

BLACKOUT: CAUSES, IMPACT, MITIGATION, AND SYSTEM RESTORATION

Prof. Dr. Omar H. Abdalla*

SUMMARY

A blackout, which means total loss of electric power supply to customers in an area, is the most severe form of power outage that can occur. Electricity outages may last from several minutes to several weeks depending on the nature of the blackout and the configuration of the electrical network. A blackout of a few hours or even several days would have a significant impact on social activities and economy of the country. In addition to tripping electric appliances and losing home and street lighting, critical infrastructure such as telecommunication and transport systems would stop operation.

Water supply, production processes and commercial activities would cease. Emergency services such as fire, police or ambulance could not be called due the breakdown of the telecommunication systems. Financial trading, cash machines and supermarkets would in turn have to close down, which would ultimately cause many problems to all sectors of the society. In case of interconnected power grids of different countries, a blackout may spread across the border transmission lines; thus, leading to a catastrophic impact. The objective of this article is to discuss major blackouts occurred in various parts of the world and to analyze their causes, impacts, lessons learned, mitigations and methods of system restoration. A set of recommendations to mitigate/avoid blackout is presented. Blackouts in Arab countries and their impacts will also be described. Statistics of system outages are presented. System restoration plans and the roles of frequency and voltage controls during restoration are discussed.

CONTENTS

- 1- Introduction to Electrical Power Networks
- 2- Major Power Outages
- 3- Electrical Outages in the Arab Countries
- 4- Causes of Electrical Blackouts

- 5- Mitigation
- 6- Restoration
- 7- Recommendations

1- INTRODUCTION TO ELECTRICAL POWER NETWORKS

Electric power systems ^[1] are among the largest man-made systems in the world in

*Prof. Dr. Omar Hanafy Abdalla, Fellow of ESE,
Department of Electrical Power and Machines Engineering,
Faculty of Engineering, Helwan University,
Helwan 11792, Cairo, Egypt
E-Mail: ohabdalla@ieee.org

modern times. These large systems extend from power plants, including large generators, steam or (hydro) turbines, and systems for burning fuel needed to generate steam (or canals, tunnels and huge pipes to direct water to water turbines). From the production stations, the generated electricity is transferred to the load centers through electricity transmission and distribution networks, where the voltage is first raised in the transformer substations attached to the power plants (high voltage and extra-high voltage) in order to transfer electricity over long distances through transmission networks in an economical manner. The voltage is then lowered again by the step-down transformer substations to the appropriate level for distribution networks (medium voltage) and then the voltage is lowered again to the appropriate level (low voltage) used in homes, commercial buildings, etc. The electrical network feeds millions of subscribers, with each unit, whether it be a residential apartment, shop or large factory, counted as a subscriber. You can imagine the huge size of the electrical networks that cover these areas, especially the electrical networks interconnected between countries. The Egyptian electricity grid is connected to the east to Jordan by 400 kV submarine cables, and the Jordanian interconnection network extends to Syria and Lebanon. From the west, the Egyptian grid is also connected to Libya by 220 kV overhead lines, and the electrical interconnection networks extend from Tunisia

to Algeria and then Morocco and cross to Spain by submarine cable through the Strait of Gibraltar. There are similar links between North American countries and Canada and links between European countries and also between some Asian countries. This expansion of electrical networks and their interconnection to each other is due to the increasing demand for electricity. The stable operation of these large electrical networks requires a continuous balance (at all times) between load demand and generation capacity as the generation capacity must be equal to the load power including electricity transmission losses in the network. If there is an imbalance between the generated power and the power consumed in loads and losses, the power grid is exposed to real risks that may lead to a complete collapse if the situation is not remedied quickly (it may be a few seconds or a fraction of a second).

The problem here is that millions of subscribers connect and disconnect electricity at times that suit them and in a purely optional way without considering the considerations of operating the electrical network, and every consumer connects the switch to the device he wants to operate at the time he chooses and for the period he desires, and then disconnects the electrical device or equipment at the time he determines by choice, and this is of course the right of the user of electricity and for his comfort. This random operation and disconnection of millions of subscribers places

a great burden on electricity network operators, who must anticipate loads in advance ^[2], plan and equip the appropriate generation and transmission networks ^{[3], [4]} to feed these loads with constant voltage and constant frequency, in addition to taking into account the economics of distributing the loads to generating units to reach the lowest cost.

