Reliability Coordination of Power Stations Connected Radially to Grid through EHV Pooling Stations

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Abstract: Notification of the Electricity Act 2003 paved way for rapid generation capacity addition in India. High capacity transmission corridors were created to overcome the 'right of way' constraints and to optimize future evacuation requirement. Several EHV pooling stations were built to provide grid access to pit head generating stations located in a particular area that would get commissioned in a staggered time frame. The generating stations are connected to the EHV pooling station through spur lines that are usually constructed by the respective generation developer in the matching time frame. This paper shares the operational issues experienced in the Western Regional power system of India in respect of such large generation complexes. The challenges associated with grid integration of new generators and associated lines & bays, protection coordination and operation & maintenance have been discussed through case studies. Remedial measures taken for improving the reliability and availability of such radially connected power plants have also been highlighted. The paper is also relevant for integration and evacuation of large wind farms and solar parks through pooling stations and green energy corridors.

Keywords: *Protection Audit, Blackout, House load operation, Low Frequency Oscillations, Protection Coordination, PSS tuning*

Introduction

The Indian Electricity Act 2003 delicensed generation and introduced open access in transmission to increase competition and encourage private participation in generation capacity addition. [1]. The philosophy adopted for transmission planning changed from building 'Associated Transmission System (ATS)' to building 'Common transmission infrastructure' for optimal utilization of national resources. Several 765/400 kV EHV pooling stations were envisaged near pit heads and de-pooling stations were envisaged near major load centres for dispersal of power. High capacity HVAC and HVDC corridors were also built to augment the inter-regional transmission capacity and optimize the right of way. [Ref Fig 1].

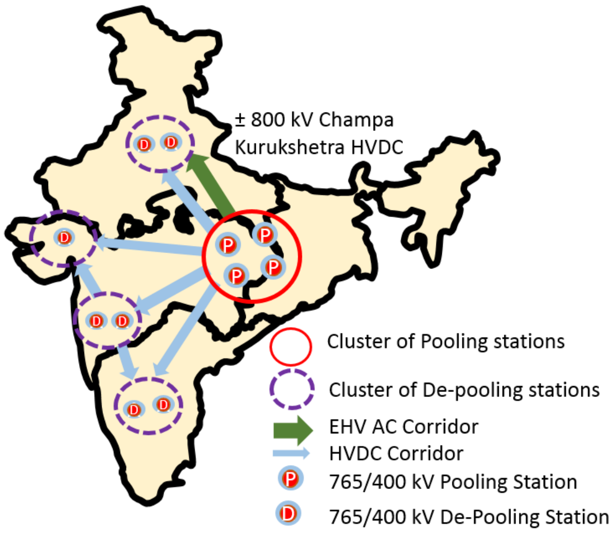

Figure 1: High Capacity corridors with Pooling and de-pooling stations.

Most of the power stations get connected radially to the pooling stations through dedicated transmission lines from their station to the point of coupling with the grid. Several plants in a particular geographical area are connected radially to one EHV pooling station. [Ref Fig 2].

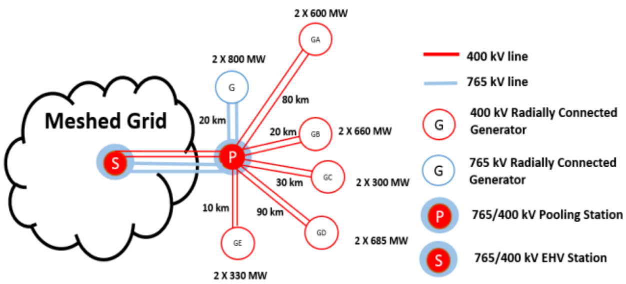

Figure 2: Typical configuration of generating station connected radially with pooling station

A large number of such stations with large size sub-critical (300 MW, 360 MW, 500 MW) or supercritical units (600 MW, 660 MW, 685 MW) have come up in the State of Chattisgarh and Madhya Pradesh in the

Western Region [2]. There are thirty-one (31) 765/400 kV stations out of which eight (8) are pooling stations for evacuation of such power plants. The total number of 765 kV lines in Western region is 81 along with a ± 800 kV 6000 MW HVDC bipolar link. Additional 765/400 kV pooling stations are presently under commissioning stage for thermal as well as for evacuation of renewable energy under the green energy corridors. References [3] to [6] provide case studies of grid events and highlight the challenges associated with protection coordination in the Indian Power system [3-6]. Such issues are regularly discussed at the regional forums [7, 8]. However, this paper highlights the operational challenges associated with power stations connected radially with the grid through EHV pooling stations. It discusses the initiative and remedial measures taken at the grid level to improve the reliability of such power stations and enhance the security of the grid under such a configuration.

