self-starting of unit-2 at Bairasiul through DG supply. 220kV Bus-A at Bairasiul was charged through this unit followed by charging of 220 KV Bairasiul – Pong line (95 km) from Bairasiul end, charging of 220 kV Bus-1 at 220 kV Pong, charging 220/66 kV transformer at Pong and feeding local load at Pong as well as loads of 66 kV Talwara and 66 kV Sansarpur.

The subsystem was operated for 37 minutes and then it was synchronized through 220 kV Bus coupler at Pong HEP. For the purpose of synchronization, the Pong Bus-1 (in the subsystem) voltage and frequency was regulated from Bairasiul HEP to match with Pong bus-2 voltage (towards main grid side) where synchronization was done.

The drill lasted for about one and half hour. It was a case where two generating utilities were involved. It was highlighted that proper voice communication between agencies involved plays a vital role in early restoration of system during contingency. During this drill several inconsistencies were detected between the SCADA display seen at control centres and the actual field condition. These were addressed.

7. Black start exercise with Tehri HEP

Black start drill with Tehri HEP (THDC) was conducted in March 2008. It involved two parts. The first part involved islanding of the subsystem and its resynchronization while the second part involved building up of the subsystem and synchronization with the rest of the grid. The subsystem contained one unit (250 MW) of Tehri HEP, one 400 kV bus of Tehri HEP, one of the circuits of 400 kV Tehri-Meerut line, one 400 kV bus at Meerut, one 220 kV bus at Meerut and the entire 220/132 kV substation of Shatabdinagar. This subsystem along with the circuit breaker/ isolator status is shown in fig.3.

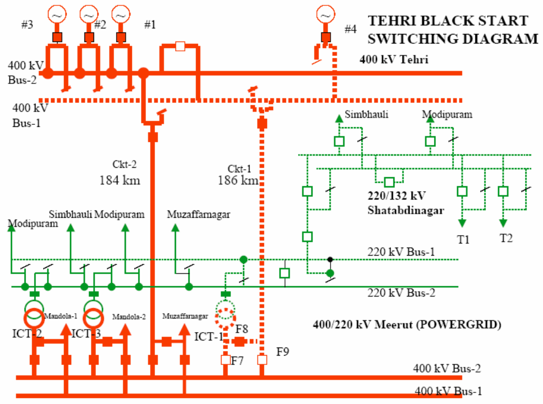

Fig. 3: Tehri subsystem for black start drill

In the first part re-synchronization of the subsystem with the grid was done through the 400 kV bus coupler at Tehri while in the second part synchronization was done at 400 kV Meerut through one of the Main breakers of 400 kV Tehri Meerut line.

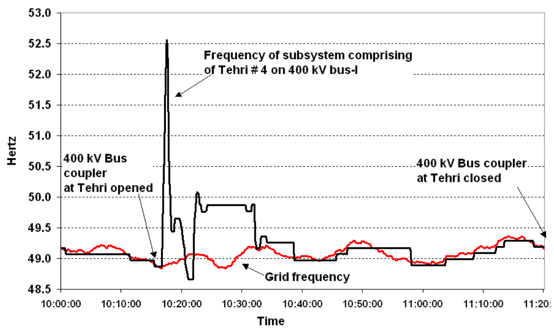

Fig. 4: Islanding and re-synchronization of Tehri unit # 3

The second part of the exercise involved self starting the Tehri unit, charging dead 400 kV bus at Tehri, charging one circuit of 400 kV Tehri-Meerut, charging one 315 MVA, 400/220 kV ICT, charging one circuit of 220 kV Meerut-Shatabdinagar, energization of 220/132 kV Shatabdinagar substation and feeding approximately 70-100 MW load at Shatabdinagar in radial mode.

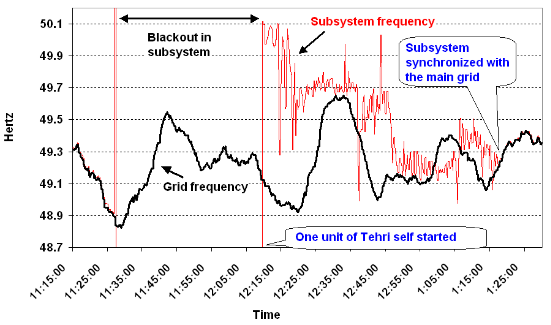

Fig. 5: Tehri subsystem frequency vis-à-vis Grid frequency

The complete drill took over 3 hours to complete. The total duration of islanded operation of Tehri unit was 67 minutes while the duration of load interruption at Shatabdinagar for black start drill was 46 minutes.

