Cascade Tripping of the Power Grid
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Abstract—Cascade tripping is the tripping of power grid in unbalanced condition or it is the tripping of safety devices and isolation of the part of the system to prevent damage to equipment. Cascade tripping occurs during under frequency or other unbalance condition. When demand is more than power generated the frequency of machine goes down. When this frequency is less then certain limit, the grid will trip. This will result in sudden loss of power. If demand is less then generation, it will also cause such situations. Which is also called blackout or grid failure. To avoid this synchronism must be maintained in the grid. Synchronous generators thousands of kilometers apart must operate stably and in synchronism during infinitely many load and power transfer conditions, equipment outages, and power disturbances following a short circuit or other disturbance, one group of generators could accelerate relative to another group, causing instability and loss of synchronism. Implications of blackout are clearly enormous for the electrical power industry. Parts of grid are being stretched to their limits.

Keywords: Cascade Tripping, Blackout, Power grid

I. INTRODUCTION

Many of the world’s grids are heavily loaded and operating close to their maximum capacity. When sudden bulk transfer occurs, the grid becomes unstable and vulnerable to system wide disturbances such cascade tripping or blackout. Cascade tripping occurs when demand is more than power generated the frequency of machine goes down. When this frequency is less then certain limit, the grid will trip[1]. This will result in sudden loss of power. Which is also called blackout or grid failure.

Frequency plays an important role for stability of grid. Generators separated by thousands of miles must rotate together with split cycle synchronization and the flow of power thousands of transmission lines must be coordination over large regions of country. Not only supplies have to be synchronized but also so do supply and demand and they also have to be synchronized everywhere.

Cascade on an electrical system is dynamic unplanned sequence of events that one started cannot be stopped by human intervention. Power swing voltage fluctuations cause sequential tripping of transmission lines, generators and automatic load shedding in a widening geographic area. The fluctuations diminishes in amplitude as the cascade spreads eventually equilibrium is restored and the cascade stops.

Cascade tripping of safety devices and isolation of the part of the system to prevent damage to equipment under low frequency or unbalanced condition. For balanced operation of generating units in power grid, frequency plays an important role. Severe frequency swing due to large unbalance between generation and load may force load shedding or even result in system failure, thus affecting the continuity and reliability of supply [2]. So, synchronous generators thousands of miles apart must operate stability and in synchronism during infinitely many load and power transfer conditions, equipment outages and power disturbances.

Fig. 1: Basic diagram of the power system

II. POWER GRID

National Grid may be perceived as a mesh of interlinked transmission lines, interconnecting different electrical regions, viz., Northern, Eastern, Western, Southern and North-Eastern regions of the country. All the regional grids, accept eastern and northern- eastern regions, operate independently with only a limited exchange of power across the regions [3]. Prior to independence, small generating stations were used to supply power to local loads through small haphazard radial transmission system, which gradually progressed towards the formations of State grids in 60’s, regional grids in mid 70’s, progressively moving on a long and arduous journey to provide a backbone for formation of a “National Grid”, by way of integration of the existing regional grids, with suitable augmentations. The following are the frequency condition region wise:

1. In western region minimum frequency integrated over an hour during the month touched 47.76 Hz maximum frequency was 51.75 Hz. Normally western regions operated in the range of 49.8 Hz to 50.2 Hz. Similarly northern and southern regions are also operated in the same range.

2. Eastern and northern-eastern regions are operated at the range of 49.8 Hz. to 50 Hz.

The Northern Regional Grid covers Uttar Pradesh, Delhi, Punjab, Haryana, Rajasthan, Himachal Pradesh, and Jammu and Kashmir. It is the second largest interconnected network in the country with an installed capacity of over 27000 MW and a plant mix of 31% hydro, 65% thermal, and 4% Nuclear. Our country also has 254,000 kilometers (158,000 miles) of transmission lines to carry electric power to millions of customers. Over the next 10 years, demand for power is expected to rise by about 25% under current plans,
Electric transmission capacity will increase by only 4%, according to the Report of the President’s National Energy Policy Development (NEPD) Group, published in May 2001.

Unfortunately, reality is not so accommodating.

