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# Analyses and Discussions of the Blackout in Indian Power Grid

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## Abstract

Widespread blackouts of "7.30" and "7.31" occurred in India in 2012. Severe problems in the infrastructure, operation and management in India power grid have come to light after the successive blackouts. The fundamental reason and trigger factors are analyzed in this paper first. Based on the similar characteristics between China power grid and India power grid, in the case of Chinese grid, lessons of preventing blackout of large power grid were discussed by analysis and comparison, mainly on harmonious development and interactive operation of source-grid-load, and construction of wide-area protection system. Suggestions are proposed to improve the security and stability of large power grid with coordinated control system.

**Key words:** Indian power grid; Blackout; Source-grid-load; Interactive operation; Coordinated control; Wide-area protection

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## FOREWORDS

The severe blackout occurred consecutively twice on 30th and 31st July 2012 in northern India, which affected 670 million people's normal life and work, is the one spreading to the largest population in the world (Report of the enquiry committee on grid disturbance in northern region on 30th July 2012 and in northern, eastern & north-eastern region, 2012). As a result of the blackout, in cities of the vast affected Indian regions, subways were shut down, factories' power-supply was cut off, and households' water-supply was also cut off. Thus the Indian economy was severely impacted and in the mean time the blackout drew high attention in the worldwide as well.

With the rapid development of global economy, many countries including India are facing the challenge of cross imbalance of electricity consumption and power distribution. Meanwhile the gird construction and management are comparatively lagged, thus the security and stability of grid have severe hidden threats accordingly (Xue & Xiao, 2012). In case of some occasional natural disasters or human factors, a series of chain effects would be possibly trigged and lead to blackout consequently. In recent years, blackouts occurred from time to time in the worldwide. It reminds all the power practitioners that construction of safe and reliable grid is an urgent task at present (Xue & Xiao, 2011).

This paper analyzes the direct reasons and trigger factors of the Indian blackout according to its current situation of power industry. Based on the experiences and lessons of the Indian blackout as well as combining the practical situation of Chinese grid operation, the paper also put forward some advices on guarantee of safe and stable grid operation and construction of steady grid infrastructures as well as defending systems.

## 1. GENERAL INSTRUCTION OF CURRENT SITUATION OF INDIAN POWER INDUSTRY

As one of the top ten economies in the world, India has huge industrial systems and keeps over 7% of growing increase in the last decade. During the high-speed development of Indian economy, the nation highly pursuits development of new industry while overlooks coordinative promotion of fundamental industry. This causes infrastructure construction lag behind the increase of economic development and finally leads to comparative delay of power industry (Zeng, Li, & Dong, 2012). In the long term, there is a large gap between power supply and demand in India, which can not satisfy the basic demands of national development and civil living.

The Indian grid is composed of five regional grids namely east grid, south grid, west grid, north grid and northeast grid respectively with main transmitting voltages of 765kV, 400 kV, 220kV, 132kV AC and ±500kV DC, and 400kV AC transmission lines compose the backbone network of the Indian grid. Among the five regional grids, by adopting the modality of synchronous network operation, the north grid, west grid, east grid and northeast grid are composed as the NEW grid which can realize asynchronous interconnection operation with the south grid through DC transmission. Figure 1 shows the basic connection of the Indian grids.

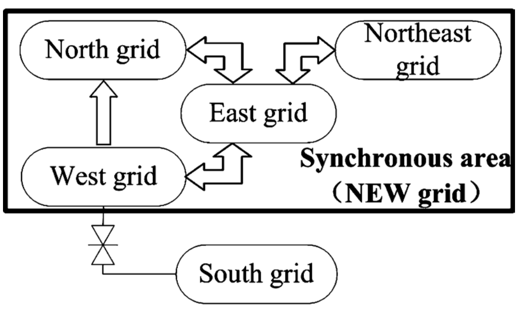


**Figure 1**
**The Structure Diagram of Indian Power Grid**

The Indian north grid has the largest business area and the most employees. By the end of June 2012, the total installed capacity of the north grid had reached 56058MW. The generator units are mainly located at eastern area of the north grid, while the electricity load center of northern area is the mid-western area of the north grid including New Delhi, which takes a long distance transmission shape namely power transmission from east to west (Report of the enquiry committee on grid disturbance in northern region on 30th July 2012 and in northern, eastern& north-eastern region, 2012), Shown in Figure 2.