Table 1: Blackout of Radial Connected Generating Station and Major Cause observed from their detailed analysis.

Sl. No.	Plant reference	Pooling Station / EHV substation	Year	Generation loss (MW)	Reasons for Blackout
I	Plant 1	EHV Station A	2014	1850	Power Swing observed after single phase fault on one line. Line tripping prior to Auto-reclosure due to power swing. SPS did not operate.
II	Plant 2	EHV Station B	2015	608	Both evacuating circuits tripped simultaneously on fault
III	Plant 3	EHV Station C	2015	265	Both evacuating circuits tripped one by one on fault
IV	Plant 3	EHV Station C	2015	Nil	Both evacuating circuits tripped one by one on fault
V	Plant 2	EHV Station B	2015	1137	One evacuating line under outage and other line tripped on fault
VI	Plant 2	EHV Station B	2015	792	One evacuating line was under outage and other line tripped on Direct trip receipt from the remote end due to protection mis-operation.
VII	Plant 2	EHV Station B	2016	1089	One evacuating circuit tripped on fault (No Auto-reclosure) while other circuit tripped on undesirable Local Breaker Backup (LBB) operation.
VIII	Plant 4	Pooling Station A	2016	1025	Both evacuating lines tripped for zone 2 fault due to incorrect protection setting at Pooling station.
IX	Plant 2	EHV Station B	2016	1092	One evacuating circuit tripped on Fault (No Auto-reclosure) while the other circuit tripped on undesirable LBB operation.
X	Plant 2	EHV Station B	2016	1211	One evacuating circuit tripped on Fault (no Auto-reclosure) and Other circuit tripped in Zone 3 from plant end due to incorrect resistive reach setting under higher loading.
XI	Plant 3	EHV Station C	2016	555	Tripping of both evacuating lines one by one on Fault.
XII	Plant 4	Pooling Station A	2016	477	One evacuating line tripped on fault while other line tripped on Relay Misoperation for zone 4 fault.
XIII	Plant 2	EHV Station B	2016	1200	Both evacuating lines tripped on Power swing during single phase Auto-reclosure on one line.
XIV	Plant 4	Pooling Station A	2016	455	PLCC mal-operation caused tripping of both circuits.
XV	Plant 2	EHV Station B	2016	1051	Both evacuating circuits tripped simultaneously on faults. Failure of Auto-reclosure.
XVI	Plant 5	Pooling Station B	2017	Nil	Both evacuating lines tripped on receipt of the direct trip from pooling station end.
XVII	Plant 6	Pooling Station C	2017	250	Due to mal-operation in the BCU at Pooling station the evacuating lines tripped.
XVIII	Plant 7	Pooling Station A	2017	250	Both lines tripped on the fault. Several issues in protection setting and logic observed.
XIX	Plant 2	EHV Station B	2017	1083	One evacuating line tripped on Fault while other tripped on load encroachment.
XX	Plant 7	Pooling Station A	2017	277	One line tripped on the fault. Other line tripped due to an issue with protection system at plant end during the fault on the first line.
XXI	Plant 8	Pooling Station D	2017	548	The issue of CVT neutral earthing at pooling station caused tripping on stage 2 O/V operation.
XXII	Plant 9	Pooling Station D	2017	Nil	The issue of CVT neutral earthing at pooling station caused tripping on stage 2 O/V operation.

Sl. No.	Plant reference	Pooling Station / EHV substation	Year	Generation loss (MW)	Reasons for Blackout
XXIII	Plant 3	EHV Station C	2017	560	Both evacuating circuits tripped one by one on fault.
XXIV	Plant 2	EHV Station B	2017	1220	One evacuating line tripped on fault while other in zone 1 power swing during A/R operation of the first line.
XXV	Plant 10	Pooling Station D	2017	149	Both evacuating circuits tripped simultaneously on the fault.

