ISSN 2347 - 3983

International Journal of Emerging Trends in Engineering Research (IJETER), Vol. 3 No.6, Pages : 373 - 379 (2015)
Special Issue of NCTET 2K15 - Held on June 13, 2015 in SV College of Engineering, Tirupati
http://warse.org/IJETER/static/pdf/Issue/NCTET2015sp70.pdf

A Qualitative analysis of Power System Blackouts -Northern Grid Case Study

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ABSTRACT:
A massive power cut blacked out the entire Northern India, leaving more than 300 million people without power, shutting down water plants, stranding hundreds of trains during July 2012. It is considered to be the worst Power system outage in the last decade. In this paper we have put together the sequence of events and their impact on the entire power system network. Based on the detailed case study and relevant discussions with PGCIL (Power Grid Corporation of India limited) authorities, possible recommendations to prevent such kind of technical lapses are suggested in this paper. The pros and cons of synchronizing the southern Grid with the Central grid being studied. Final conclusions were given.

Keywords: Cascading black out, Load Dispatch center, Synchrophasor, Power system Restoration.

I. INTRODUCTION

A Power Blackout is a long-term loss of the electric power to an area. There are many causes of power failures in an electricity network. Examples of these causes include faults at power stations, damage to electric transmission lines, substations or other parts of distribution system, a short circuit, or the overloading of electricity mains. Power failures are particularly critical at sites where the environment and public safety are at risk.

Grid Management in India is carried out on a regional basis. The country is geographically divided in five regions Northern, Eastern, Western, North-Eastern and Southern. All the states and union territories in India fall in either of these regions. The first four of five regional grids are operating in a synchronous mode, ie, the power across these regions can flow seamlessly as per the relative load generation balance.

The Southern Region is interconnected with the rest of India grid through asynchronous links. This implies that quantum and direction of power flow between Southern Grid and rest of India grid can be manually controlled.

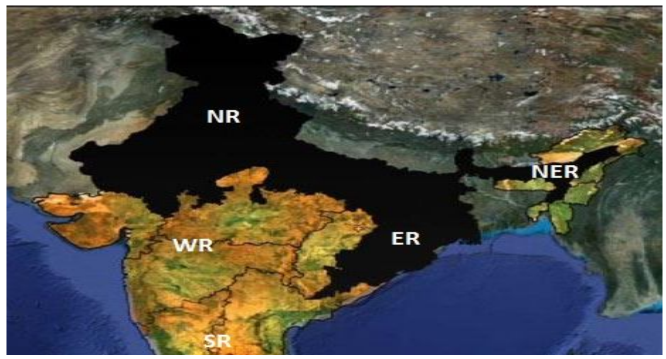

FIG:1: Geographical representation of the Grids

With respect to Fig:1, On July 30th and 31st of 2012, large portions of Northern, Eastern and North-Eastern regions of India experienced an electric power blackout. The outage affected 600 million people and 48,000MW of electric load in the 20 states of India. A major grid collapse happened at 02.33 hrs on 30-07-2012 in Northern region and again at 13.00 hrs on 31-07-2012 resulted in collapse of Northern, Eastern, and North-Eastern regional grids barring a few pockets. The physical nature of the power flows on transmission lines, rapidly changing demand patterns, dramatic changes in the system parameters, unexpected events in the grid and calamities (natural or man-made) make grid management extremely challenging. In the above mentioned case, it is the man-made events that results in the entire failure of the system. Here we have listed out some of the issues.

II. THE PRIMARY CAUSES

Several factors that contributed to initiation of this grid collapse are:

a) Depleted Transmission network

The outage of 400 kV Bina-Gwalior–Agra for up-gradation work, non availability of 400 kV Zerda-

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Kankroli and 400 kV Bhinmal-Kankroli due to insulator problems in particular weakened the NR-WR Interface.

b) Stretching the generation units to Peak Load for very long durations

Almost all the Thermal Generating units within the Central Grid were operated with their peak capacity for longer durations.

c) Under-utilized Hydro Power Stations

All Hydro Units being built produce just 39% of the site potential, produce very little power in winter and nothing when flows and therefore potential is Maximum for 16 days of high silt flows.