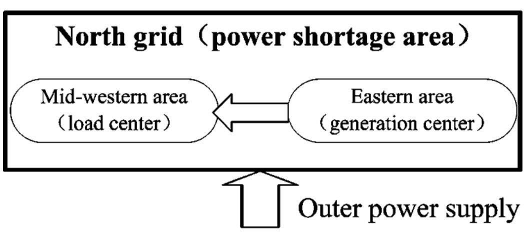


**Figure 2**
**The Flow Diagram of Northern Grid in India**

## 2. REASONS ANALYSIS OF THE INDIAN BLACKOUT

### 2.1 Direct Reasons

On 30th July 2012, the grids were in unsafe operation, because a number of transmission lines were shutdown for maintenance, particularly, only two 400kV interconnecting ties were connected between the west grid and north grid. And the 400kV Bina-Gwalior transmission line of the west-north interconnecting tie as well as some 220kV transmission lines tripped successively due to three-section protection caused by the overload, which led to further weaken of the connection between the western and northern areas. Thus massive amount of electric power was supplied to northern area through the west-east-north interconnection ties, and an important 400kV transmission line of the east grid finally tripped caused by the power flow overload of the ties. Consequently, power angle instability happened between the north grid and other regional grids, and interconnection ties between east grid and north grid were cut off successively, thus the north grid was separated finally from the east-northeast-west grids. Therefore, the shortage of massive power was caused in the north grid and a large amount of load was not cut off in time accordingly, which led to the final collapse of the north grid system. In comparison, there was power surplus in the south grid which can be maintained in stable operation through tripping measure.

Around 13:00 PM on July 31 which is only one day after recover of the 7.30 blackout, the north grid was still in shortage of power supply and overload operation. Due to power flow overload of the western-northern transmission cross section, the interconnection ties tripped successively because of three-section protection, which was similar with the 7.30 blackout and led to separated operation of the west grid and north grid. While the difference is that the oscillation center shift from the cross section between the north grid and the east grid to inside of the east grid due to strengthen of interconnecting cross section between the north grid and the east grid on the day, then a series of transmission lines tripped to lead separation of the west grid and the east grid as well as collapse of the regional grids accordingly. As a result, apart from several regional grids in isolated operation, large-scaled blackout occurred in vast areas of northern, eastern and northeastern India. Comparatively, the 7.31 blackout was much serious with more wide-spreading damage than the day before.

### 2.2 Trigger Factors

The direct reason of the Indian blackout is that some regions kept over consumption of electric power under the circumstance of shutdown of plenty of transmission lines which led to overload operation of the grid system finally. Moreover, no adoption of correct and effective control measures at the beginning of the blackout triggered a series of chain breakdowns accordingly and caused the disastrous blackout consequently (Tang, Bu, & Yi, 2012). Despite of occasional factors though, there are inevitable trigger factors behind the blackout. This paper is to analyze and discuss in view of the level of source-grid-load based on the integrated operation of gird systems.

The power source equipment is essential for guarantee of system operation. Indian power generation mainly relies on thermal and hydro. However, development of new energy such as nuclear is severe lagged. Although India is one of the leading countries in the world regarding to the reservation of primary energy resources, the per capita consumption is extremely less due to its large population of end users. In addition, due to factors including high coal price and less precipitation, India remains in severe shortage of electric power. Moreover, power outputting areas are mainly located in northeastern and eastern India while load center located in northern area. Therefore, the issues of Indian generating capacity and its power supply structure as well as distribution cause the severe insufficiency of power supply, and the phenomenon of over consumption of electric power in some areas in long term, which buries severe hidden threats to the safe and stable operation of grids.

