India's Blackouts of July 2012: What Happened and Why?

Anubhav Ratha, Masters Student, ETH Zurich, Switzerland

On 30 and 31 July 2012, two large-scale power blackouts occurred in India which undoubtedly amounted to the worst power crisis in history. The first outage affected nearly 350 million people, and the second affected around 680 million people spread over 21 out of 28 India's states.[1] In all, one-tenth of the world's population were affected. What caused the outages and how can they be avoided in the future?

India's Electricity Grid

The electrical network in India is divided into five regional grids: northern, northeastern, eastern, western and southern, as shown in Figure 1. Around two-thirds of the electricity generated comes from coal-fired thermal power plants which are concentrated in the eastern region owing to their proximity to major coal mines. Hydro generation, which accounts for another tenth of the country's total generation, is located primarily in the northern and northeastern regions. However, most of the power consumption takes place in the north, west and south regions.

Meeting the demand in these regions requires a heavy traffic of power flows across thousands of miles. The arteries for these cross-country flows are a network of 400 kV transmission lines. The distribution of power within these regional grids is in turn, managed independently in each state of India by its power utility.

During the first wave of electricity reforms in India in the early 1990s, the plan to connect the regional grids into a national grid was conceptualised, following which all regional grids, except the southern region achieved interconnectivity. The synchronous operation of these regional grids, forming the combined grid called the North-East-West (NEW) Grid, eases the power exchanges among these geographic regions to manage the surplus and deficit generation. A power transmission 'superhighway' was commissioned to tightly link these regions together. This corridor which is made up of high capacity lines connecting Agra and Gwalior in the west, to Sasaram in Bihar in the east, allow voluminous flows of power from thermal power stations in the east to the load centres in the west and north.

To coordinate the power exchanges among these regions, a National Load Dispatch Centre (NLDC) was formed in Delhi in 2009 to manage the inter-regional exchanges, in addition to the existing Regional Load Dispatch Centres

Figure 1: India's' Five Regional Grids

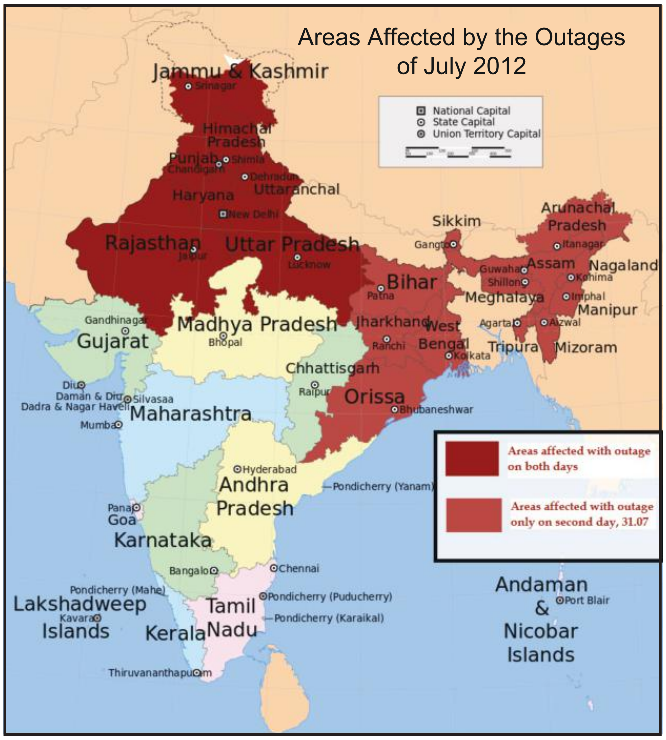
Source: Sun-Joo Ahn and Dagmar Graczyk, *Understanding Energy in India: Policies, Players and Issue* (Paris: OECD/IEA, 2012) p. 94.

(RLDCs) which had been managing the intra-regional power balance. These load dispatch centres (LDCs) are autonomous subsidiaries of the public sector Transmission System Operator (TSO) called the Power Grid Corporation of India. Their priority is to ensure generation-load balance throughout the network.