d) Lack of Regulation among SLDCs

Regulators did not integrate 50,000MW Standby Power with the grid. Domestic Load, Commercial Load, Essential Services Like Hospitals and Industries are connected to common feeders and hence the priority based load shedding was not possible. System not designed to restore Power to Essential Services in Minutes. No program to Conserve Energy and Absence of Load Shedding Policy.

e) Poor frequency profile

For historical reasons, the Indian grid Systems experienced poor frequency profile. In the Northern grid, more loads were met with available generation at the cost of frequency. System was subjected to operate in the range of 48-51.5 Hz. Power quality and Grid security was compromised during this period. The reactive power consumption was very large.

III.SEQUENCE OF EVENTS

Following are the sequence of the collapse, which took place on 30th July, 2012, leading to the Northern Grid blackout.

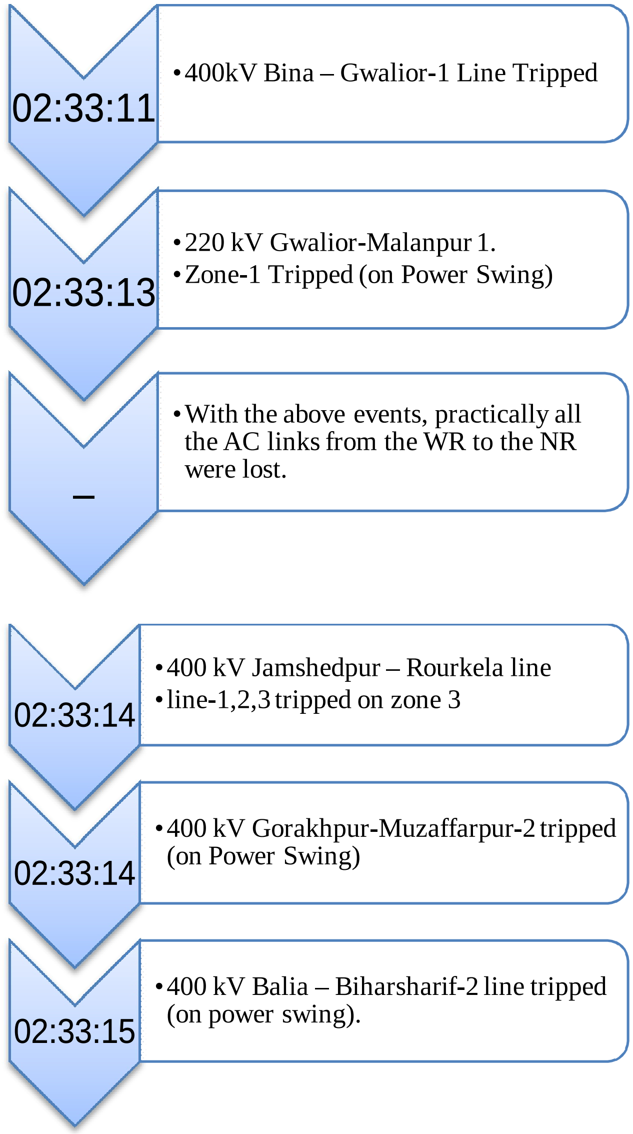

Fig:2: Flow chart showing the sequence of events

With the above events, all the AC links from the ER (Eastern Region) to the NR(Northern Region) were lost. NR was isolated from the rest of the NER (North East region) grid and ultimately collapsed on under frequency. ER-WR-NE survived as one system. Because of this pooling operation, the Grid blackout started in some areas and the remaining are the cascading events resulting into the complete blackout. Angular separation between two systems followed by power swings is possible on loss of short tie lines. This is shown in fig :3.

