Forecasting of critical contingencies of interconnected power systems to mitigate the effect of blackouts

Quintana, J., *Student Member, IEEE,* Orejuela, V., *Senior Member.*
jquintanas@est.ups.edu.ec, vorejuela@ups.edu.ec
Universidad Politécnica Salesiana

Abstract—This paper presents an analysis of the three causes of loss of stability in a power system: loss of voltage stability, loss of stability of the rotor angle and frequency stability loss. The analysis of these three factors is very important since the event of contingencies in SEP due to any of these elements could lead the system to collapse, causing a blackout. Avoiding the event of a blackout is more than important, it is necessary, because the occurrence of one of them brings incalculable losses throughout the affected area, not just economically, but other details that will be analyzed in the development of the article. The contingency analysis of power systems it is necessary to determine the worst contingencies that affect the system, after which it is important to establish the remedial measures that will prevent the collapse of the entire electrical system. These remedial measures are known as Special Protection Schemes (SPS).

Index Terms—Electrical Power Systems (EPS), blackout, contingencies, stability of power systems, voltage stability, frequency stability, rotor angle stability, voltage collapse, Special Protection Schemes (SPS).

I. INTRODUCTION

The occurrence of blackouts in the interconnected power systems means that large swathes of territory with millions of users of electric service remain without service for a specified period of time [1].

But not only are users who are out of power, but in these areas are also generating plants, which fail to provide energy to the system.

The implications are enormous generate blackouts, affecting several levels listed below:

- Economic damages
- Social repercussions
- Policy damages

A. Economics Damages

The economic effects involving the blackouts are most important. In blackouts occurred in countries with large tracts of territory economic losses reach by trillion USD [2]. These economic losses primarily affect the industrial and commercial sector, because many industries incur extra charges for the use of fuels that are used in private generators. Many of these companies pass that extra cost to users, increasing the cost of goods or services [3].

B. Social Repercussions

Socially widespread inconvenience and discomfort as increased congestion due to lack of traffic lights, reaching to sometimes accidents, endangering the lives of people in danger arise, the elevators stop working, bothering the commercial customers and building centers, the lack of street lighting produces an increase in insecurity of citizens, as the crime takes advantage of the darkness to commit unlawful acts such as theft, robbery, etc., against citizens [3].

C. Policy Damages

The political aspect is also affected, since all the discomfort caused to citizens generate an atmosphere of distrust towards the authorities. It is widely believed that the authorities are not doing enough.

With all these effects involving a blackout, the cost of non-supplied energy is very high $ 1.53 / kWh [4], compared with $ 0.0892 / kWh of energy supplied in the Republic of Ecuador [5].

II. MOST IMPORTANT BLACKOUTS IN THE LAST TEN YEARS

In the last decade we can cite eight blackouts of great importance [1]:

- Blackout in USA and Canada, which occurred on August 14, 2003.
- Blackout in Austria, which occurred on August 27, 2003.
- Blackout in London, which occurred on August 28, 2003.
- Blackout in Sweden and Denmark, which occurred on September 23, 2003.
- Blackout in Italy and Switzerland on September 28, 2003.
- Blackout in Greece, which occurred on July 12, 2004.
- Blackout in Moscow, which occurred on May 25, 2005.
- Blackout in Europe, which occurred on November 4, 2006.

A. Blackout in USA and Canada, 14 Aug 2003

This caused a blackout load shedding over 60 GW, affecting about 50 million people, with an estimated economic cost between 4-10 billion USD [1]-[2]. This was the worst blackout in the history of the United States [6].

E In USA it affected eight states:

- Ohio
- Michigan
- New York
- Pennsylvania
- New Jersey
- Connecticut
- Massachusetts
- Vermont

Canadian provinces affected were two:

- Ontario
- Quebec

The duration of the blackout was 2 days in some parts of the USA energy service was not restored until four days later. In some parts of Ontario Power restored until after a week [2].