The Indian electricity grid is expected to always operate at a frequency of 50 hertz. This is essential for efficient operation of household appliances, industrial loads and to maximise the lifetime of infrastructure. Whenever the demand in a regional grid exceeds the supply, the frequency of the grid tends to drop. To compensate, the generators all over the interconnected system start pumping more power into the network which then requires more power to be transmitted over the transmission lines. Carrying power above the rated capacity of the transmission lines results in increased thermal stresses and when the safety limits are crossed, a protective shutdown of the lines is activated. In turn, this partial shutdown of some of the grid connectors may lead to yet more stress and the subsequent shutdown of the other lines in the network, followed by turning off of generators and eventually causing a blackout. The sequence of events in July 2012 closely resembled this classic 'spiral breakdown effect' of a power system. Figure 2 portrays the areas affected on the two days outages.

Employees manually fill containers with diesel during a power cut at a fuel station in New Delhi 31 July 2012. REUTERS/Adnan Abidi

Figure 2: Areas Affected by the Outages of July 2012



Source: Wikipedia article on India blackouts of 2012 at <http://en.wikipedia.org/wiki/2012_indian_blackouts> [22 Jan. 2013]. (Licensed under CC By - SA 1.0 via Wikimedia Commons)

What Caused the Outages?

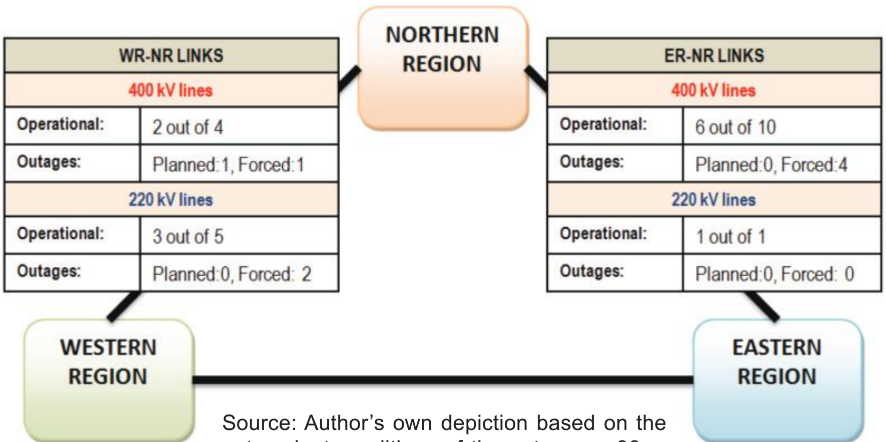
Around 0230 hours on Monday 30 July 2012, there was a disturbance in the NEW grid leading to the disconnection of the Northern Regional Grid from the rest, and ultimately resulting in an outage plunging 8 out of 28 Indian states into darkness. About 32 hours later, around 1300 hours on Tuesday 31 July 2012, a similar disturbance emerged, this time triggering the collapse of the northern, northeastern and eastern grids, together affecting about 680 million people. This outage was the largest in the history of electric networks.

As evident from the reports published by the Enquiry Committee on Blackouts commissioned by the regulatory authority of India, the Central Electricity Regulatory Commission (CERC), the NEW grid was operating in a stressed situation throughout the month of July.[2,3] The failure of southwest monsoon rains had led to an unprecedented increase of agricultural demand in the northern region. This was accompanied by a power surplus in the western region which resulted in very high outflows of power to the Northern region. Adding further to the woes of the imbalanced system, only two of the four 400 kV high capacity west-north interconnections were operational as shown in Figure 3.