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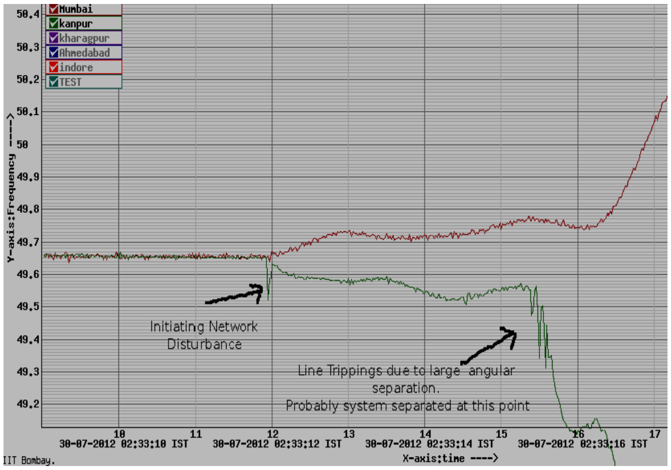

Fig:3 : Recording Showing Angular Separation between NR and Rest of NEW Grid on 30/07/2012

After the grid was restored on **30.07.2012**, another grid collapse took place on **31.07.2012.**This is purely due to the lack of emergency restoration actions and the continuous excess power consumption by the SLDCs.

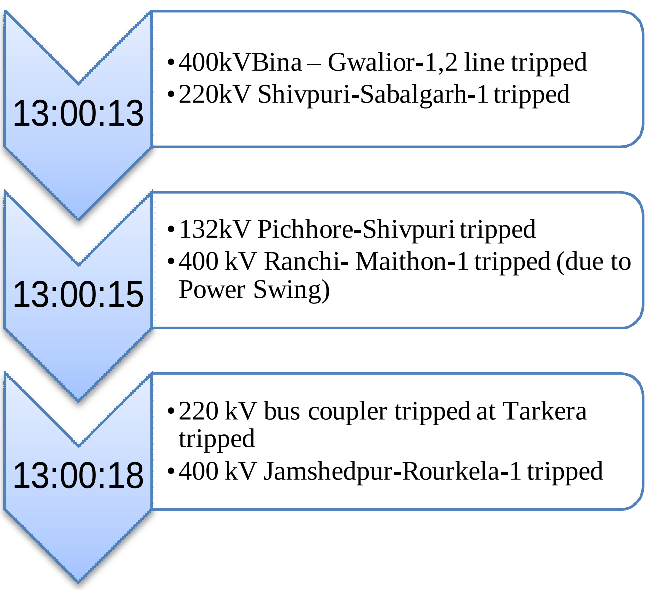

Fig:4(a): Flow chart showing the impacts of trips

Once again due to severity of the frequency fluctuation, practically all the AC links from the WR to the rest of the grid were lost and WR got isolated along with Ranchi and Rourkela buses.

After event , the NR got practically isolated from the ER+NER and frequency started dropping (observed in the NR system) after a gap of about 1 minute from the previous major event. The subsequent events of cascaded tripping led the NR, NER and ER system to practically total blackout.