During this event, more than 400 531 transmission lines and 261 generating units fired power plants. Fig. 1 shows the general area affected by failure [7].

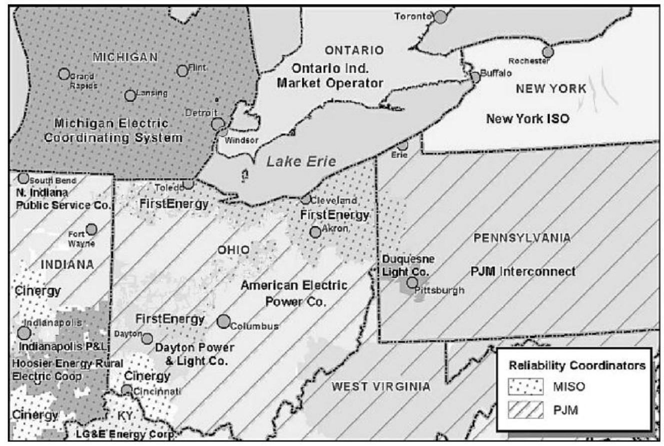

Fig. 1. Affected zone by the blackout happened in USA and Canada 2003 [7].

B. Blackout in London, 28 Aug 2003

On the night of August 28, 2003, the southern part of London suffered a blackout. Energy generation of 724 MW was lost, affecting 410,000 users. Lasted half an hour [1]-[2].

C. Blackout in Sweden and Denmark, 23 Sep 2003

On 23 September 2003 the Nordic power system was hit with the most severe disturbance in the last 20 years. About 4 million people were affected. In Sweden the demand not supplied was around 10 GWh in Denmark and 8 GWh. This blackout duration was 8 hours [1]-[2].

D. Blackout in Italy and Switzerland, 28 Sep 2008

People affected by this blackout was over 56 million. The Italian electricity system collapsed and lasted more than 48 hours. Interrupted was 17 GWh energy [1]-[2].

Other impacts that had this blackout was that the mobile phone system failed. Nearly 30,000 people were trapped on trains, hundreds of passengers were stuck in the subway stations and many flights were canceled. It also caused the death of three persons [1]-[2].

E. Blackout in Greece, 12 Jul 2004

This blackout was in the hottest time of the year when the peak demand is greatly increased due to the use of air conditioners. The interrupted power was 4,500 MW [1]-[2].

It affected about 5 million users and had a duration of 1 hour. The implications that had, among others, were traffic accidents and traffic congestion due to the lack of traffic lights. Many people were trapped in elevators and some networks of cellular operators overloaded [1]-[2].

F. Blackout in Moscow, 25 May 2005

The blackout occurred on May 25, 2005 in Moscow affected about 4 million users, which were trapped in elevators, subways and vehicular traffic [1].

The estimated economic damage was 70 million USD. It lasted 32 hours and the total load was disconnected 3539.5 MW [1]-[2].

The voltage level on the southern part of the Moscow power system suffered a voltage drop. As the response of the responsible personnel to operate and control the system was not fast enough, the failure occurred [1].

This caused great confusion among Russian citizens, because their country is rich in energy resources, but did not have adequate infrastructure to keep supplied power demand [1].

G. Blackout in Europe, 4 Nov 2006

An incident in the grid of Europe (UCTE) caused a blackout across the network. Severe failures occurred which led to a blackout, affecting more than 10 million people. The interrupted power was 14 GW [1]-[2].

The countries concerned were:

- Germany
- France
- Belgium
- Spain
- Austria

As results of the failures, the European transmission network was divided into three zones. In the northeast area was over-frequency, on the west side there were low-frequency and in the southeastern part also suffered from a decline in frequency. In these areas, users were disconnected from the network. At night, the electricity service was restored to users [1].

Below in Table I summarizes the most important data of the aforementioned blackouts and others who are important to mention.