One of the two unavailable lines had been placed under planned outage since Saturday, 28 July 2012 for up-grading to 765 kV, while the other underwent a forced outage the next day due to equipment failure. This situation exerted enormous pressure on the two available lines, one of which (Agra Gwalior 400 kV line) was already carrying power at the edge of its capacity limits of around 1000 MW.[4] On Sunday, 29 July 2012, the critical Agra-Gwalior line nearly collapsed around 1500 hours, 36 hours prior to the actual major grid breakdown. Even then, no stringent steps were taken at this stage to curb the demand in the northern region or to curtail the generation in the western region. Instead power from the surplus western region detoured via the central and eastern states to reach the deficit northern region. This is where the decisions of the state government-owned utilities came into play. The states are expected to operate a special class of protective devices on their power lines called Under Frequency Relays (UFRs) which respond to changes in frequency, detect sharp drops in frequency (indicative of high loading in the system) and disconnect the loads connected to them. However, the state-owned utilities seldom maintain these relays because they are typically under tremendous political pressure to continue drawing power from the grid even if the system appears to be compromised. The non-tripping of these UFRs put the system in a state of high risk such that the failure of any single crucial component led to a cascade of shutdowns. The timeline in Figure 4 portrays the sequence of events that began at 0010 hours on 30 July with the further weakening of the west-north linkage leading to the isolation of the northern region from the NEW Grid, and ultimately the blackout.

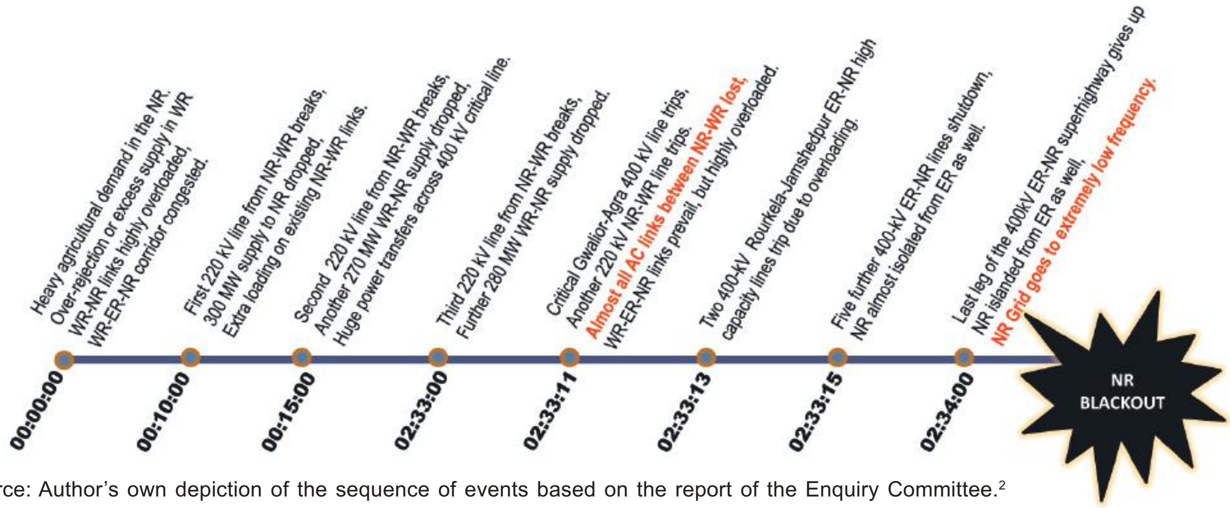
Just 32 hours after this first outage, there was another disturbance in the NEW grid, originating again in the critical west-north regional interface. There was still a high power vortex in the northern region and power surplus in the western region. As a part of the supply restoration process, three out of the four NR-WR 400 kV links were made operational. When two of these failed to operate in overloaded conditions at 1300 hours on 31 July, a very similar cascade of shutdowns of other NR-WR links followed as shown in Figure 5. However, in this case the grid was already considerably weakened by the outage on the previous day. Several WR-ER connecting lines were still down and the entire system was in a compromised state, struggling to barely meet the load. At this stage, 38 links

Figure 3: Overview of Transmission Line Resources Available in the Critical System Corridors



Source: Author's own depiction based on the antecedent conditions of the outage on 30 July 2012, as presented in the report of the Enquiry Committee.