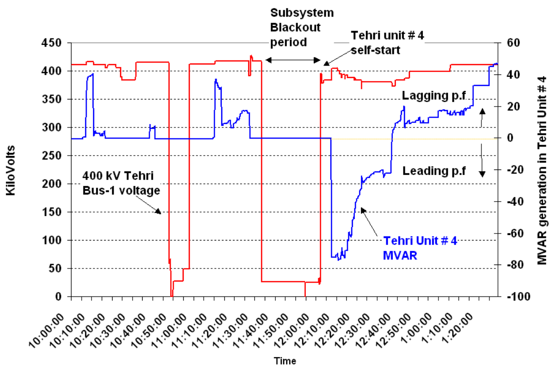

Fig. 6: Tehri 400 kV bus-I voltage and Tehri HEP MVAR generation

8. Black start drill with Jhakri HEP

Black start drill was conducted with Jhakri HEP in October 2009. A subsystem contained one unit of Jhakri (250 MW), one 400 kV bus at Jhakri, one circuit of 400 kV Jhakri-Abdullapur, one 400 kV bus of 400/220 kV Abdullapur, one 220 kV bus of Abdullapur, one 220 kV bus at Jorian and radial load at 220/66 kV Jorian (in Haryana).

Black start drill involved self start of unit # 3 (250 MW) at Jhakri, charging of dead 400 kV bus (Bus-I) at Jhakri, charging of 400 kV Jhakri-Abdullapur ckt-I (180 km, triple snow-bird conductor), charging of 400/220kV ICT-3 at Abdullapur, charging of 220kV Abdullapur-Jorian-I, charging of 220/66kV transformer at Jorian and islanded operation of the Jhakri unit with load at 220/66 kV Jorian (51 MVA @ 0.85pf) substation of HVPNL.

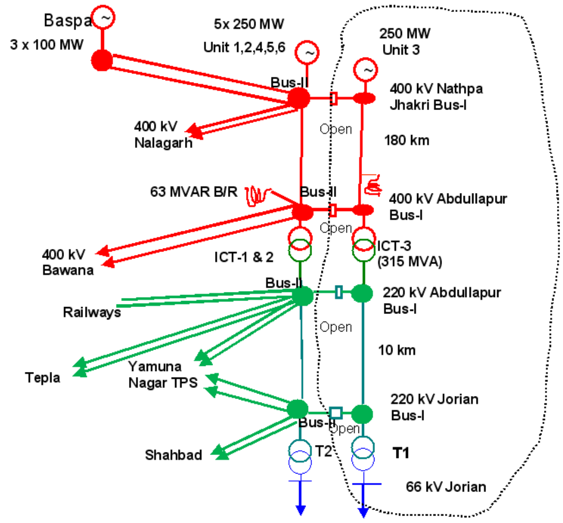

Fig. 7: Jhakri subsystem for black start drill

The sub system was synchronized with the NR grid at 400kV Abdullapur (at 49.63 Hz. Duration of Islanded operation of Jhakri Unit#3 was 1hr 43 minutes. Around 40 MW load in Jorian was fed in islanded mode for 18 minutes.

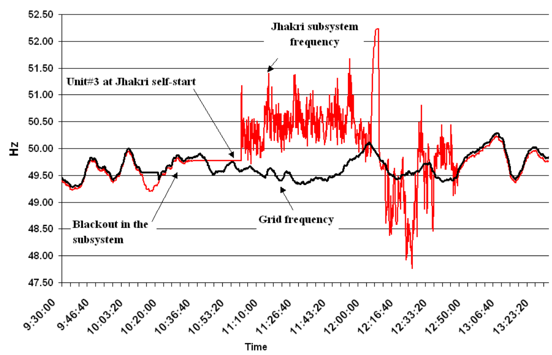

Fig. 8: Jhakri subsystem frequency vis-à-vis grid frequency

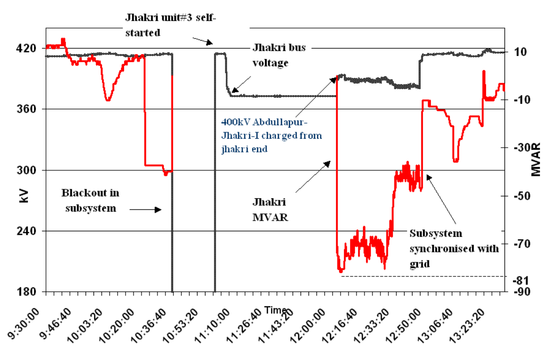

Fig. 9: Jhakri bus voltage and MVAr generation

The plot of frequency, voltage and load in the subsystem can be seen in Fig. 8 & 9. During the drill it was observed that built up of the subsystem was delayed because of the tripping of 400 kV