Grid construction is the basis of maintenance for system security. While the weak power infrastructure remains the bruising of Indian power industrial development and dramatically impedes development of power technology. As for grid planning, India adopts AC/DC series and parallel architecture among regional grids while modality of force AC/weak DC or force DC/weak AC is adopted generally for transmission. Besides, some important transmitting cross sections are kept in heavy load operation and related interconnection ties are close to transmission limits due to power distribution. Therefore, once in case of DC blocking or breakdown tripping of key transmission lines, interconnection among regional grids would be further weaken, and power flow will shift to AC channel of cross section of regional grid, which would possibly lead to oscillating operation of main grid or trigger much severe breakdowns with potential extreme damages.

Load management is the key factor of influencing system stability. India adopts dual management system of national grid corporation and state electric power bureau instead of united power managing mechanism. Indian power dispatch is composed of four levels including central, regional, state and local, who takes into consideration in priority for its own benefit in dispatch. Moreover, the power superintendence committee can only proclaim certain penalization but not intervene sub-level operation directly. Absence of effective coordination and cooperation among dispatching levels leads to inability for realization of all-around based optimal management. All grids are in operation with low efficiency, and regional diversity causes considerable gap regarding the electric power consumption. In duration of grid limitation, the dramatic exceeding of electricity consumption still happens which is extremely easy to cause overload, and grids are possibly collapsed due to the low stability.

## 3. DISCUSSIONS ON PREVENTIVE MEASURES FOR BLACKOUT OF LARGE-SCALED POWER GRID

The Indian disastrous blackout is an inevitable result trigged by hidden threats existed in chains of grid. Chinese grid is under construction and establishment of smart grid operating modality featured by regional integration and united operation. Chinese and Indian grids have some similarities, and Chinese social economic development is also similar with Indian. Therefore, this paper is to take Chinese grid for instance and conduct comparative analysis, based on experiences and lessons of the Indian blackout, to discuss relevant approaches and measures for prevention of blackout of large-scaled power grid or defending of extension of local accident.

### 3.1 Coordinative Development of Source-Grid-Load

China and India, the two leading powers of population, are both in the stage of economic explosive development and have huge demand for energy. In recent years, the infrastructural construction of Chinese grid has achieved greatly. However, coordinative development of source-grid-load should be strengthened comprehensively with no relax of vigilance for prevention of blackout.

As for power generation, China and India are similar in terms of energy mix. Thermal power still be relied in most majority of areas, which accounts for great proportion. And power generation depends significantly on reservation of fossil energy. In aspect of power generation by renewable energies including wind and solar etc, electric power workers and scholars have conducted plenty of intensive studies. However, with gradual increase of the penetration, the replacement of a portion of conventional energy will inevitably have problems including stability of voltage and frequency etc. due to the randomness, intermittence and fluctuation of new energy (Lei, 2003). For example, large-scaled tripping accidents of wind turbine generators occurred for times in recent years in Gansu province, which severely impacted the stability of regional grid (Sun, Zhang, & Lin, 2012). The practices prove that China is still facing the challenge of technical breakthrough on large-scaled grid integration of power generation of new energy. In case of inability to overcome related difficulties, the power supply would possibly be stuck in plight.

As for power transmission, due to severe imbalance of power generating and electricity consuming areas, Chinese and Indian grids are in the same feature of large-scaled long distance power transmission and adopt the AC/DC series and parallel transmission modality among regional grids with extreme complicated dynamic characteristics. In case of heavy load, breakdown of AC transmission lines could possibly leads to DC blocking problem, and breakdown of DC transmission could also possibly leads to overload tripping of AC interconnection ties, which severely threats regional transient stability (Wang, Zhang, & Xia, 2008). A key cause of the Indian blackout is absence of firm grid networking architecture which can mitigate partial fluctuation in certain limit and subside the impact on the all grids caused by regional breakdown. China is now emphasizing on development and construction of extra-high voltage backbone AC grid network and ultra-high voltage DC transmission network which can significantly strengthen security and reliability of grid operation through emphasizing electric interconnection among regions (Shu, Zhang, & Zhou, 2007).