Figure 4: Timeline Showing the Critical Events that Led to the Outage on 30 July 2012



Source: Author's own depiction of the sequence of events based on the report of the Enquiry Committee.[2]

between the various parts of the northern, western and eastern grids were disconnected due to overloading within a short span of one minute. Along with this, most of the generation protection systems in the eastern region shut down, thus taking away a huge chunk from the net generation pool. The northern, eastern and northeastern regions were cut off from the western grid and consequently suffered a blackout. Meanwhile in the western region, which had a surplus of generation and had lost its loads in the northern region, the frequency overshot to 51.4 hertz. However, the immediate isolation of the western region from the NEW grid and the tripping of generations saved the region from suffering an outage.

Restoration of Supply

On both days, the process of restoring supply to the loads was initiated soon after the incident. However, due to its sheer magnitude, it took a long time for the grid to come back online because the generators needed to be put online in several stages, always such that the supply corresponded to the loads already connected at each stage. The restoration of supply on both days was extended to a large portion of the loads lost within 8-10 hours of the outage. However, loads in some areas were still not served for as long as 16-20 hours after the actual grid collapse. In addition to the size of the impact area of the outage, the generation mix constituted another key issue in the restoration process. Due to the delayed onset of the monsoons, the hydropower generation in the northern region was negligible and the loads relied mostly on the thermal power generated from coal plants in the east. It is quite widely known that thermal power stations do not respond quickly and incidents of tripping such as this require them to be cooled and stabilised prior to ramping up production again. For a typical thermal power station, this process can take as long as six to eight hours.

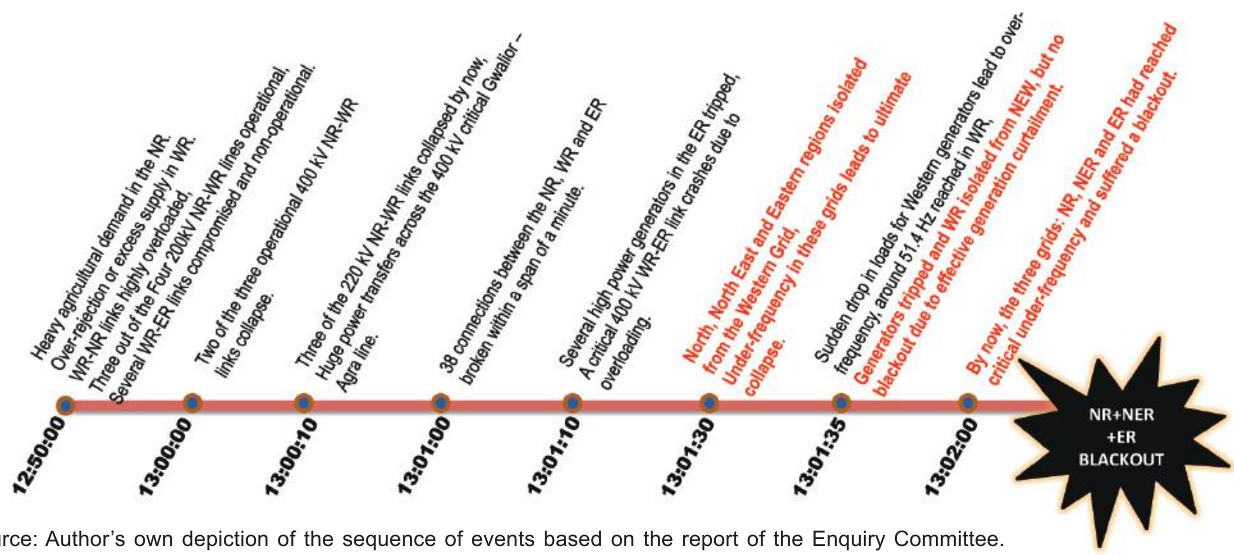
Among the first services to be restored were the railways. The New Delhi Airport, one of the busiest in the world, had its power supply within 15 seconds of the outage, thanks to its own backup provisions. All major hospitals in the region were also equipped with their own backup systems which came online soon after the grid collapse.[5] Power outages in India are indeed not infrequent. Thus, medium-to large-sized commercial loads often own their own backup supply systems, mainly in the form of diesel generators. All industrial establishments have their own captive power plants (CPPs). Fortunately, these minimised the impact of the outage on large-scale industrial production.