**III. REASONS OF BLACK OUT**

Cascade tripping occurs due to unbalance in grid, mainly due to under frequency situation. Under frequency in power system occurs in the following circumstances.

1. During steady condition when on line generating capability is inadequate to meet the load requirement a steady decline of frequency occurs.
2. When sudden loss of large generating unit occurs or there is a sudden tripping major of transmission line carrying bulk load in a system, a sudden decline in frequency is observed.

For all practical purposes, electricity flowing through grid cannot be stored. Once it is generated electricity must flow somewhere. If there is not enough demand it will cause voltage spikes, if it is too little, it will cause voltage dips.

For high voltage power to remain stable synchronism must be maintained when the synchronism is disturbed by inevitable local events such as sudden loss of major transmission line or generator power can begin to flow in an uncontrolled manner causing automatic safety devices to trip and isolate parts of the system to prevent damage to equipment.

Blackout result when generation is separated from load. The grid typically will withstand any single event (single generator failure or single transmission-line failure) under worst case conditions. This called “N-1” contingency planning. But the system can collapse if several failures take place in rapid succession when the grid is already stressed. Such events include.

- Multiple lightning strikes
- Falling trees
- Equipment failure
- Human error
- Wires sagging into underbrush
- Overloads, voltage sags, frequency deviations.

-Sabotage.
-Fire.

**Unseal operation of grid occurs when:**

- Under frequency condition in power grid causes unusual operation of machines in grid. This kind of situation causes automatic safety devices to trip to prevent damage to equipment.
- When demand is more than power generated, the machine will overload. So speed will decrease. So frequency goes down. Sometimes it may happen that demand is very much less than generation, it will also cause unbalance condition. If there is not enough demand it will voltage spikes, if it is too little, it will cause voltage dips.

**In thermal plants under frequency causes following effect in generator:**

- Higher flux density resulting in machine saturation and higher field requirement.
- Excessive core losses.
- Heating of core and other parts.
- Reduced speed reduced cooling effect.
- Reduced reactance of the machine resulting in higher fault currents.

**In hydro power plants under frequency causes following effect in generator:**

- Increases flux level and magnetic saturation.
- More iron losses.
- Over heating and over loading.
- Decreased speed and poor ventilation and hence overheating.

**Load frequency mechanism is as follows:**

Frequency of the system is closely related to real power balance in the network. Under normal operating conditions the system generator run synchronously and generate together the power that at each moment is being drawn by all load plus the real transmission losses. The synchronous operation of generator represents a stable system state [4]. By that, it means, that once a generator has been synchronized into network, electromechanical forces built up within the machine that tend to keep it running at the same speed as the rest of the network. Once the speed of the generator has been locked to the rest of the system and may control its power generation by controlling the torque from its prime mover. By opening water gates in case of Hydro turbine, or steam valve in case of steam turbine a greater torque is applied to the generator, there by tending to accelerate the generator. However, its speed is tied to the system, and what happens Is that its rotor advance its angle a few degrees. The results in the increase in delivered current and power, and the same the currents built up a decelerating torque within the machine that exactly counteracts the increase in accelerating torque [5]. Each generator thus have a perfect torque balance, their speed, thus frequency must remain constant. The ideal way to operate the system would, therefore, be to instruct the machine operator to set all water gates and steam valves of various generators at a value that would exactly correspond real power balance with constant speed and frequency. Unfortunately, reality is not so accommodating.

![Power Flow Diagram](https://example.com/power-flow-diagram.png)
Relation between load and frequency:
There is no specific method to reckon reduction in load due to reduction in frequency. This is usually done through tests on system. In India, the motor load is high as 80% of the overall system load, while in European countries this is between 40% to 50%. Therefore reduction in load for 1% reduction in frequency in India will be higher that 2.5%.
Tests conducted in Tamilnadu system have shown the 100 MW of loss of generation results in fall of frequency from 50 to 49.25 Hz when the system load was 1845 MW. Therefore, for loss of generation of 5.4%, frequency reduction was 1.5% giving a relationship of about 3.6% reductions in load for 1% falls of frequency. Certain observation made at the time of tripping of Dehar units has shown this relationship between 3.5% to 5%. Therefore, Indian grid system this figure has taken as 3.5% load reduction corresponding to 1% reduction in frequency.