(Power Plant 1: 3 X 660 MW; Plant 2 :2 X 660 MW; Plant 3: 2 X 500 MW; Plant 4: 2 X 600 MW; Plant 5: 2 X 685 MW; Plant 6: 2 X 600 MW; Plant 7: 4 X 300; Plant 8: 2 X 600 MW; Plant 9: 2 X 800 MW; Plant 10: 4 X 360)

Power Station Blackouts

Table 1 provides the instances of blackouts that occurred in power stations connected radially with the meshed grid at pooling stations. The number of such blackouts shows a rising trend. There was one blackout in the Year 2014, five in 2015, six in 2016 and ten in 2017. It can be inferred from table 1 that Plant 2, 3, 6 and 7 have faced blackouts on multiple occasions while the Plants connected to Pooling station A / D or the EHV station B / C have experienced blackouts on more than one occasion. Further, it may also be observed that in 10 out of 25 cases the generation loss was more than 1000 MW which caused a frequency drop by more than 0.1 Hz in the Indian grid. Analysis of the individual cases reveal few common issues and operational challenges that need to be addressed to prevent such occurrences.

Operational Issues

The common operational issues and challenges associated with radially connected power stations are illustrated under following categories:

1. Pre-commissioning coordination
2. Protection coordination
3. Maintenance coordination
4. Dynamic and Small Signal Stability
5. Substation Layout
6. House Load operation

Each of these issues is described in detail with one or more case studies. In addition, the remedial actions which have been implemented and their inherent benefits observed by these plants have also been discussed in detail.

A. Pre-Commissioning Coordination

The EHV pooling station is generally owned by the by Inter-State Transmission licensee (ISTS) while the bays at the pooling stations are generally owned by the generating station whose power gets pooled. Thus commissioning of the transmission elements in the EHV pooling station requires coordination between multiple utilities. It has been observed that several grid events could be attributed to improper coordination during the commissioning stage. Few of the avoidable deficiencies are listed below:

1. Multiple CVT earthing causing undesirable over-voltage (Sl. No. XXI and XXII in table 1)
2. Lack of local breaker backup coordination (Sl. No. VII, IX in table 1)
3. Enabling of the rate of change of frequency (ROCOF) protection setting in lines.
4. Different auto-reclosure dead time setting at both ends of the line (Sl. No. XVII in table 1).
5. Issue with the carrier aided distance protection scheme (Sl. No XIV and XVI in table 1).

In order to streamline the inter-utility coordination during integration and commissioning of new elements into the grid, a detailed procedure has been evolved by NLDC and followed throughout India by RLDC’s. The procedure mandates utilities to furnish confirmation regarding protection coordination with remote stations before seeking permission to charge the elements for the first time. The utilities are encouraged to cross check all wirings and protection logic to avoid undesirable tripping.

Before first time charging and consequent the major changes in network topology the utilities are advised to confirm implementation of the revised relay settings. Central Transmission Utility (CTU)/State Transmission Utility (STU) has to validate the protection setting for this newly connected entity prior to their first time charging. It has been made mandatory that in case of any mal-operation observed during the event, immediately a thorough check of the system to be carried out jointly by pooling station and the affected generating station. Best practices are shared with incoming generating stations by RLDC. Workshops are also organized to sensitize the new grid users with the regulatory and security requirements [8].

B. Protection Coordination

Proper protection coordination of generating stations connected radially with pooling stations is very important as an undesirable tripping could cause a large collateral generation loss.

Most of the radially connected generating stations are connected to pooling station through short EHV lines. These stations along with their interconnecting lines to the pooling stations get commissioned in different time frames. Thus the protection setting at the incumbent power station/substation also has to be reviewed with every incremental augmentation in the network around the pooling station [9].