Jhakri-Abdullapur-I from Abdullapur end when the line was charged from 400 kV Jhakri end with only one Jhakri unit on bar within the subsystem. The problem was overcome by introduction of a delay of 100 ms in the Stage-II over voltage protection setting at Abdullapur. The above experience was referred to Northern Regional Power Committee (NRPC) protection sub-committee. After deliberation the sub-committee recommended the adoption of above setting throughout the Northern region.

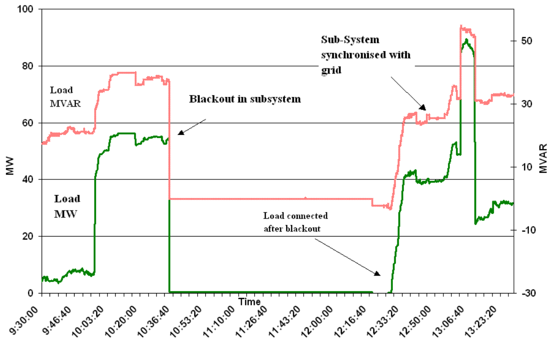

Fig. 10: Jhakri subsystem MW and MVAr load

A similar drill carried out on March 2008 highlighted the issues related to Auto Synch Relay used in generating stations and substations [4]. The Synchro check relay has settings related to the permissible angular separation, frequency difference and voltage difference between the two systems being synchronized. The SKE check synchronization relay allows lower tolerance (up to 20^{o} in angular separation, up to 0.095 Hz in frequency and up 10 % difference in voltage magnitude) while the SKD check synchronization relay allows wider tolerance in angular separation (up to 35^{o}) angular separation, up to 0.225 Hz in frequency and up to 20 % difference in voltage magnitude). Thus the time taken for synchronization of two systems through an auto synchronization facility would depend on the type of check synchronization relay and its setting. At the time of black out and system restoration the setting of check synchronization might have to be optimized.

9. Black start drill with Salal HEP

Black-start drill with Salal HEP was conducted successfully in Oct 2009. The drill comprised of blackout at 220kV Jammu, self starting one unit at Salal (with the help of DG supply), charging of dead 220kV bus-1 at Salal, charging of 220kV Salal-Jammu-I, charging of 220kV dead bus at Jammu and feeding load at Jammu, Sidra, Kalakote and Bari-Brahmana in islanded mode. The subsystem was synchronized with the NR grid at Kishenpur through line CB of 220kV Salal-Kishenpur-I (at 49.45Hz)

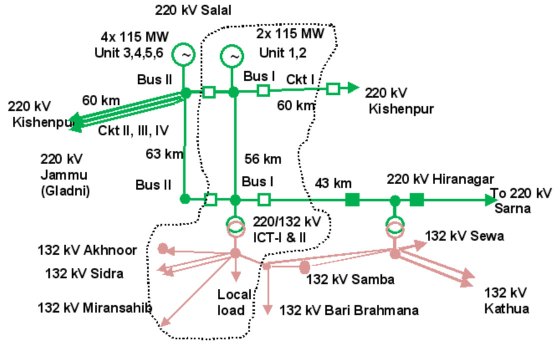

Fig. 11: Salal subsystem for black start drill

Total duration of black start drill was 98 minutes and the maximum duration of islanded operation of Salal unit # 2 was 83 minutes.

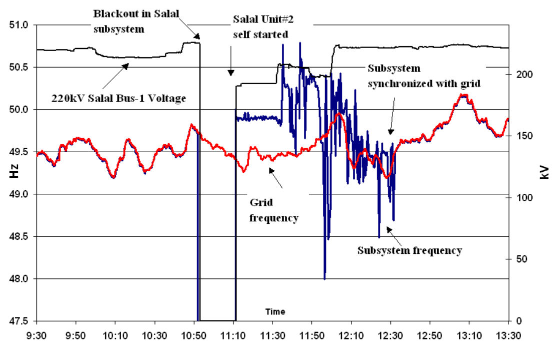

Fig. 12: Salal bus voltage, subsystem frequency vis-à-vis grid frequency

Duration for which load at Jammu was fed in islanded mode was 52 minutes and the maximum load met in the islanded subsystem was 28 MW.

