A Review Study on Power System Blackouts

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Abstract**—** The blackouts occurring in a power system is one of the most significant problems which is dealt by the supply utilities in today's power system networks. A lot of factors lead to the occurrence of blackouts; overloading of transmission lines, ice coating on them, protection and control system failures being the most prominent ones. Adoption of certain control strategies like N-1 contingency, maintaining load generation balance and cascade to more fault contingencies can be very effective to reduce power system blackouts. The following paper puts forward a review study about blackouts from different countries, their causes and their solutions. The following paper can provide important references to grid protection strategies.

Keywords**— blackouts; N-1 contingency; cascade efficiency; power system; grid protection**

I. Introduction

The most prominent blackouts occurring in the recent past happen to be the North American blackout in 2003, the European blackout in 2006 and the famous Indian blackout of 2012. Apart from financial crisis, these blackouts caused a great inconvenience to the citizens of the country. The prominent reasons being the tripping and overloading of the transmission lines, protection and control system failures, collapse of voltage, cyber attacks and many others. The experiences learned from these blackouts can prove to be significant references to improve the present existing power grids. The following paper provides a review study on the current scenario of power system blackouts in the world and the reasons that caused them. This paper also discusses certain improvement techniques that can be implanted in order to avoid them. The main purpose of this review study is to obtain potential protective mechanisms against power system blackouts in order to design power system protection plans.

II. History Of Blackouts In The World

A detailed description of the various blackouts that has occurred is being described this section. The Greek island of Kefalonia saw an unlikely blackout on 24th January, 2006. [1] The deposition of loads of ice on the transmission lines and collapsing of transmission towers due to that has been the main reason for this blackout. A 15cm thick ice sleeve covered the conductor surface of the high voltage tower. The region saw the cut in electricity by 300MWh. Since, the blackout, Kefalloia island commissioned an additional number of substations to cope with such a situation in the future. Moreover, the distance between the towers has been re-established in order to endure the climatic changes. Certain anti-icing methods have been derived and implemented on the new and existing lines since then so that power system blackouts can be avoided in the near future.

A series of cascade blackouts occurred throughout New York, Massachusetts, Ohio, Connecticut, Canada, Ontario, Vermont, New Jersey, Pennsylvania and Michigan on August 13, 2003 [2]. A loss of 61,800 MW lasted for almost a week before the power was fully restored thereby affecting 50 million people. After the blackouts, the key causes surfaced out, prominent among which were the failure of the automation system. For instance, the contingency of the Midwest ISO ad the State Estimator were not fully automatic. Moreover, increasingly limited generation, poor management in load rising and imbalance in the reactive power were very much inadequate in the Midwest ISO. In order to avoid short circuits, trees around the high voltage lines are trimmed of at a certain distance. Sometimes, uneven trimming of trees can also cause such kind of blackouts. After this accident, the grid has been upgraded to modern smart grid technologies. The older power systems used system control and data acquisition systems (SCADA). But SCADA is inefficient when it comes to large power system networks as the coordination is very slow and the reliability of the system communications is based on telephone calls. Moreover, smart grid technologies provide monitoring and pervasive control, advanced communications and digitalized systems. But, smart grid technologies even after having advanced control and monitoring systems, the system operators face cyber security issues.

On July 30th and 31st, 2012 India faced two subsequent blackouts affecting 620 and 700 million people respectively. The blackout of 30th July was due to the overloading of the 400KV Gwalior-Bina double transmission lines as one of the double lines was under maintenance. This overloading caused a series of tripping throughout the network thereby causing a generation shortage of 32 MW. The higher demand due to the lack of required output and poor response to the already then existing issue caused a serious blackout on the next day, i.e. 31st July, 2012. Following reasons were anticipated for the blackouts of 30th and 31st July, 2012:

1. Improper and unplanned maintenance work.
2. Weather forecasting is not appropriate.
3. Inadequate control mechanisms for stabilizing HVDC lines in power grids like the absence of static and dynamic reactive power controls.
4. Improper response to control the voltage and frequency by the State Electricity Boards.
5. Malfunctioning of distance relays due to transmission congestion.

Outage system, peak load and inadequate management of the power quality were the forerunning factors for the great Indian blackout. The Indian Power Grid measured the system parameters y installing Remote Terminal Units (RTUs). The real time monitoring must be changed from RTU to Phasor Measurement Unit (PMU) so that the power system measurements can be monitored at a fast rate. RTU measurements are generally slow, provides RMS values with no phase angles and there is no time correlation for various RTU measurements unlike the PMU measurements. Distributed energy sources can be integrated to prevent such kind of blackout accidents. In order to prevent power losses due to blackouts, small distributed generations can be used.

Vietnam on May 22nd, 2013 saw a severe blackout due to the tripping of the 500 KV line thereby separating the Southern grid from the Central and the Northern grid system of the country. The reason for the blackout happens to be a moving truck which while moving a true got itself bumped into the 500 KV line. This incident caused a series of tripping in the generators and transmission lines thereby isolating the southern grid from the central and northern grids of the country. After this incident, new strategy in developing certain relay systems has been proposed and successfully implemented. Out of step relays, under frequency load shedding relays, over current relays, over excitation limiter relays ad distance protection relays have been successfully implemented since then [4].