Zone 2 time delay coordination

Major challenges are experienced in ensuring proper coordination between the time delay in the Zone 2 relay setting adopted at the generating stations and the remote pooling substation. There have been cases where poor coordination resulted in multiple tripping in case of either Zone 2 fault coupled with the failure of carrier aided accelerated trip or in case of a fault at the dead end substation while charging the line from the other end. The blackout in the system in the year 2015 referred in [10] and in the year 2016 referred in [11] were caused primarily due to the above deficiency.

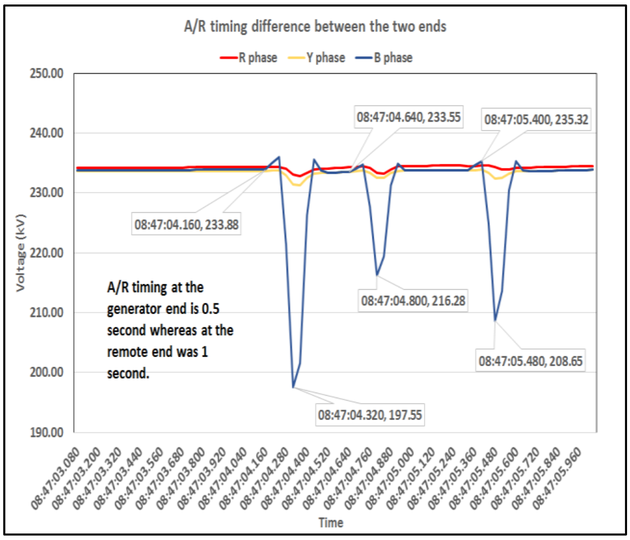

Figure 3: Different auto-reclosure timing

Auto-reclosing coordination

Figure 3 illustrates the case of un-coordinated auto reclosing dead time at the two ends. At the generating station (Plant 6) end the dead time for auto-reclosure on the evacuation line was 0.5 seconds while at the pooling station it was set as 1 second [12]. This led to the feeding of the same fault from the system two times while auto-reclosure was performed from each end due to different time setting.

Distance relay setting coordination

During the blackouts mentioned in Sl. no I, X, XIII, XIX and XXIV given in table 1, power swing/load encroachment was observed in power plant 1 and 2. During the single-phase auto-reclosing on one of the evacuation lines, the power flow on the other line increased and caused relays to pick up in zone 2/zone 3 [Fig 4] as the resistive reach setting was not properly calculated and coordinated.

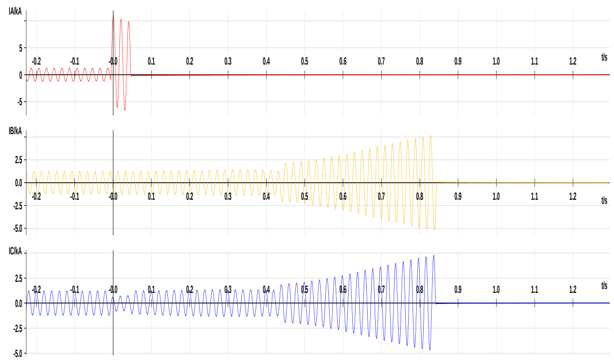

Figure 4: Power swing in the healthy phases during auto-reclosure causing tripping of lines in load encroachment.

To resolve the above issue, power plants were advised to calculate resistive reach and check load encroachment in Zone 1/2/3 for the worst case scenario i.e. N-1 of one circuit and with only two phase of the other circuit. This setting was adopted in three of the generating plants which were connected to the grid through long lines. Since then no such issues have been reported. The same information was shared with other radially connected power plants to avoid spurious tripping in future.

Undervoltage and Overvoltage relay coordination

Another major challenge is the overvoltage setting coordination of transmission lines from the pooling station where so many generating stations are connected. If all of the lines are set with same overvoltage setting, it may result in multiple tripping under the scenario of overvoltage.

Further, it has been observed that when one of the evacuation lines is subjected to a high impedance fault, then due to the voltage dip, auxiliaries of power plant such as induced draft (ID) fan, forced draft (FD) fan, boiler feed pump (BFP) got tripped due to under voltage tripping of associated equipment. Therefore, all such generators were advised to check and optimize the under voltage protection settings for their auxiliary system to avoid unwanted tripping of auxiliaries which may result in tripping of Boiler and Generator.