As for power distribution, Indian grid is lack of practical and effective management mechanism for power demand. Each state keeps power consuming over the quote in long term in order to satisfy the local demand while overlooks entire security requirement of grids. This becomes the fuse of blackout. China should learn the lessons from India and emphasize regional load management and dispatch. With the growing development of scientific technology, apart from the conventional industrial, commercial and civil electric load, new emerging load such as electric vehicles as well as other forms of power storage devices accounts for increasing proportion in grid and become friendly controllable load to grid with positive prospect for utilization under the united management mechanism (Hu, Song, & Xu, 2012). By reasonable dispatch, this new load can be utilized for real-time response to grid requirement and involvement of balance for supplying & demanding, as well as important measure for balance of intermittent power fluctuation in order for further improvement of grid stability.

### 3.2 Interactive Operation of Source-grid-load

The rapid widespread of the Indian blackout can to some extend be attributed to absence of integrated connection among source-grid-load which can not form positive mutual aid in case of threat and finally lead to instant collapse of the grid. Therefore, improved control system must be constructed on basis of united development of source-grid-load, and lessons should be taken from the Indian blackout to strengthen interactive operation of source-grid-load in order for realization of perfect self-healing ability of grid (Yao, Yang, & Wang, 2012).

The flexible interaction of source-grid-load means through multi interactions among power source, load and grid, the aim to improve power dynamic balancing ability of electric power system can be realized more economically, effectively and safely. This is one of the key trends for development of smart grid in the future (Yao, Yang, & Wang, 2012). Figure 3 shows its basic operational modality.

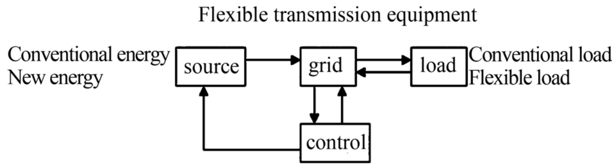


**Figure 3**
**The Diagram of Source-Grid-Load Interaction**

Power source is the origin of grid energy flow and essential guarantee of electric power supply. Once the penetration of new energy (Ajayi, Fagbenle, & Katende, 2011; Mostafa, Sedrak, & Dayem, 2011) which has dispersion characteristics is highly raised in future, some energy forms which are close to load side can be realized for on-the-spot connection forming micro grid and distributed generation (Han, Deng, & Wen, 2010). On this basis, improved management mechanism of micro grid and distributed generation can be established. In case of blackout, operation mode can be shifted rapidly by control measures to guarantee isolated operation of some regional grids and meanwhile prevent large-scaled current shift to the backbone grid in order to avoid of further deterioration and expansion of accident.

As the other side of the dynamic balance of grid energy flow, load feature and performing characteristics decide the security of grid to large extend. With popularization of electric vehicle technology (Masoum, Deilami, Masoum, & Abu-Siada, 2013), new flexible load will have certain power generating features and can be effective measure for stabilizing generation-load power fluctuation. Meanwhile, the improvement of power storage technology can also provide short term but effective power support for load area. The above-mentioned measures can realize two-way energy interaction with grid according to requirement (Callaway, & Hiskens, 2011). The utilization of new technology for optimized management of load will have positive complementary benefit to grid system.

With rapid development of new theory and material, the flexible AC transmission system (FACTS) is adopted for widespread utilization. Besides, many advanced power electric devices including the united power flow control (UPFC) and voltage source changer based high voltage DC (VSC-HVDC) will also play key roles for security and reliability of grid operation (Hu, 2011). The flexible power transmission equipment can actively adjust and optimize the distribution of grid power flow to response to real-time dynamic change of power and load, playing positive series connecting role in energy transfer proceeding of source-grid-load.

The interactive operation approaches of source-grid-load can still be exploited. Based on the national situation of power industry and grid development, China should guarantee comprehensive interaction and coordinative balance of power source, grid as well as load, and effectively prevent negative impacts caused by local breakdown to the all grid systems in order to meet the essential demand of smart grid development in the future.

### 3.3 Defence Construction of Security and Stability for Wide Area Systems

In the process of the Indian blackout, the units of auto low frequency load shedding devices which are equipped to the north grid, no perform effectively and stop fast fall of the system frequency leading finally to the collapse of the regional grid in circumstance of dramatic reduction of the grid frequency after separation with backbone grid,. Therefore, taking prompt and effective control measures for safety and stability is significantly essential to prevent large-scaled blackout in case of accident (Zhang, 2004).