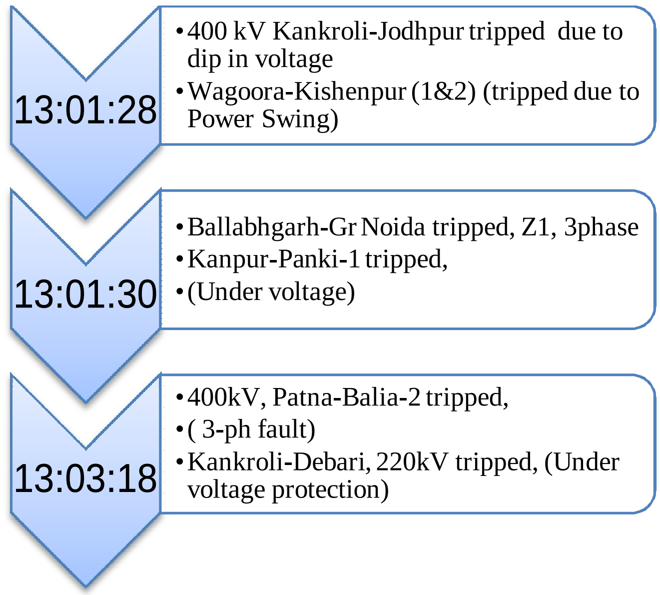

Fig:4(a): Cascading effect of tripping of HV lines

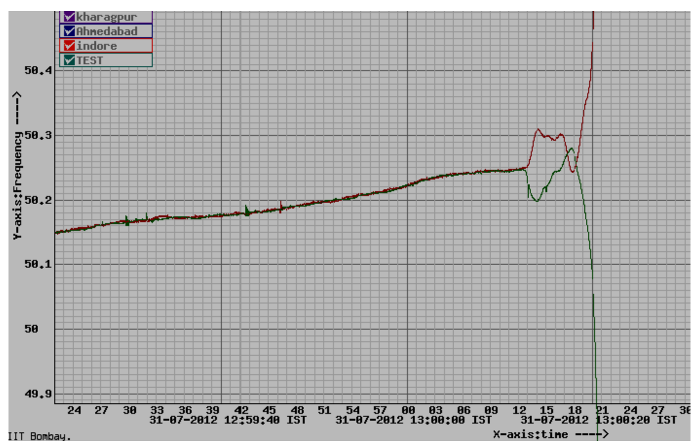

Fig:5: Recording Showing Angular Separation between NR and Rest of NEW Grid on 31/07/2012

IV) SYSTEM RESTORATION REQUIREMENTS

a) Quick primary response from generators

Mandatory activation of primary frequency response of Governors i.e. the generator’s automatic response to adjust its output with variation in the frequency.

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b) Optimum utilization of available assets

A large number of high capacity 400 kV lines have been added to the intra-regional and inter-regional systems in the recent past. However, a significant number of lines are generally kept open to contain high voltages. This makes system weak and such system may not be able to cope contingency.

c) Autonomy to Load Dispatch Centers

The State LDCs are nowadays facing huge political pressure rather than technical problems. An absolute autonomous operation may reduce the system failure possibilities.

d) Intra-State transmission Planning and its implementation

Better coordinated planning of outages of state and regional networks, specifically under depleted condition of the inter-regional power transfer corridors. This does not at all exist in the present scenario.

e) Operation of defense mechanism

Violation of the various system securities by Central Commission and Grid Connectivity & Grid Standard mechanism has not been taken seriously and the attention has solely been on overdrawals from the grid.

f) Dynamic security assessment and proper state estimation

At present the control centers do not have any tool to periodically assess the security condition of the system. State estimation solutions obtained from conventional techniques to be modernized.

V) POST BLACKOUT ANALYSIS

The black start procedure was already been prepared by RLDCs and was available with all utilities. However, during the grid disturbances it was been observed that substantially longer time has been taken by certain generating stations to come on bars. Some of the utilities expressed that to initiate start up process, certain delays were encountered on account of commercial issues in obtaining the start- up power supply from other outside agencies.

Various load dispatch centers, substations and generating stations, which were to implement the restoration operations in the real-time, upon receiving instructions from the apex load dispatch centers were not adequately managed in terms of experienced manpower and also particularly during odd hours. It was observed that after lighting up of the units, some of the units had taken longer time than others to synchronize with the grid. The observed time duration ranged from 2 hours to 4 hours in case of various generating units and 2 hours to 9 hours for other units. In case of gas based stations the time duration ranged between 1 to 6 hrs at some places.

Coal fired thermal power stations involve considerable amount of preparatory actions before actual start-up like operationalizing major auxiliary systems like circulating water (CW) system, compressed air system. Also start-up power is required to be provided to each unit and station auxiliary which involves charging up of number of transformers within the station sequentially and in turn is time consuming. It was also brought out by the stations that sudden tripping of the unit at high load lead to bursting of LP Turbine diaphragms in many of the units requiring replacement before start-up could be taken up and involved about 4 hrs for replacement of diaphragms for each unit.

Therefore, it is clear that start up time of generating stations was long to facilitate faster recovery in case of grid disruptions.

VI) OUR OBSERVATION AND RECOMMENDATION

Recommendations have no value unless they are implemented. It is useful to think of the recommendations presented below