IV. EXAMPLES OF CASCADE TRIPPING

Collapse of the Northern Regional Grid of India

The Northern Region Grid of India witnessed a massive disturbance on 2 January 2001. Over 1500 MW of generation was lost and the entire region plunged into darkness, subjecting public at large to immense inconvenience and a loss to the tune of 7 billion rupees. It took 16-20 hours for the system to limp back to near normalcy. The last major grid disturbance in the region was in January 1997. The CEA (Central Electricity Authority) carried out a comprehensive enquiry into the incident following directions from the Ministry of power, and the results have been made public. The CERC (Central Electricity Regulatory Commission) initiated suo–moto proceeding and passed an order based on the public hearings held 15-16 January 2001.

Build up to collapse:
In the early hours of 2 January 2001, the demand was much less than availability, following widespread rains, and a few thermal machines had been closed down to contain the frequency. However, there was a constraint in the transmission capability in the east-west corridor due to outage of one of the HVDE bi-poles and a reduction of the power capability of the other pole to 500 MW. This reduced further when parts of the two 400 kV links owned by the STU tripped in quick succession due to insulator flash overs. This in turn led to heavy loading of the remaining links, with power flow touching 800 MW in one of the 400 kV lines, and cascade tripping of the remaining links. Eventually the grid split into two. In the western part, the frequency dropped due to shortfall in generation and the subsystem collapsed, while in the eastern part the frequency shot up to about 53 Hz, tripping all the running machines and leading to the eventual collapse of the subsystem. Only a few gas turbine units in Delhi and one nuclear unit survived on local load. All other nuclear units tripped and were poisoned out.

System restoration:
The system was restored in two parts: the eastern part taking power through the AC bypass of the inter-regional HVDC link and the western part starting the hydel units at Bhakra. The two parts were synchronized after 8.5 hours. There were no doubt a number of hiccups due to tripping of lines, problems in controlling voltage, improper load generation balance, etc. A large part of Delhi remained without power for over 12 hours.

Analysis:
The enquiry carried out the CEA committee and the submission made during the public hearing held by the CERC reveal the following;
- There was a general lack of grid discipline. For example, (1) the generators had not been on ‘free-governor’ mode operation although this was required by the IEGC (Indian Electricity Grid Code), (2) instructions given from the RLDC (regional load dispatch centre) were not promptly acted upon, and (3) under frequency relay schemes were not fully operational.
- The role played by the RLDC was not adequate or effective. Its orders for backing down, for example, did not reflect the urgency of the gravity of the situation. Also, it does not appear to have considered other options for congestion management like increase in hydro generation in the western part, coupled with load shedding. This might have helped avert the incident as it was not triggered by a sudden event and the system depletion was gradual.
- The maintenance and performance of the transmission system was not adequate. The insulator flash overs and the resultant tripping of two important links in the east-west corridor occurred due to poor maintenance of the 400 kV lines owned by the STU. It passes through the polluted areas near Panki. Similarly, the performance of the HVDC link, especially of the convertor transformers manufactured by BHEL (Bharat Heavy Electricals Ltd), was not satisfactory and affected the transmission capability in the corridor.
- There were also inadequacies in the switchgear and reactive power compensation devices at some locations, as the restoration process revealed. The load dispatch and communication facilities are not adequate. Lack of time synchronization between recording instruments installed at different locations makes it difficult to correctly establish the sequence of events.
- The restoration procedure was slow. Extending supply and build up of load was difficult due to equipment problems, delays in providing start-up power, lack of coordination, etc. The black start procedure and the grid protection scheme must be reviewed. There is need for better training and capacity building for grid operators.

Necessary planning:
- First and foremost, local electric utilities should be intimately involved in DG and CHP system planning and operation within their service territories. Since DG/CHP units are typically installed on electric distribution systems, the local utility is well positioned to ensure that DG/CHP system work in concert with the grid.
- Second, regulators and transmission operators should consider all the ramifications of more DG/CHP on grid performance and work with utilities and DG/CHP installers to pursue timely and efficient strategies that balance risks and rewards for all parties.
- Third, standardized interconnection requirements, standardized procedures for determining stand-by charges, and appropriate incentives for all stakeholders involved will further facilitate the installation of DG/CHP in quantities sufficient to achieve meaningful grid- support benefits.