TABLA I
BLACKOUTS WORLDWIDE

Locación	Fecha	Personas afectadas	Duración	Potencia interrumpida	Costos económicos
Brasil	ene-2002	170 M	5 H	23.766 MW	178 millones USD $
USA - Canadá	ago-2003	50 M	2 días	62.000 MW	4 - 10 billones USD $
Suiza - Dinamarca	sep-2003	4 M	8 H	4.700 MW	56 millones USD $
Moscú	may-2005	4 M - 20.000 - 1500	32 H	3500 MW	168 millones USD $
Pakistán	sep-2006	160 M	5 H		
Europa	nov-2006	15 M	2 H	14 GW	42 millones USD $
Brasil - Argentina	nov-2009	87 M	4H	24, 4 GW	146 millones USD$
USA	sep-2011	7 M	11 H		12 - 18 millones USD $

III. CONSEQUENCES OF BLACKOUTS

To predict a blackout is very difficult. Their impacts can be destructible. The estimate of future risk is a very important task, not only to prevent major economic damage but also to protect human lives. Fig 2 indicates the number of blackouts in the last decade. It can be seen that a high number of blackouts occurred in 2006.

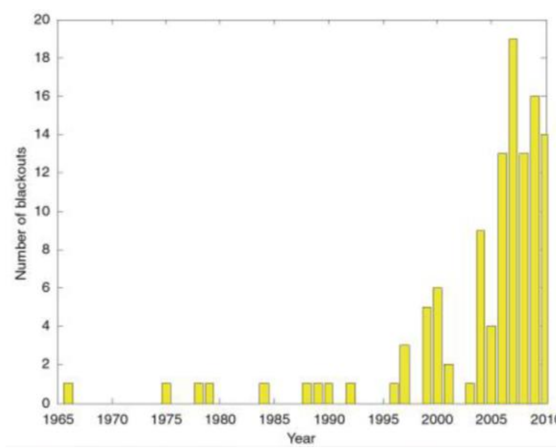

Fig. 2. Number of blackouts in the last decade [1].

Fig. 3 shows the number of people affected because of the blackouts, which seem to be increasing.

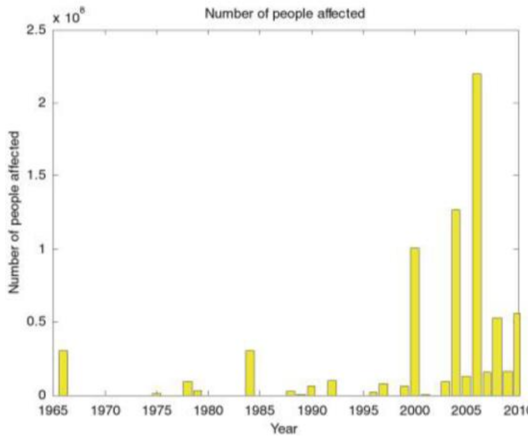

Fig. 3. Number of people affected by blackouts in the last decade [1].

IV. Prevention of Blackouts

There is no solution to prevent blackouts, but many things can be done to minimize its consequences listed Ahead ion:

- Analysis and audits.
- Schedule preventive and corrective actions.
- Monitor the interconnected power system.
- Having control and diagnostic centers.
- Operate safety limits in real time at all times.
- Contents protection coordination studies.
- Testing on the elements that are part of the system of protection, as the relays.
- Check operation of schemes of protection systems.
- Conduct studies of dynamic stability and transient stability.
- Evaluate the conditions of aging infrastructure and improving procedures of maintenance.
- To assess the safety control systems and protection systems.
- Strengthen the network.

V. Operation States of Power Systems

The states of operation of an interconnected power system are five, see Figure 4.