1. Primary response from generators and operation of defense mechanisms, like Under Frequency & *df/dt* based load shedding and Special Protection Schemes, should be ensured in accordance with provisions of the grid code so that grid can be saved in case of contingencies.
2. Synchrophasor based WAMS as implemented by USA Electricity reliability council, should be widely employed across the network to improve the visibility, real time monitoring, protection and control of the system. They offer a wide application for real time monitoring and control of the system, especially under the dynamic conditions. Adequate number of PMUs should be installed to improve the visibility and real time monitoring of the system. Further the applications related to the synchrophasor based wide area monitoring, protection and control should be embedded in the system.
3. Improve System Protection to Slow or Limit the Spread of Future Cascading Outages.
4. Load Dispatch Centers should be equipped with Dynamic Security Assessment and faster State Estimation tools.
5. There is need to plan islanding schemes to ensure supply to essential services and faster recovery in case of grid disruptions.
6. Start up time of generating stations need to be shortened to facilitate faster recovery in case of grid disruptions.
7. Frequency band needs to be further tightened and brought close to 50 Hz. Frequency Control through Generation reserves/Ancillary services should be adopted, as presently

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employed unscheduled interchange mechanism is sometimes endangering the grid security.

8. For smooth operation of grid systems, it is absolutely important that all the power generating and transmission systems are connected on a very reliable telecom network. Since power grid has its own fibre optic cables, practically covering major nodes and power stations, a proper communication network must be built using dedicated fibres to avoid any sabotage or cyber attack on the power system.
9. Intra-State transmission system needs to be planned and strengthened in a better way to avoid problems of frequent congestion.
10. In order to avoid frequent outages/opening of lines under over voltages and also providing voltage support under steady state and dynamic conditions, installation of adequate static and dynamic reactive power compensators should be planned. The regulatory provisions regarding absorption of reactive power by generating units needs to be implemented.
11. If the system is insecure (in an alert condition), the following preventive actions can be taken:

a) Use any controllable elements, like HVDC and TCSC, to re-route power flows. If continuous capability limits have been reached short time overload capabilities may be used to buy some time for other actions. The amount and effect of the rescheduling will have to be checked using online load flow/stability analysis.
b) Generation rescheduling may be attempted. An available hydro-generator may be called on to generate power.
c) Load tripping may be attempted to reduce line loading.

12. A recent industry survey showed nearly all the thermal power plants in India having less than seven days of coal stock, a critical level, and many of the country's power plants running below capacity. Such a scenario can contribute to grid failure and lead to delays in restoration of power supply. Energy efficiency in different sectors : "2 megawatt of electricity generated is equal to 1 megawatt of electricity saved." Going forward, this equation will soon change to 3: 1.

According to the Planning Commission of India, nearly 25,000 MW of capacity creation can be avoided through energy efficiency in the electricity sector alone. According to a recent Cyber Media Research study, energy saving potential ranges from 20% to 30% in different sectors (industrial, transport, agriculture, municipal etc.). Private participation in the transmission sector: The Indian power sector was opened to private players a long time ago but these players are working mainly in generation and distribution sectors. More private participation in transmission will help the Power Grid Corporation of India Ltd., the world's biggest transmission company by capacity, to ease some pressure by laying new transmission lines and by preparing innovative plans for this sector.

When an HVDC (back-to-back) scheme is used as a tie between two control areas or used as a separator, the restoration procedure becomes much simpler as the flow of power can easily be maintained at the pre-set value or within a range/dead-band between intended zones/areas. Since an HVDC link can control the power flow at all times and therefore needs to be rated only for scheduled power transactions and agreed emergency support, a back-to-back HVDC station is normally a more economical alternative, for interconnection of two relatively large ac networks or for isolating a particular priority network zone/area.

VII) INTER CONNECTED GRIDS

As the southern grid was not synchronized with the rest of the country, Southern India survived the crisis. Southern grid is urged to be synchronized with other four grids. If it is being done so then advantages are that power can be diverted to where it is needed, if there is high demand or a breakdown. National grid system can cope better with peak consumption hours occurring at different times at different locations in the area. Supplies can be regulated, and control of pricing etc. In a lot of cases it would result in cheaper energy supplies rather than separate suppliers charging vastly different rates for production and supply. Secure and reliable power supply.

Disadvantages like some power are wasted in heating the cables. If such massive blackout occurs without proper follow up of recommendations then all five grids can turn a country like India completely in dark.