In view of the high speed required to cope with load changes and equip the appropriate generation of electricity, it is important to provide large electrical networks with control centers, including national, regional and distribution network control centers ^[5].

In addition, each power plant is normally equipped with a central control room, in addition to the presence of basic controllers for each generating unit to control the generator voltage through excitation systems, automatic voltage regulators, as well as frequency control through speed governors.

2- MAJOR POWER OUTAGES ^[6]

There are two types of major power outages: the first type is called complete blackout in which all the loads connected to the electrical grid of a specific area or the entire electrical grid of a particular country are interrupted. A very large number of people (tens of millions) are affected, and their electricity supply is cut off for several hours and the outage may extend to a day or more. The second type is called partial blackout, which means that electricity is cut off in a

limited part of the electrical grid and a large number of people are affected by it for a number of hours. In general, it is difficult to differentiate between the two types of complete or partial outages in light of the interconnection of networks locally and internationally, and both have great damage and risks to humans, as everyone depends on electricity in various aspects of modern life. The national economy, the business sector, the private sector and individuals also bear heavy losses and huge sums of money as a result of these interruptions due to electricity needs at all times. When these interruptions occur, the lighting of homes, streets and shops disappears, complete blackout occurs, factories stop working, and electric means of transportation such as subways, electric elevators and the like are disrupted.

Sensitive devices such as computers in banks and companies also fail and may cause the loss of a significant part of the information. Hospital lighting, water lifting and pumping devices and equipment, etc. may also be affected. If the outage continues for long periods, communications and radio and television broadcasting equipment can stop working. Traffic may also be halted at airports. Vulnerability is greater if there are not sufficient backup generators for emergency operation. According to the World Bank report, Fig. 1 shows the percentage of firms that experienced power outages over the last complete fiscal year ^[7].

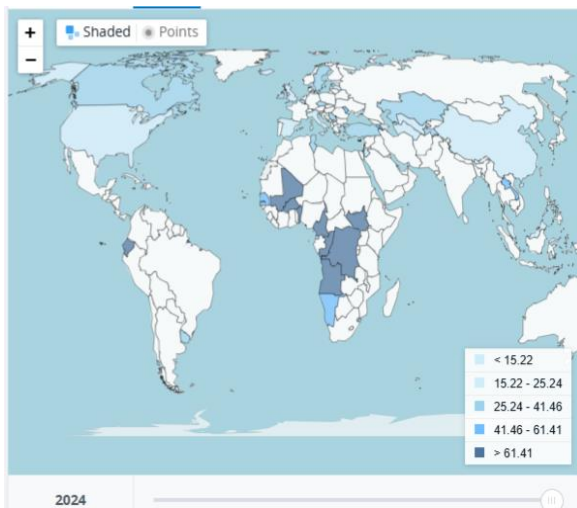


Fig. 1 Firms experiencing electrical outages (% of firms) [7]

Iberia Blackout

On 28 April 2025 at 12:33 CET, the power systems of Spain and Portugal were subjected to a total blackout [8]. A small area in France, near the border with Spain, was also affected by the incident for a short duration. The rest of the Continental European power system did not experience disturbances. Figure 2 shows the affected area due to this major blackout [9].

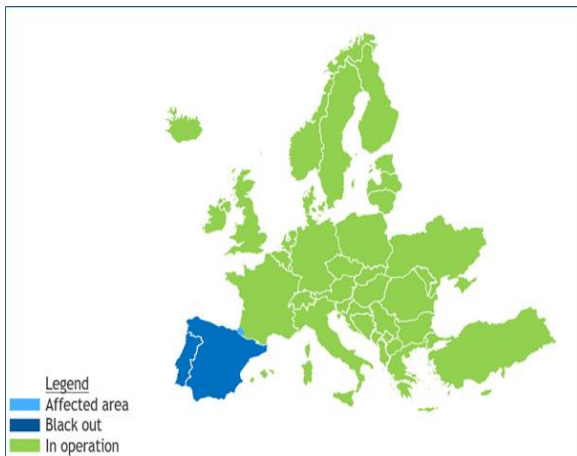


Fig. 2 Affected area due to Iberian blackout

Figure 3 shows the frequency and voltage in the substation of Carmona (Spain) and of the frequency in the rest of Continental Europe (substation of Bassencourt, Switzerland) during the incident. Before the incident, Spain was exporting 1000 MW to France, 2000 MW

to Portugal and 800 MW to Morocco.