V. SOLUTIONS OF CASCADE TRIPPING

The network should have sufficient capacity to allow the unexpected loss of the most critical network element at any time, without any primary transmission plant being overloaded or any normal customer load being shed. This criterion has been adopted for the analysis of future requirements included in this review. To prevent black out following are the fundamental rules of grid operations.

- Balance supply and demand
- Balance reactive power supply and demand to maintain voltages
- Monitor flows to prevent overloads and line overheating
- Keep the system stable
- Keep the system reliable, even after loss of a key facility
- Plan, design and maintain the system to operate reliably
- Prepare for emergencies Training Procedures and plans
- Back-up facilities and tools Communication
- Each control area is responsible for its system.

Some advanced methods can be used to void black out. To avoid black out important point is to avoid frequency variations and unbalances in grid and to maintain synchronism in the grid.

- A system that could measure and monitor voltage and current input through our the grid in real time has long been a priority for utilities of governmental organization and major industrial users such a system would enable operators to detect the first signs of instability and take appropriate action to stop the disturbance from spreading.

- A new advanced phasor measurement system has been developed which includes Global Positioning System (GPS) and application software to measure and monitor the status of a power grid. The PMUs (phasor measurement units) are located at key points in the grid, such as in substations, to measure various types of input, such as synchronized phasor measurements which allow to compute and to monitor different type of instabilities (e.g. voltage instability, frequency instability) on a System Monitoring Center.

- To avoid cascade tripping we have to improve power grid also. ORNL (oak ridge national laboratory) researchers are helping industry develop and evaluate new technology that could improve the efficiency and reliability of existing transmission lines.

- Today’s overhead transmission lines consist of aluminum conductor strands wrapped around a steel core. Because of the weight and properties of the steel, these cables will stretch and sag if they are heated up too much by carrying too much current. Sagging lines caused by excessive current and hot weather triggered a major power outage in 1996 in the northwestern United States. To overcome this limitation, 3M developed a composite consisting of Nextel ceramic fibers and an aluminum-zirconium alloy to make an advanced cable that can carry more current than current that steel aluminum lines without sagging at higher temperatures.

- The power grid of the future will include high temperature superconducting (HTS) cables, with offer much less resistance to the flow of electricity than do copper lines. “A superconducting cable will conduct up to 5 times as much current as a copper cable of the same size. Because an HTS cable loses little energy as heat, it will cut electrical transmission losses in half, from 8% to 4%. An HTS cable is more environmentally friendly than a copper cable also because it is cooled with safe inexpensive liquid nitrogen rather than oil-impregnated paper insulation, which may leak oil.

- Another technology is the flexible alternating current transmission system (FACTS), a combination of large scale power electronic devices that can control the flow of power through transmission and distribution lines.

- FACTS can control the voltage magnitude and phase angle at both ends of the line, as well as the amount of real and reactive power that is passed through the line,” says Kirby. FACTS devices could greatly increase the power-flow capacity and stability of our existing transmission lines.

- Another alternative is to use distributed generation and grid power alternative technologies. For years distributed generation technologies fuel cells, micro turbines, reciprocating generator sets, static turbine switches, and others have been considered ‘alternative’ and optional.

- However Power system planning and operations aim to balance the risk of failures against an economical design & operation, and when problem arises, to have mitigating measures on hand. These measures are
designed to minimize the cascading of failures and the size of area affected.

VI. CONCLUSIONS
Cascade tripping is a tripping of safety devices and isolation of part of the system to prevent damage to equipment during low frequency or unbalanced condition. Once it started we cannot stop it, but by some techniques we can gain power back in very less time or by taking appropriate action we can prevent it in many cases. However solutions to prevent this from ever happening again are now readily available and easy to implement. The success of National Grid shall largely depend upon the strength and performance of the underlying network to wheel power up to the consumer end. Therefore, to extend the benefits of National Grid to the ultimate consumer, it is essential that development of sub transmission and distribution system is commensurate with the development of National Grid.

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