VIII) IMPACT ON OTHER GRIDS

The northern Indian states draw more power from the country's grid than they are allotted. India has circuit breakers to cut off power to states that overdraw, but the officials concerned do not adhere to this law and keep the supply running. In addition to the above point, the irregularity of monsoons, affect the production of hydropower supply, thus making the supply to the grids less. Even with the financial status available to our nation, the problem of acute power shortage has not been overcome. The following fig 6 shows Figure 6 uses P-V analysis to show the impact of increased load levels on

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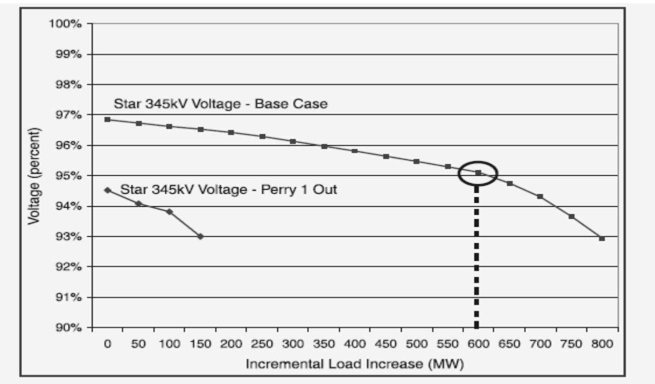
voltages at the Star bus with and without the Perry unit before the loss of the OBRA twin line in Uttar Pradesh at 15:05 pm on 30th July, 2012. The top line shows that with the Perry plant available, local load could have increased by 625 MW and voltage at Star would have remained above 95%.



But the bottom line, simulating the loss of Perry, indicates that load could only have increased by about 150 MW before voltage at Star would have become unsolvable, indicating no voltage stability margin and depending on load dynamics, possible voltage collapse. The above analyses indicate that the entire western area and parts of southern area were highly vulnerable on the afternoon of 30th July, 2012.

Although the system was compliant with NTPC Operating Policy, for single contingency reliability before the loss of the chembur-allahabad line at 15:05 hrs, had the Perry plant its system would have neared voltage instability or could have gone into a full voltage collapse immediately if the area load were 150 MW higher. Although there are financial penalties for overdrawing, it's still cheaper for states to buy electricity from the Centre at set rates than from open-market national energy exchanges. The next priority is to get the finances of the distribution utilities in order by curbing widespread theft, updating obsolete transmission networks and allowing them to increase prices.

Very importantly there should be a public address system by which the people can be warned prior to a possible black out about the worst sequences of a total grid collapse. Certainly a major portion of public will come forward to minimize their power consumption at least during the over drawal conditions. It is very painful to learn that neither before nor after this blackout nobody was worried about the lessons that to be gained from that incident.

IX) CONCLUSIONS:

Even as India installed record 20,000MW new generation capacity last year power shortages in North, West and South Regions has not reduced – most of the imported units are Defective. Northern region installed under utilized Hydro Power Units that produce around 10,000MW power from 15,500MW installed capacity when they ought to produce 30,000MW. North India has not integrated 15,000MW standby power to the Grid. But the most shocking aspect is that due to the gross incompetence of Regulators, Power Generating and Distributing Companies, who are not cutting the load during black out, the Generators were tripped, that led to Grid Collapse. Grid is not designed to restore Power to Priority Services like Hospitals and Railways quickly.

For economic as well as environmental reasons, India needs to shift to non-polluting renewable sources of energy. Renewable energy is the most attractive investment because it will provide long-term economic growth for India. Decentralized off-grid renewable distributed generation sources like solar, wind, hydro, biomass, biogas, geothermal, hydrogen energy and fuel cells are the answers. These sources have the advantage of empowering people at the grassroots level and utilize distribution and transmission methods with little to no emissions. India should consider developing targets for electrification that include renewable off-grid options and/or renewable powered mini-grids. This will take a substantial electrical load off the existing power grid and also reduce the need for installing additional transmission and distribution systems. Deployment of large-scale solar and wind projects are needed to begin a smooth transition from fossil fuels and nuclear power that is harming both communities and the environment. India can use renewable energy for meeting all future energy needs because it is sustainable, locally available free of charge, eco-friendly and eliminates global warming. Overall a chaos theory found out from such a massive blackout in India is presented in this paper. By forcible application of recommendations presented in paper power blackout not only in India, any nation can overcome such grid disturbances.

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