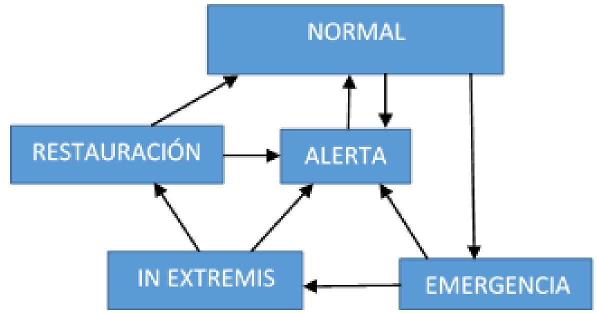

Fig. 4. Operation states of power systems [8].

A. Normal

E In the normal state the power system meets the demand for energy of all users. All values of voltages, currents and powers are within established technical ranges. The system is able to support any contingency estimable [8].

B. Alert

We speak of alertness when the values of voltages, currents and powers exceed permissible technical values due to an unexpected increase in demand or a severe contingency, but the system is still intact powering users.

In this state a further increase in demand or other contingency may jeopardize the operation of the power system and preventive actions should be taken to restore the system to its normal state [8].

C. Emergency

In the emergency power system is still intact, supplies power to users, but the boundary violation is more severe.

Emergency rule generally follows the alert when they have not carried out preventive actions or they have not been successful. Power systems can take the emergency directly from normal state after unusually severe contingencies as multiple faults.

When a system is in a state of emergency is necessary to conduct effective corrective actions that first alert and then the normal state [8].

D. In Extremis

Power systems can transition to the in extremis from a state of emergency if they have not completed the corrective actions and the system is no longer intact due to the reduced supply of emergency after a load shedding or when they have fired units generation due to the lack of synchronism. If corrective actions are not enough to overcome this state inevitably comes a blackout, which can be partial or complete [8].

E. Restoration

For the system power state in extremis return to normal alertness or the state of restoration is necessary. In this state the operators of the power system control actions performed in order to return to power the users [8].

VI. Stability in Power Systems

The stability of the power system is nothing but the ability to have electric power systems, for a given initial operating condition, to recover or return to the operating state of equilibrium when it has been subjected to a disturbance [9].

This means that a power system is stable when its operation remains intact after a disturbance. This will depend on the operating conditions and the nature of disturbances [10].

In Fig. 5 you can see the classification of the stability of power systems [11].

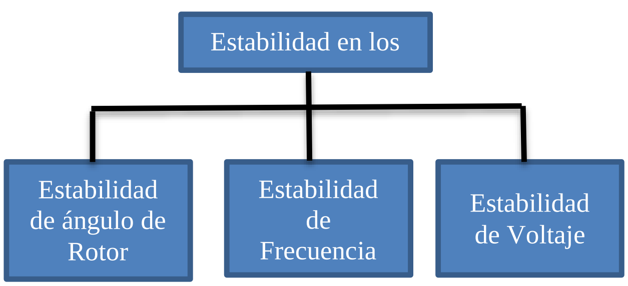

Fig. 5. Classification of stability in power systems [11].

A. Rotor angle stability

The rotor angle stability is the ability of interconnected synchronous machines of a power system to maintain synchronism under normal operating conditions and after suffering a disturbance [9].

This stability is lost when the rotor of synchronous generators advances or exceeds a certain angle, then the magnetic coupling between the rotor and the stator has an abnormality. This leads to the rotor to lose synchronism with the rotating field held the stator currents and starts rotating relative to the field by taking a slip relative to the pole [12].

B. Frequency stability

The frequency stability refers to the ability of a power system frequency to keep the balance after a serious anomaly in the system, which results in a significant imbalance in the generation and load.

This balance depends on the ability to maintain or restore the balance between power generation and consumption of it, with minimal unintentional loss of load. Instability may result occurs as frequency swings shot leading to units generating and / or consuming loads [10].

C. Voltage stability

Voltage stability refers to the ability of a power system to maintain stable voltages in all system buses having been subjected to a disturbance under a given initial operating condition. In Fig. 6 you can see an example of voltage collapse.