The sequence of events during the incident is summarized as follows. At 12:32:57 CET and within 20 seconds afterwards, a series of about 2.2 GW generation trips were occurred in Spain. Accordingly, the frequency decreased and a voltage increase in Spain and Portugal. Between 12:33:18 and 12:33:21 CET, the frequency of the Iberian Peninsula grid continued decreasing until reaching 48 Hz. Then, the automatic load shedding defense plans of Spain and Portugal were activated. At 12:33:21 CET, the AC transmission lines between Spain and France were disconnected by protection system. At 12:33:24 CET, the Iberian electricity system collapsed completely and the HVDC lines between Spain and France stopped transmitting power. The restoration process started at 2:44 CET by re-energizing the first 400 kV line between Spain and France. The process continued by re-energizing the connections to Morocco and Portugal. At 00:22 CET on 29 April 2025, the restoration process of the power grid was completed in Portugal, and at around 04:00 CET, the restoration process grid was completed in Spain.

Indian Blackout

On July 30 and 31, 2012, the Indian blackouts, which are considered the biggest ever power outages in the world, left over 600 million people (nearly half of India's population), in 22 out of 28 states in India, without electricity supply for several hours.

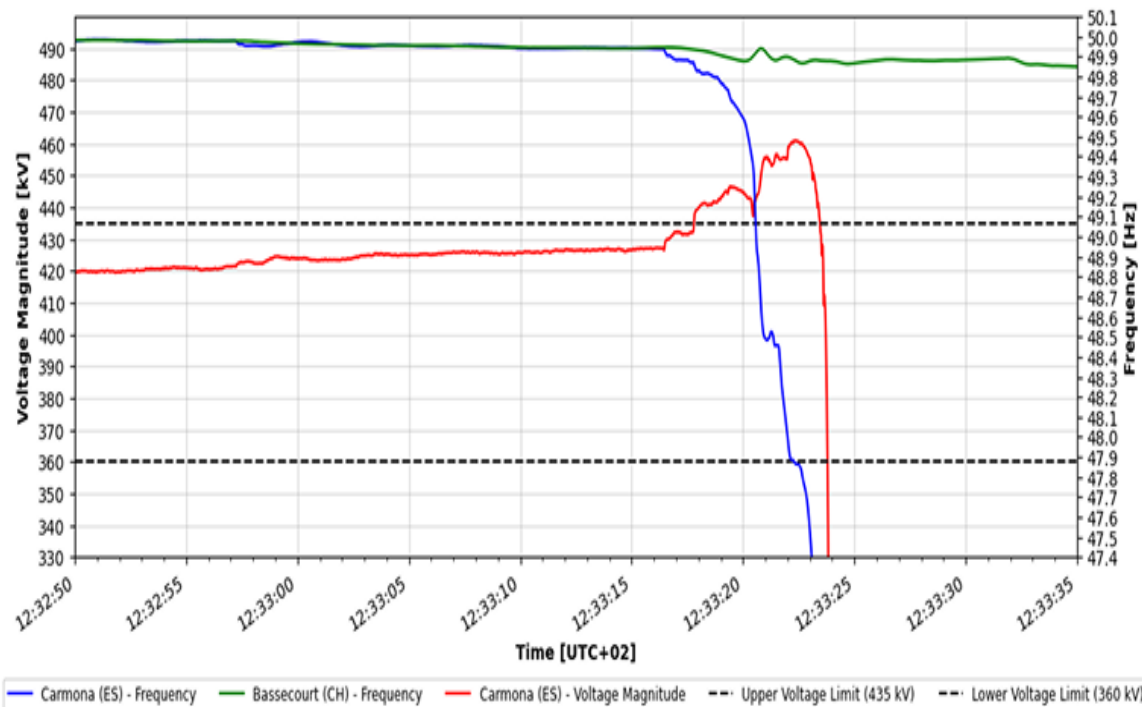


Fig. 3 Evolution of the frequency and the voltage in Spain and Continental Europe during the incident (sources Red Eléctrica, Swissgrid) [8].