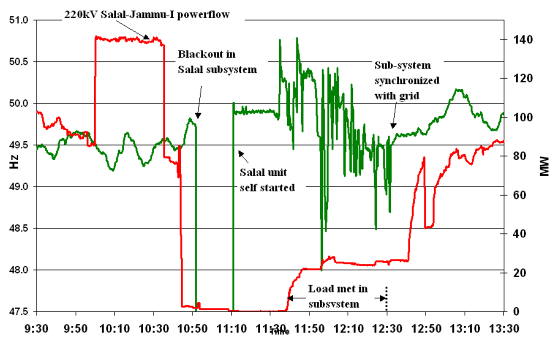

Fig. 13: Salal subsystem size and frequency

During the drill several unforeseen constraints emerged due to certain inadequacies in transmission system and non-availability of synchronization facility at substations.

The drill revealed the importance of switching schemes, the need for avoiding prolonged usage of bus coupler breaker as line breaker and the need for avoiding cannibalization of transmission facilities that are provided but used less frequently.

It was learnt that several substations have synchronization trolleys of old vintage that do not have check synchronization relay. Synchronization with such trolleys has the hazard of rough synchronization and consequent loss of stability and equipment damage. The experience also highlighted the importance of human skill in system synchronization. Both the above matters were also referred to NRPC Operation Coordination subcommittee and efforts are being made to address them suitably.

10. Trial of AC bypass at HVDC Vindhyachal Back-to-back station

The HVDC back-to-back station provides asynchronous interconnection between two areas. In India HVDC back-to-back stations are available at Pusauli (between Eastern Region and Northern region); at Vindhyachal (between Western Region and Northern Region); at Gazuwaka (between Eastern Region and Southern Region) and at Bhadravati (between Western Region and Southern Region). In parallel with these back-to-back stations an AC bypass link has also been provided to facilitate extension of juice to the neighbouring region in case of total black out in the region.

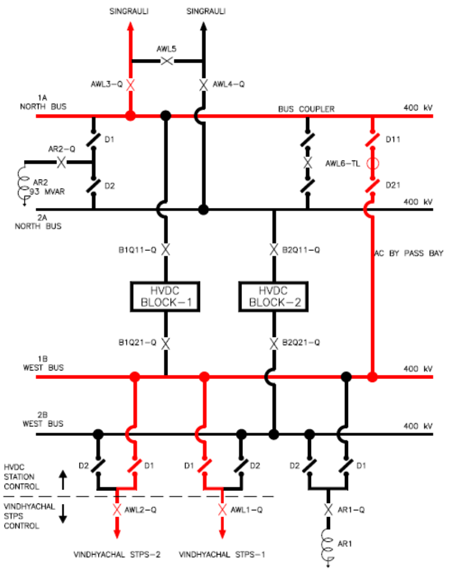

Fig. 14: Switching diagram of Vindhyachal back-to-back station

Trial of AC bypass at Vindhyachal HVDC back-to-back was successfully conducted in October 2009. The objective of the drill was to demonstrate the healthiness of the 400 kV AC bypass at Vindhyachal back-to-back and its ability to quickly extend start up supply from Western Region to Singrauli in Northern Region in case of a black out.

During the drill, it was demonstrated that the start-up power could be extended from Vindhyachal STPS in Western Region to Singrauli STPS in Northern Region in nineteen (19) minutes. The system operated in AC bypass mode for fifty-eight (58) minutes. The power flow in AC bypass mode was negligible because the Line Circuit Breakers at Singrauli STPS end were intentionally kept open from fault level considerations (It was not a part of the drill also). Successful completion of the drill gave a great deal of confidence to the operators.

In the past during a grid disturbance, which occurred in Northern region at 0445 hours on 2nd January 2001, start up power supply was extended to 400 kV Singrauli STPS in twenty-five (25) minutes via the AC bypass at Vindhyachal HVDC back-to-back stations.