Healthiness of PLCC

Carrier-aided distance protection scheme plays a vital role in the security of radially connected generating plants under transient faults. Therefore it is essential that their healthiness is ensured all the time. However, it has been seen that plants have undergone blackout due to the issues associated with power line carrier communication (PLCC). In table 1, plant 4 and plant 5 tripped due to an issue with PLCC healthiness as given in Sl. no. XIV and XVI respectively. A system for continuous monitoring of the healthiness of PLCC needs to be put in place and deficiencies need to be removed without delay [10].

Resolution of all such protection coordination issues are being facilitated from the regional level by taking following measures:

1. **Protection coordination meeting at pooling station:** Once in every quarter or whenever there is new element interconnection from pooling station, a meeting for protection coordination is called by the pooling station where all directly connected entities participate.
2. **Third Party Protection Audit:** As recommended in the Taskforce [9] all such pooling substation have to undergo third-party protection audit at an interval of five years or in the event of any major change in network configuration.

C. Maintenance Coordination

The bays in which the transmission lines emanating from the generating plant are terminated at the pooling station are generally owned by the respective generating plants while the major transmission line evacuating the power from the pooling station may be owned by different ISTS licensee. This poses a serious challenge in coordinating the operation and maintenance activities particularly when a bus outage is required. The varying maintenance schedules adopted by different generation/transmission utilities lead to multiple requests for an outage of elements in a particular pooling station. Poor inter-utility coordination for outage increases the outage duration and subjects the system to insecurity. The maintenance challenges are being addressed through a monthly review of outage plans to optimize the downtime of various elements.

D. Dynamic and Small Signal Stability

Low frequency oscillations have been a triggered in the Indian grid under various contingencies or operating conditions [13]. In one of the cases, high amplitude-poorly damped oscillations of 0.86 Hz [Ref Fig 5] were observed at a power plant (power plant 4) when one of the evacuating lines tripped [14]. The oscillations persisted for 5 minutes and were observed at nearby generating stations also. Post facto analysis revealed that the Power System Stabilizer was out of service at the station.

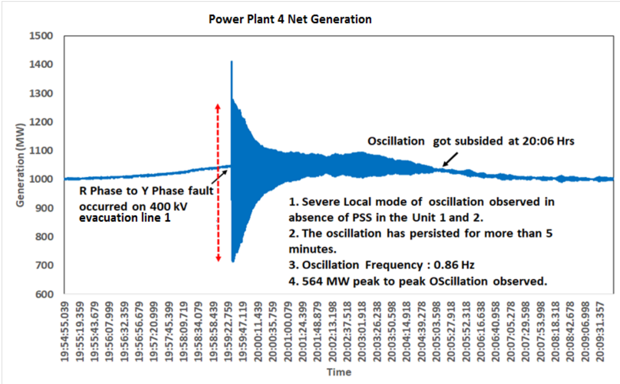

Figure 5: Low frequency Oscillation in Power plant 4 during a contingency (No PSS).

In another case, one of the outgoing lines from a station (Plant 1) had a single phase to earth fault. Single phase auto reclosure operated. However, a large power swing was observed at a power station (Plant 1) during the auto reclosing dead-time and caused a three phase trip of both the evacuating lines [5]. In five cases, high amplitude, poorly damped low frequency oscillations were observed at power plant 1, under an N-1 contingency. Oscillation plot for one of the cases is shown in figure 6.

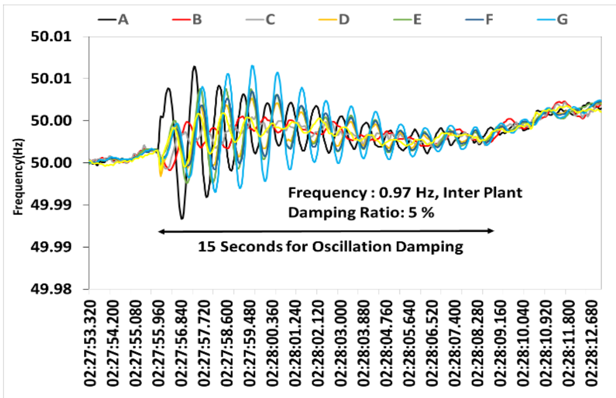

Figure 6: Plot of oscillation observed in frequencies near to power plants 1 during an N-1 contingency.