USA Blackout

An outage occurred in the United States of America on August 14, 2003. About 50 million people were affected, as power outages lasted for several days in some areas, and the capacity of loads connected to the grid was about 61,800 megawatts. The cost in America was estimated to be between \$4 billion and \$10 billion. Canada lost about 18.9 million man-hours and lost about C\$2.3 billion. The weather on that day was very hot summers and the electrical grid connecting the western and midwestern regions of the United States and the province of Ontario in Canada was highly loaded before the complete blackout occurred. The scenario began when a 680 MW generating unit in Ohio was separated. About an hour later, a power transmission line in northeastern Ohio was disconnected due to overload. The disconnection of this line

resulted in additional overloads on other power lines in the grid. This, in turn, led to a rise in the temperature of the conductors and an increase in their sagging than permissible, and the contact of one of them with trees, and the occurrence of a short-ground and then other separation of transmission lines. After that, the electrical network was subjected to major shocks in electrical power, causing a large number of generators and transmission lines to disconnect, and within three minutes 21 major power plants were completely disconnected, including seven nuclear plants. The separations continued until complete blackout occurred.

Russia Blackout

On May 25, 2005, there was a major outage in the Russian capital, Moscow, leaving millions of people without electricity, and

stopped following this accident, electric public transport, as well as stopping pumping water and an explosion occurred in one of the chemical plants caused the leakage of large quantities of nitric oxide gases and pollution in the surrounding air. Business on the Moscow Stock Exchange was also halted, with economic losses estimated at about \$70 million.

UK Blackout

The partial outage that occurred in south London, the capital of the United Kingdom, at 18:20 on August 28, 2003 was due to the discovery of the problem of gas accumulation in the oil bowl of one of the electrical transformers, where engineers at the National Control Center received a warning signal from the complement of the compound Bochoz relay with the damaged transformer at 18:11. Immediately, the procedure for disconnecting this transformer began, which usually takes 5 to 10 minutes to rearrange the transmission network. A few seconds after the dismissal, another unexpected error occurred and the protective equipment and separation equipment began to work. Events continued until the blackout reached about 20% of the loads at that time, equivalent to 724 megawatts, and this interruption affected about 410,000 subscribers, as well as the loss of electricity supply to some parts of the railway and London Underground network. Procedures for restoring the electrical supply began at 18:26 and were completed at 18:57.

Italy Blackout

The blackout of Italy occurred on September 28, 2003, when the Italian grid imported 6,951 MW from neighboring networks, including 300 MW via a submarine DC cable between Greece and Italy. At 03:01:21, a flash spark occurred (Flashover) between one of the power lines and a tree, and the process of restoring the connection did not succeed, then another spark occurred on another line about 24 minutes after the first, which led to the disconnection of the line and increased load on the rest of the lines. The frequency of the Italian network declined to 49 Hz, and the load shedding program began to work to restore the balance of generation and load. However, the slow decline in frequency continued until the complete blackout of the Italian network at 03:28 due to imbalance and voltage collapse. The recovery procedures for northern Italy began from 03:28 to 08:00, and the rest of the network was recovered from north to south until 21:40.

Macedonia Blackout

On 18 May 2025 in the early morning, a partial blackout occurred in the power system of North Macedonia. The incident resulted in a loss of almost 100% of load in the electricity grid of North Macedonia for about one and a half hours (from 04:59 to 06:27 CEST). Restoration of the power system was successfully performed and proper actions taken by the TSO of North Macedonia. The rest of the Continental European power system

was not significantly affected by this partial blackout.