11. Black start drill on Despatcher's Training Simulator (DTS)

Despatcher's Training Simulator available at RLDC is used for imparting hands on experience to operators in a simulated environment. In one of the DTS sessions conducted in NRLDC during May 2009, the black start drill of Bhakra complex was simulated. The entire procedure was explained to the participants. Teams were formed and different roles were assigned to each team. One of the team had to play the role of load despatch centre while the others were assigned the responsibility of the different substations involved in the restoration process. Logistics such as operator consoles, live telephone sets and log sheets were also put in place. Switching instructions were exchanged over the telephone while the switching was done in DTS mode. The session was highly appreciated by the participants.

12. Learning opportunities during a black start drill

A black start drill can be an excellent learning experience for any System Operator [6, 7, 8]. It gives them a golden opportunity to interact with the engineers at substation, generating station and at other load despatch centres. It helps them to become intimate with the grid and get a first-hand experience of the challenges in system restoration during a real blackout.

Black start mock drills are like laboratory experiments in the power system operation and control. One can see the behaviour of power system under different scenarios. For instance one can observe that the frequency and voltage fluctuations in a small subsystem are much higher than in a large grid. This is due to low system inertia in the small subsystem. Moreover the advantages of a large interconnection and the importance of primary response and AVR control in a generator can be very well appreciated after witnessing such drills.

Despite having a planned procedure for the black start drill, there could be surprises during execution, particularly in respect of protection system settings and substation switching arrangements. Those constraints have to be circumvented in real-time. There could be a need for a temporary change in certain protection settings such as reverse power relay, over voltage and synchro check relay. Thus such drills help in identifying inadequacies in the system that could delay the restoration of system post blackout and also highlights the importance of adequacy in transmission system. For instance, it emphasizes the need for keeping the bus coupler breaker healthy and available rather than keeping it in service continuously as line breaker for a particular feeder. Likewise the bus isolators also need to be kept healthy to enable shifting of feeders from one bus to the other at the time of need. The availability of synchronizing facility at grid substations along with the skilled operators also gets highlighted.

The success of the black start drills depend on the collective efforts of several utilities/operators and the healthiness of the generating, transmission and SCADA facilities. Further the system restoration procedures in respect of the participating generating stations also get validated. The black start drills could also be used for verifying the simulation results particularly in respect of voltage rise during line charging, the impact of switching bus reactors and estimate of fault levels.

The black start drill tests the various capabilities of the generators and transmission system. The various capabilities of the generator that primarily gets tested are the capability to self-start with auxiliary supply from local diesel generator; to automatically regulate its generation to match the load in the subsystem; to operate on partial load in islanded mode without losing stability; to regulate the speed of the generator; to regulate the voltage in the subsystem and to synchronize with the grid without load loss. Need could arise for temporary change in setting in turbine governor droop, Automatic Voltage Regulator and synchro check relays. The transmission facilities, which invariably get tested, are the capability of the switchgear, capability of the reactive resources, flexibility available in switching arrangement, protection system [8] and the synchronizing facility. Similarly the SCADA/EMS facilities, the telemetry (analogue and digital) along with the communication system, the authenticity of substation diagrams, data archival, data retrieval and scenario replay facilities also get tested during the drill.

During the black start drills it has been observed that the restoration time has been on the higher side. The constraints that generally delay the restoration need to be removed. There is also an urgent requirement of human capacity building in this area. Further the black start drill often requires interruption of power supply in a certain area. As a part of good utility practices the consumers of that area must be informed in well in advance and the period of power supply interruption needs to be minimized as much as possible.

13. Conclusion

Our present life style has become highly dependent on reliable power supply. Interruption in power supply even for a short duration causes huge discomfort and great economic loss. With meshed network, the risk of a sporadic local event, propagating into a widespread blackout, has increased manifold. Since the risks and stakes are very high suitable strategy needs to be devised to mitigate the impact of blackout and facilitate a quick recovery post disturbance. Hence Blackstart drills are vital from this perspective and the experience gained during mock drills has been very useful in identifying deficiencies in the system that have to be addressed. These exercises could help in strengthening the technical solidarity also give confidence to the operators which can be very helpful during crisis and disaster management.

14. Acknowledgement

The authors acknowledge the support and encouragement given by the management of Power grid Corporation of India and Power System Operation Corporation. Special thanks to Sh. S.K. Soonee, CEO, POSOCO for his guidance on the subject of System restoration and black start. The authors also acknowledge the valuable contribution of colleagues and engineers for conducting black start drills and providing inputs for documenting. Special thanks to Sh S.R. Narasimhan D.G.M., POSOCO who had been deeply involved in designing and executing several black start exercises in Northern Region.

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16. Disclaimer

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