Could It Have Been Avoided?

The outages were clearly the result of a spiral effect involving several factors that led to increased stress on the network, which ultimately gave away. A few of the most obvious factors that led to the outages were:

- **Heavy Over-Drawing by the Northern States and Over-Supply by the Western States** Despite several directives from the National Load Dispatch Centre in Delhi ordering the immediate curbing of power over-drawls,[6] the northern states continued to over-draw

Figure 5: Timeline Showing the Critical Events that Led to the Outage on 31 July 2012



Source: Author's own depiction of the sequence of events based on the report of the Enquiry Committee.

A passenger looks through the window of a train as he waits for electricity to be restored at a railway station in New Delhi, 31 July 2012. REUTERS/Adnan Abidi

power from the grid in the order of 2000 MW, while in the western states, over-production was around 2700 MW. Had the NR-WR links been in place, this would have been alright to maintain. The scheduled outage of a crucial 400 kV artery due for upgrading to 765 kV and the forced outages of a few links led to the inability to mitigate this supply-demand skew. When in need of power, the state utilities have the option of buying power from private producers. However, this requires upfront payment and most of the state utilities have enormous debts due to political pressure to keep their retail tariffs low. Thus, they generally resort to the cheaper way of over-drawing power from the national grid.

- **Self-Interest Ahead of Grid Security** The operation of UFRs to curtail part of the load on the system could have minimised the impact of the outage or perhaps avoided it completely.[7] However, the socio-political pressure and the huge negative balances of the state utilities rendered them with no leverage to act on their concerns about grid safety. Due to several states simultaneously not implementing load curtailment measures, the disturbance in the system resulted in a large-scale blackout.

- **Economics of Generators** To cope with unexpected regional grid imbalances, the Availability Based Tariffs (ABTs) mechanism was put in place in 2002. ABTs provide incentives to electricity suppliers to adhere to their committed scheduled generation plan.[8] According to this scheme, generators and loads (which could be industries or state utilities) declare the power they are likely to supply to the network or draw from it, 24 hours in advance to enable the LDCs to plan the physical flows in the network day ahead. However, if the loads consume more than their committed schedule, the demand exceeds the supply in the system and hence the frequency starts to drop. As a result of this, the cost of each unit of power escalates, making it more expensive for loads to buy power and more profitable for generators to supply more than agreed. If a buyer at such a time reduces its consumption, he is rewarded by being paid a special premium, called the Unscheduled Interchange (UI) rate, thereby incentivising the loads to do so. The same UI rate is charged as a penalty to generators who fail to deliver the promised power. It is fixed by the central electricity regulator, CERC, and goes up with increases in the frequency deviations from the 50 hertz. However, with time, rising fuel costs have led to increases in the cost of electricity generation, making backup systems which switch to roof-mounted solar panels more attractive. The cost of batteries to employ solar energy after sunset is the limiting factor, however. Nonetheless, the flexible operation of micro-grids undoubtedly has the possibility to curtail demand at crucial peak hours and prevent such large-scale outages in future.

Chronic shortages of coal and gas, and ever increasing demand have led to the severe burdening of India's power sector. In 2011-12, India suffered a national energy deficit of 8.5 per cent and a generation-load capacity deficit of 10.6 per cent during peak hours.[12] The impact of these deficits always falls heavily on the rural areas where supply is restricted to 8-12 hours a day in most states.[13] During the same year, India's big cities endured around 60 hours of outage per month during the peak demand season.[14] Hence it is sad that this outage, as unparalleled as it was, seemed like an almost normal event to most people in the country, who are used to suffering frequent supply disruptions. While development and modernisation are longed for by India's populace, the policy and governance mechanisms to fulfil them are nowhere in sight.

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