3- ELECTRICAL OUTAGES IN ARAB COUNTRIES

In view of the importance of this topic, the League of Arab States, in partnership with the Ministry of Electricity and Energy in Egypt, organized a seminar entitled “Lessons Learned from the Restoration of Electrical Networks in Emergency Circumstances” on May 25, 2006. The seminar was held at the headquarters of the League of Arab States in Cairo and was attended by a number of specialists and those interested in this field in Egypt and the Arab countries ^{[6],[10]}. The seminar was co-organized by the Arab Union of Electricity Producers,

Transmitters and Distributors through the Coordination Committee for the Operation of Arab Interconnection Networks and the Egyptian Electricity Holding Company, in cooperation with the Secretariat of the Council of Arab Ministers concerned with electricity affairs. The symposium dealt with a number of working papers presented in the scientific sessions throughout the day, including working papers from Egypt, Saudi Arabia, Syria, Jordan, Libya, Tunisia and Morocco. Table (1) and Table (2) provide brief statistics of the most important interruptions that occurred in the Arab countries and were presented at the symposium.

Table (1) Total Power Outages in Arab Countries

Country Time Date	Total Installed Capacity (MW)	Total Load (MW)	Loads affected by the outage (MW)	Restoration Time
Egypt 19:00 24/04/1990	9200	7600	7600	6 hours
Yemen 19:35 17/11/2000	645	425	425	5 hours
Tunisia 12:46 30/6/2002	2850	1303	1303	From 50 minutes to four hours
Jordan 19:29 9/8/2004	1650	1288	1288	15 minutes to two hours
Bahrain 08:32 23/8/2004	1849	1289	1289	From 10 hours to 12 hours

Egypt Blackouts

On September 4, 2014, Egypt faced a partial blackout affecting Greater Cairo and other governorates. The blackout occurred at about 6 am and lasts for several hours, resulting in some key services to stop. One of the major transmission circuits near Cairo was overloaded due to a maneuvering operational

error, causing the network to trip and leading to the blackout.

Egypt's other blackout was on April 24, 1990, the last night of Ramadan. This complete blackout occurred at seven o'clock in the evening when the network was heavily loaded, at peak load.

Table (2) Partial Power Outages in Arab Countries

Country Time Date	Total Installed Capacity (MW)	Total Load (MW)	Loads affected by the outage (MW)	Restoration Time
Morocco 15:00 GMT 03/7/2000	4620	2602	1358	5hrs 8min
Saudi Arabia (Western Region) 3:31 08/8/2003	7995	6214	1946	02:49 (hh:mm)
Libya 19:00:56 8/11/2003	4700	2787	2063	Half an hour for major cities 6 hours for the rest of the network
Jordan 12:11 22/11/2003	1650	1068	801	15 to 60 minutes
Tunisia 11:38 24/2/2004	3010	1389	547	15 to 45 minutes
Bahrain 06:47 30/06/2004	1849	1172	240	01:18 (hh:mm)

The events began with the forced exit of the double-circuit power line, which was transmitting 1650 MW at 500 kV of power from the High Dam hydro power station to the load centers in Cairo. This separation occurred in the first part of the line between Aswan and Nag Hammadi. The outage of this line caused a swing in the electrical power through the 132kV link that extends between the High Dam and Nag Hammadi. As a result, this link was separated by an out-of-step relay. As a result, the Egyptian grid split into two isolated electric islands. The first is in the south and contains the High Dam and Aswan reservoir generating power plants and a few loads, thus being overloaded. The other isolated electric island was from Nag Hammadi and extended north to Cairo, Lower Egypt and the rest of the grid, and it experienced a severe lack of generation compared to the load. The defense plan at that time could not deal with this major

problem and complete blackout occurred as a result of the separation of generating units in the South Island due to the frequency surge protection relays, and the separation of the generating units in the North Island due to the under-frequency protection relays.

Jourdan Blackouts

Regarding the two interruption incidents in Jordan, the seminar papers stated that the first was on November 22, 2003, when the Jordanian-Syrian link line was exposed to a short circuit between two phases (phase-to-phase fault), which caused the tripping of the transmission line between Aqaba and Amman due to protective devices and equipment. The southern part of the Jordanian grid is suffering from generation shortage and low frequency. As a result, a number of generating units were disconnected by devices and equipment of protection against frequency drop and feed shortage. The value of loads affected by the

outage was about 75% of the loads that were connected to the network before the accident.