In order to resolve such issues following measures have been taken:

1. **Angular Separation under N-1 Contingency under different loading:** System study was performed for all the radial generators for finding the angular separation between the generator and its pooling station under N-1 contingency. This provided the idea of vulnerable stations.
2. **Transient study for Generators with High Angular Separation:** Transient studies were performed for Generators having more than 15-degree angular separation (as found in step 1).
3. **Power System Stabilizer (PSS) Tuning:** PSS tuning was completed for all these generating stations with high angular separation.
4. **System protection scheme (SPS) Implementation:** SPS for implementing runback under an N-1 contingency was designed and got implemented. SPS operation was coordinated to reduce the amplitude of power swing and allow single phase auto-reclosing.

The above steps were implemented in three generating plants. The impact of these measures in Plant 4 may be seen by comparing Fig 5 with Fig 7. Similarly, Fig 6 may be compared with Fig 8 to assess the impact of the corrective measures implemented in Plant 1. No blackout has been reported at these Power plants since then [13]. Figure 7 illustrates reduced amplitude of oscillations and improved damping at power plant 4. For similar contingency at plant 1, the oscillation which persisted for more than 5 minutes (Fig 6) earlier got damped within 10 seconds (Fig 8) after tuning of PSS 1. The oscillation frequency also changed from intra-area mode to inter-plant mode.

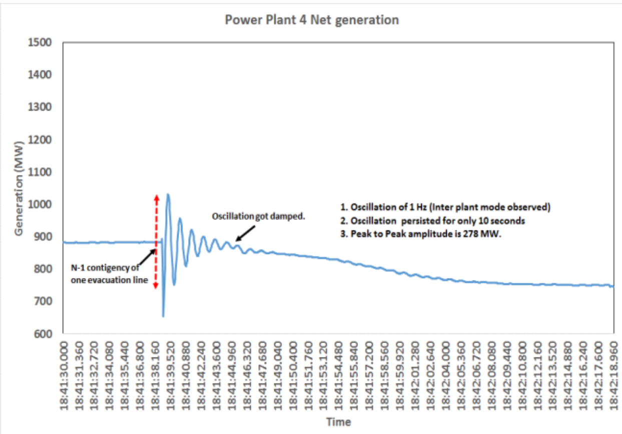

Figure 7: Improvement in damping of LFO in Power plant 4 with tuned PSS and SPS implementation.

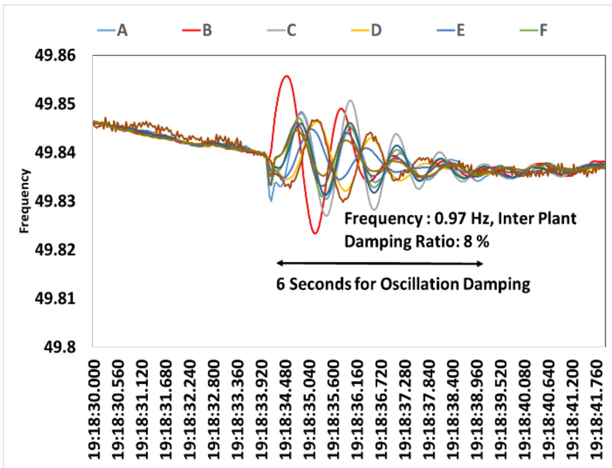

Figure 8: Plot of oscillation observed in frequencies near to power plants 1 during N-1 contingency after implementation of the remedial steps.

E. Substation Configuration

Most of such generating stations have one and a half breaker bus bar scheme and few have double main transfer scheme. There was a case of the blackout in one of the power plants (Plant 2, with a one-and-half breaker scheme given in Fig 9) in the Western region when both buses tripped. It can be observed that both evacuation lines were in the same diameter so with the outage of both buses, units got isolated from the grid. Thus the substation layout plays an important role in station reliability under various contingencies.