Collapse in the voltage is one of the most important reasons for power system blackouts in the world [5,6]. If the lines, generators, transformers or any other power system element fails, other system elements will be overloaded thereby causing low voltage level at the system buses. This causes tripping of distance relays on the transmission lines. Moreover, those components which are overloaded will be tripped thereby propagating the overload problem to other elements of the power system. The lack of reactive support becomes more urgent as more elements are tripped leading to the tripping of the over excitation limiter relay of the generator thereby aggravating the low frequency problem. Depending upon the system strength, voltage collapse takes more time than seconds to occur thereby providing enough time to respond to this voltage collapse.

Bangladesh Power System (BPS) underwent a nationwide blackout on 1st November, 2014. Response failure of the spinning reserve and sudden outage in a HVDC station coupled with the generator maintenance in the western part of the BPS led to this nationwide blackout [7]. As the frequency fell to 48.9 Hz, the load shed happened to e 69MW instead of 25 MW. Five load shedding stages were preceded before the blackout. The under frequency protection scheme must e improved by improving the rate of change of frequency, improving the critical operating inertial reserve to more than nine seconds and certain grid island techniques must be implemented in order to control and establish the Bangladesh Power System.

Smart grids have been developed by several power systems including the function of peak curtailment, two way communications, load balancing, demand response support and sustainability. Following advancements make the grid easily controllable and reliable. Security issues are the only challenges that these power systems face. The personal databases are floated and stored in the internet which becomes an easy prey for the hackers to breach the internet and get through these personal details. Breaching the internet protocols and performing a cyber attack was the main reason for the famous Ukranian blackout that happened on 23rd December, 2015 affecting 225000 customers for several hours. The cyber attackers attacked the security and breached the protocols thereby attacking the SCADA network of the country's power system. These attackers uploaded false and junk data into the system thereby creating a collapse. The attackers were thorough in their knowledge of the power system parameters, their features, metering measurements, network topology, and specifics of SCADA network devices including other related data detection schemes. The proper solution in this regard is to strengthen the already defensive system to prevent blackouts or any kid of faults that can ignite a cyber attacking strategy. Ukranian power system deployed some of the most unique features in their cyber schemes to prevent any such kind of blackouts in the future [8,9].

San Diego on 8th September saw a blackout due to an outage in the Pacific Southwest which triggered a power cut for twelve hours affecting 1.5 million customers of the region, including some parts of southern California, Arizona and Baja California affecting a total of 2.7 million customers to face the blackout. Line tripping due to peak load has been sighted as the foremost reason for this outage. The transmission line of southern California and Arizona was designed to withstand a single line trip of 500KV. 500 KV Hassayamapa North Gila line (H-NG) is a major transmission line that connects Arizona to San Diego area via the Imperial Irrigation District (IID). During the peak load, it caused the surrounding lines to get overloaded and caused a major trip leading to a blackout. The main reason for this blackout has been due to the insufficient load shedding [10].

III. Power System Blackouts Improvement Schemes

Different models and systems have different optimization techniques to prevent blackouts. Many new control schemes have been adopted by various power grids to prevent such kind of outages in such a way that the installation of new components could revise the grid codes and the original protection schemes already existing in the grids. Basically periodic supervision of the load shedding mechanisms, relay systems, coordination processes of the grid, special protection system and control systems must be ensured for smooth running of the power system networks. Moreover, the increasing trend of renewable energy usages for power generation must also be taken into consideration by implementing certain protection strategies of grid integration by renewable energy sources. The general causes of power system blackouts can be summed up to be multiple tripping of overloaded lines, static and dynamic stability loss, and voltage instability in transmission networks, inappropriate load shedding and many others. Following improvement schemes can be implemented in order to avoid power system blackouts:

I. Reactive power optimization and voltage control
II. Installation of new and improved control systems
III. Reinforcement of the grid
IV. Re- designing of load shedding strategies
V. Suitable locations for new generators
VI. Automatic operations and alarms during severe incidents
VII. Using more number of tie lines
VIII. Installation of advanced protection relays

The modern day power system should be self sustainable while dealing with blackouts. It should have the facility for automatic re-closing of transmission lines and re-integration of the components. Restoration of a power system after a blackout has to be automatic and quick. The present day power systems can employ sensors and products, special protection schemes, high voltage direct elements and state of art controllers can help the system to be more stable thereby avoiding blackouts.

IV. Conclusion

The following paper reviews the power system blackouts that affected Greece, North America, India, Bangladesh, Vietnam and Ukraine. All the countries had a separate unique reason for their failures. The significant conclusion that can be drawn from the failures in these countries is that if power system can be improved and the series of tripping failures can e predicted beforehand, then the blackout can be avoided. Enhancement and prediction lowers the probability of blackouts to a great extent. The general causes of power system blackouts can be summed up to be multiple tripping of overloaded lines, static and dynamic stability loss, and voltage instability in transmission networks and inappropriate load shedding. Moreover, this work also summarizes the important steps that have to be taken in order to make the power system more stable in relation to blackouts.

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