The second outage in Jordan on August 9, 2004 was due to the separation of five generating units of 130 MW each at the Aqaba power plant as a result of a sudden shutdown of fuel (natural gas). This was followed by the disconnection of the electrical interconnection line with Egypt and then the separation of the interconnection line with Syria. The result was a complete blackout in the Jordanian grid.

Morocco Blackout

A partial blackout occurred in Morocco on the 3rd of July, 2000, during a short-circuit test on generating units and the main transformer in El-Gadida power station. The incoming 225kV transmission line was earthed. A flashover occurred on the busbar isolating switch leading to disconnection of the transmission line by the busbar differential protection system. This caused a second 335 MW and 104 MVAR loaded generating unit to trip. The 225kV high-voltage lines also disconnected, increasing the load on the interconnection line between the Moroccan grid and the Spanish grid from 228 MW to 500 MW. After 29 seconds, a third 335 MW and 80 MW loaded generating unit separated, increasing the load again on the link with Spain to 830 MW. And the voltage began to drop throughout the electrical network. About 2.3 minutes after the third generation-unit was disconnected, the load on the Spanish

interconnection line increased again to 890 MW, causing a voltage collapse that sequentially disconnected a number of generating units and transmission lines. There was a swing in the power transmitted between the rest of the units that eventually led to the separation of the grid into three isolated electric islands. The first island in the north is connected to the Spanish network, and the second island in the east is connected to the Algerian network. The third island in the south (including Casablanca) was without power and was completely blackout. The percentage of loads affected by the outage was about 52.2%.

Bahrain Blackouts

In Bahrain, there were two outages, the first on 30 June 2004, when the Bus Zone Protection devices and equipment responsible for the 220kV distribution busbars area operated to disconnect the circuit breakers connecting the buses, causing a complete trip of the station and widespread interruptions in all associated areas. The percentage of loads affected by the outage was about 20.5%. Tests revealed that the main cause of the failure of the 220 kV buses was a large leakage of FS6 gas from one of the equipment insulators and severe deterioration of the insulator.

Bahrain's second outage on 23 August 2004 occurred due to a so-called load rejection of a large and important equipment at Bahrain Aluminum Company (ALBA). As a result, the frequency in the network increased and the

speed governors began to work to reduce the capacity of the generators. But the frequency dropped to 48.55 Hz, causing the load shedding program to run that initially succeeded in raising the frequency to 49.9 Hz. Unfortunately, there was a over-voltage that lasted for several minutes, disconnecting all generators operating in the grid by overvoltage protective devices and equipment. Seven minutes after the start of the event, the Bahraini grid was completely disconnected causing 100% system blackout.

KSA BLACKOUTS

The power outage that occurred in the southern region of Saudi Arabia on August 3, 2003, according to the papers presented at the symposium, was due to the rise in the reactive power (MVAR) of one of the generators at the Jizan power plant. The events continued until the ratio of interruptions reached about 65.9%.

The other outage, which occurred in the Western Region on August 8 of the same year, was due to a single phase to ground fault of the 380kV transmission line between Aziziyah and Shuaiba. The percentage of loads affected by the outage was about 31.3%.

YEMEN BLACKOUT

In Yemen, there was a complete power outage on 17 November 2000 due to a multi-phase short-circuit of the 33 kV distribution busbars at one of the substations.

TUNISIA BLACKOUTS

In Tunisia, there were two blackouts: The

first was 100% power outage and was the result of the increase in the current in the transmission line of 225 kV and its separation by overload protection. The second was a partial outage of 39.6% due to contact between a tanker and a 90kV power line.

LIBYA BLACKOUT

The partial outage of 74% occurred in Libya on 8 November 2003 was due to a short-circuit on one of the 220/30 kV transformers at the West Tripoli substation.

For more details, study and analysis of the blackouts discussed in this section, the reader can see the technical working papers of the symposium held by the League of Arab States referred to in this article ^[10].