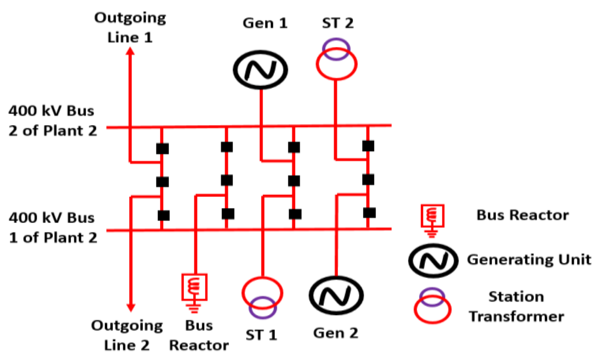

Figure 9: Power Plant 2 substation layout causing a blackout in case of tripping of both buses.

So, in case of one and a half breaker scheme, it is desirable that the outgoing line should be in the same diameter as the generating unit [Ref figure 10]. This will help in keeping the units in service with evacuation lines even if both the buses are dead. In this configuration, it is advisable to keep the major loads of the power plant in order to survive under the stressed condition on the unit auxiliary transformer (UAT) rather than station transformer.

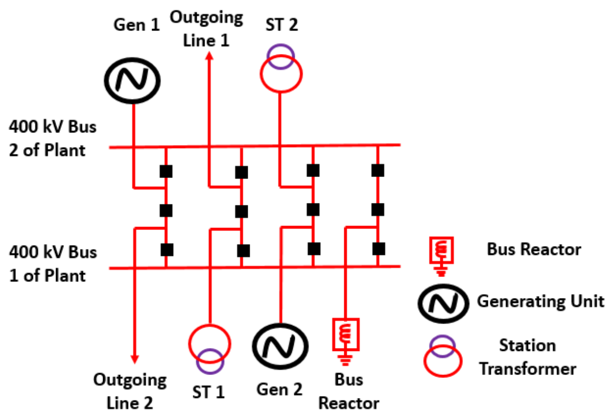

Figure 10: Suggested Station layout

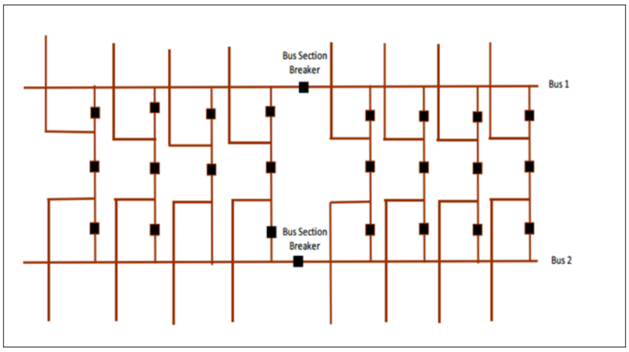

Figure 11: Bus sectionalisation of pooling station for higher reliability and security

In case of large pooling station with one and a half breaker scheme bus having more than 14-24 elements could be sectionalised such that uniform distribution of feeder and generator should be present in each section for enhancing reliability during all conditions as given in figure 11.

F. House load operation

CEA standard technical specification for sub-critical and critical thermal units [15-16] stipulate that all units having a capacity of 500 MW and above should be capable of running on house load with high pressure and low-pressure turbine bypass scheme and should not trip on over frequency. However, in most of the cases listed in table 1 the power station blacked out when both the evacuation lines tripped. This indicates that the house load operation scheme implemented at these station needs to be thoroughly reviewed and tested. If one or more units survive on house load, the plant can be quickly revived as soon as the evacuating lines are restored.

Summary

The paper documents case studies to highlight the challenges associated with the operation of the power plants connected radially to pooling stations. The authors suggest that the reliability of the power station could be enhanced if the above issues are taken care during the planning and commissioning stage itself.

The paper also shares the strategies adopted in the operating horizon to overcome the challenges faced. The authors suggest that a common protocol or reliability standard needs to be evolved to institutionalize the best practices in this regard.

G. Acknowledgement

The authors acknowledge the support and motivation received from the POSOCO management and colleagues. The authors are grateful for the liberal inputs and feedback received from the practicing engineers in different utilities and POSOCO.

Disclaimer

The views expressed in the paper are that of the authors. They may or may not represent the views of POSOCO.

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