Up to present, Chinese power system has three safe and stable defending levels which can adopt different controlling strategies according to varieties of breakdown and severity, making great contribution to the security of Chinese grid in long term. Among the three levels, the traditional two levels adopting stable controlling technology based on accident testing are featured by strong pertinence, fast speed and high reliability, but cannot deal with exceptional accident out of the breakdown category (Xue, 2006). While as the last defense at present, the third defending level adopts the local characteristic response based controlling mode, and takes extreme measures including generating units tripping, load shedding as well as regional separating, paying the huge cost for controlling (Xie, Li, & Wu, 2004).

With extensive utilization of the GPS technology and synchronous phase measurement unit (PMU) in power system, the practical response based safe and stable controlling technology is possibly to be realized. The wide area measurement system (WAMS) collects wide area synchronous information with untied time mark, and extracts system dynamic feature from the practical disturbed track. Figure 4 shows its basic operating mode.

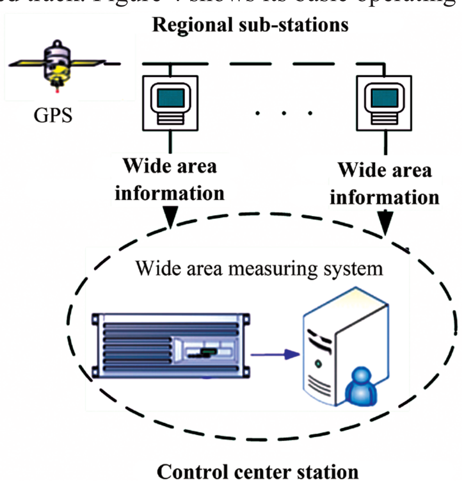


**Figure 4**
**The Structure Diagram of PMU / WAMS**

The wide area controlling system equipped with PMU/WAMS can be utilized for identifying and positioning the breakdown, identifying the transient instability mode, identifying the mode, modal and damp of low frequency oscillation, as well as realizing the closed-loop damping control (Xue, Lei, & Xue, 2012). Related controlling system has been put into operation in many countries and regions, accumulating valuable practical experiences (Taylor, Erickson, & Martin, 2005).

Due to the prominent features of heteronomy and nonlinearity of power system, there is strong coupling among electrical quantities. Regional breakdown can possibly trigger chain accidents and lead to blackout finally. Therefore, it is necessary to take reasonably safe and stable controlling measures in view of overall situation to solve the deficiency on observability and controllability in original controlling plan. Based on the above-mentioned reasons, China is emphasizing on development of safe and stable controlling plan based on the PMU/WAMS in recent years, expecting to choose and finalize more reasonable protecting and controlling strategy through acquisition of real-time data of large grid operation. And this will be positive complementary benefit on functionality and effectiveness to the three defending levels of conventional power system.

Finally, it is necessary to point out that the Indian grids had already been under unsafe operation before the blackout due to shutdown of plenty of transmission lines as well as heavy load demand in north. At that time, dispatching centers of the north and west regional grids ordered dispatcher to reduce load which was not effectively implemented and failed to stop the following-up chain accidents. Therefore, it is still necessary to further improve the dispatching and controlling management mechanism, apart from establishment of new effective safe and stable controlling system, in order to realize quick response to accident and united command of accident recovery. Besides, dispatchers should be ensured with certain authority to deal with accident to establish high efficient accident handling mechanism, and able to make effective orders at the beginning of accident or in the proceeding of chain breakdown in order for prevention of blackout (Fang, 2012).

## CONCLUSION

This paper analyzes the main reasons of the 7.30 and 7.31 Indian blackout in 2012. In the light of the problems of infrastructural construction, technical management and dispatch planning of the Indian grid, it discusses and puts forward advices on coordinative development and interactive operation of source-grid-load, construction of safe and stable defense for wide area, as well as dispatching and controlling management mechanism for Chinese grid based on comparative perspective. The loss caused by the blackout is impossible to be retrieved. However, the lessons learned from the disastrous Indian blackout will be hopefully warning for safe and stable operation of grids in the world.

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