4 - CAUSES OF ELECTRICAL BLACKOUTS

The reasons for the occurrence of electrical outages in the countries of the world are due to natural factors or wrong performance of equipment and electrical devices that make up the electrical network and sometimes as a result of human errors. The following are the most important reasons:

- 1) Natural factors that may cause electrical network disruptions include electric lightning strikes that hit exposed overhead transmission lines. This may cause the voltage to rise to dangerous levels that lead to breaking electrical insulators and dumping huge amounts of electricity through the network that lead to the operation of protective devices to

separate the damaged parts of the network, which causes an increase in the load on the rest of the transmission lines by more than their capacity and disconnecting them as well through protective devices. The sequencing may remain until there is an imbalance between the power generated in the grid and the loads connected to it and may eventually reach a complete blackout and stopping generating units. The complete blackout that occurred in New York City on the evening of July 13, 1977 was due to an electric lightning strike that hit one of the main transmission lines, followed by the collapse of the insulators and the separation of the line, then the events rolled and another lightning strike hit another line until the network reached the complete blackout. Natural and climatic factors also include hurricanes and strong winds that may cause overhead transport lines or their contact with trees and the occurrence of high short currents that lead to the separation of these lines and the succession of events until complete blackout occurs. Earthquakes and volcanoes may cause a similar effect leading to complete power outages.

2) Another factor causing blackout is the occurrence of malfunctions in transmission lines, such as contact failure of conductors and the occurrence of short-circuits, which requires fast disconnection of these damaged lines from the network, resulting in an increase in the load on other healthy lines as well as

transformers, and if the load exceeds its rate limit, the rest of the lines and other units in the network will be disconnected. Separations may develop until complete blackout occurs.

3) Due to economic pressures as well as the restructuring of systems for the production, transmission and distribution of electrical power, it may be necessary to operate lines and equipment at their maximum rates. When exposed to any increase in load or any shortage in generation, the risk increases, and overloaded lines ^[11] may be exposed to excessive sags of the conductors as a result of high temperature. This may exceed the permissible distances between the conductor and the ground, so a short-circuit occurs that causes the separation of these lines and events continue leading to complete or partial blackout. Overloading of generators or transformers may lead to falling into the same problem.

4) Also, when a major failure occurs in one of the main equipment in the electrical network, such as generators or transformers, this may lead to a significant decrease in the generation compared to the load and eventually lead to total or partial blackout.

5) It is well known that all parts of the electrical network are equipped with protection and control devices, and that any malfunction of these devices or wrong adjustment may cause the wrong operation of these devices and disconnection of lines or

large electrical equipment such as generators and transformers. The fault may develop into complete disconnection and network collapse.

6) Due to the importance of the important role of devices and means of communication between control centers and between the main components of the electrical network and the equipment of switching and their vital role in the transmission of information, the occurrence of any malfunction in these devices may lead to major errors in information, which loses control of the network to the extent that causing interruptions.

7) Human factors also play an important role in the operation and control of electrical networks, and human errors may cause the connection or disconnection of important equipment or lines that eventually lead to a rapid sequence of events until complete shutdown occurs.

5- MITIGATION

Investigations of blackouts have shown that causes were due to human errors or technical reasons, such as lack of maintenance, overloading, malfunction of protection system, etc. Mitigation methods are available to reduce the risk of blackouts. These include improving system reliability, increasing transmission system capacity, use of FACTS devices, wide area monitoring systems ^[12], etc. Online security assessment is an effective tool to reduce blackout risks. The problem is that all these causes and events follow in very short

times (seconds or fractions of a second) and therefore it is necessary to take the necessary measures to avoid these human errors and to reset, review and calibrate the control and prevention devices periodically and also immediately after significant changes in loads or installations and new expansions ^[11] in networks at all levels. But what is it like when malfunctions occur beyond the control of operation and control engineers or malfunctions occur as a result of natural or climatic factors? Large networks are usually equipped with control systems to separate some less critical loads when load demand exceeds generation capacity. This situation arises in the event of the separation of a large generating unit or a number of generating units or the disconnection of one of the lines that transmit electricity from adjacent electrical grids or remote generating stations. In this case, the overloads begin to take the necessary energy from the energy stored in the rotating parts of the generators remaining in the network, causing a decrease in their rotational speed and thus a decrease in frequency. Frequency relays detect frequency decreases and begins programmed disconnection of parts of the loads. The load separation continues as the frequency continues to decrease until the network stabilizes and the load balances with the generation. This process is called load shedding.

The measurement, control, disconnection

and protection devices are programmed and adjusted in advance with accurate calculations and analyzes of the electrical network before faults occur, taking into account the so-called spinning reserve, as well as the possibility of immediate feeding from neighboring networks without exacerbating the problem or transferring it to the neighboring network. Network interconnection control centers as well as national and regional control centers play an important role in dealing with these events and requirements.

Disconnection in electrical grids may lead to so-called islands, i.e. the division of the network into separate parts or areas, each with a number of generating units and loads. Some separated areas may be overloaded and others may have over generation. The are over generation leads to an increase in the speed of generators and an increase in both frequency and voltage in the network to dangerous limits. Therefore, generator protection devices disconnect them from the network if the frequency exceeds a certain limit.

Operation and Control engineers must intervene in a timely manner by monitoring the measuring and monitoring devices before it is too late. They should have well-prepared plans and programs to deal with this problem.

It is worth noting that in the network control centers there are advanced and fast computers equipped with powerful software to calculate the power flow in the electrical

network and to calculate the values of currents in transmission lines and bus voltages to ensure that these currents or voltages do not exceed the permissible limits. When any excesses are detected, the control engineers must remedy the situation and develop appropriate solutions in advance, such as reducing loads and adjusting the flow of current by connecting or disconnecting some lines before major errors and problems occur.

6- RESTORATION

System restoration after blackout is a very complicated process requiring highly skilled and trained operators to be able to restore the isolated generators, transmission lines, loads and other system components. The factors which can affect restoration of a power system are the status of the system, the availability of equipment, duration and starting characteristics of system components.

The restoration process could be divided into three stages (or phases) ^{[13]-[15]}.

- a) The first stage is the black start phase.
- b) The second stage is the network reconfiguration phase.
- c) The third stage is the load restoration phase.

In the first stage restore the black start generating units such as hydro electrical plants and rebuild related transmission lines. The black start units send the required cranking power to the non-black start generating units.

In the second stage, reconfiguration of the power grid is implemented, as a mean to restore generators, transformers and important loads. In this phase of restoration, the operators should take precautions to avoid over voltage in the transmission lines and overexciting transformers. The restoration process might fail because the over voltage problem. In the third stage, all loads should be restored. The load pick-up is based on the rate and capabilities of the generators.

7- RECOMMENDATIONS

- * Emphasis on reviewing the performance of network equipment and devices in terms of maintenance programs, technical tests and calibration.
- * Emphasis on following up human performance in terms of the ability to deal consciously and thoughtfully with the rapid events of power outages and training on scenarios and steps to restore electrical supply.
- * The need for periodic review of the control and protection devices and updating them to keep pace with changes in the network.
- * Work to reinforcing the electrical transmission networks and adjust the network's needs of active and reactive powers to keep pace with the increasing demand for electrical energy and planning to add generation units at

appropriate times.

- * Emphasis on developing detailed and accurate plans and programs in the event of major outages and the necessary steps to restore the network.
- * Work on modernizing control centers according to the latest international technologies.
- * Attention to preparing the correct operating instructions for electrical power networks and training operating engineers on them.
- * Recommending the need to use modern tools and programs to analyze and learn from events and take the necessary precautions to prevent their recurrence and mitigate their damage.
- * Calling on Arab countries to speed up the implementation and operation of Arab electrical interconnection networks because of its many economic and technical benefits and contribute to reducing electrical outages.
- * Exchange of experiences and information between Arab electricity network operators in the field of restoring the operation of networks and also benefit from foreign experiences in this field.
- * Developing the engineering education programs at universities, in addition to promoting research in the field of future electrical power systems and smart grids.

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