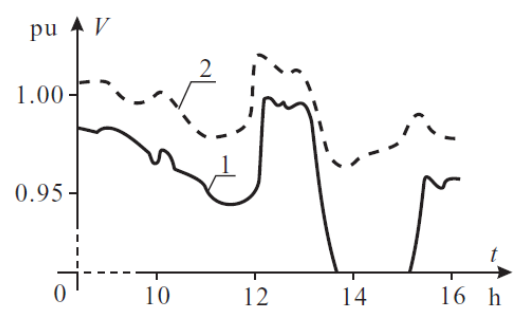

Fig. 6. Example of voltage collapse: (1) voltage variation during the day of the collapse, (2) change in voltage during the previous day [8].

Instability that may result occurs in the form of a progressive fall or rise in tensions of some buses. One possible outcome of voltage instability is the loss in an area, or a good transmission lines and other items using their protection systems leading to cascading outages [10].

VII. Protection Schemes

For any of the three stability losses that may occur in the power system and if they are not controlled, leading to system collapse undoubtedly blackout will occur. However protection schemes are designed to minimize the effects of uncontrolled loss of stability.

A. Special Protection Schemes (SPS)

According to [13] the special protection schemes are designed to detect a condition of system instability, overload or voltage collapse cause is known. The prescribed actions may require the opening of one or more lines, disconnection or trip generation units, rejection or intentional load shedding or other measures to alleviate the problem identified.

In Peru, the Committee of Economic Operation of the System (COES) has established the following SPS [14]:

"Scheme of Automatic Load Shedding by low frequency.

Schemes of Automatic Disconnecting Over-frequency generation.

Automatic Rejection Scheme for Low Voltage Charge"

,,

It should be mentioned that all EEP are designed and planned for a particular power system [15].

VIII. Conclusions

When the contingencies in the interconnected power systems led him to the loss of stability, and this could not recover, but instead led to the collapse was undoubtedly blackout will occur. The loss of stability in power systems can be given for loss of stability in the angle of the rotors of synchronous machines, the loss of stability in frequency and loss of stability in voltage. The occurrence of a blackout brings not only economic loss but also social costs that are desirable in any way. The Special Protection Schemes detect anomalies or contingencies that can lead to collapse and based on pre-established remedial actions and those actions executed planned load shedding and / or generation.

References

[1] M. Čepin, *Assessment of Power System Reliability: Methods and Applications*. Springer, 2011.

[2] SESAME (Securing the European Electricity Supply Against Malicious and accidental thrEats), "Analysis of historic outages." 30-Sep-2011.

[3] R. P. Aguilar Chiriboga, J. C. Cepeda Camapaña, and J. Játiva Ibarra, "Análisis técnico comercial del colapso nacional del 1 de marzo de 2003," 2006.

[4] CONELEC, "SESIÓN DE DIRECTORIO DE 14 DE ABRIL DE 2011 - RESOLUCIÓN 025-11.pdf." 14-Apr-2011.

[5] CONELEC and MEER, "PLAN MAESTRO DE ELECTRIFICACIÓN 2012- 2021." .

[6] H. Zheng, *Investigation of Power System Blackouts and Reliability Improvement for Power Distribution Systems*. ProQuest, 2007.

[7] G. Andersson, P. Donalek, R. Farmer, N. Hatziargyriou, I. Kamwa, P. Kundur, N. Martins, J. Paserba, P. Pourbeik, and J. Sanchez-Gasca, "Causes of the 2003 major grid blackouts in North America and Europe, and recommended means to improve system dynamic performance," *Power Syst. IEEE Trans. On*, vol. 20, no. 4, pp. 1922–1928, 2005.

[8] J. Machowski, J. Bialek, and D. J. Bumby, *Power System Dynamics: Stability and Control*. John Wiley & Sons, 2011.

[9] L. L. Grigsby, *Power System Stability and Control, Third Edition*. CRC Press, 2012.

[10] P. Kundur, J. Paserba, V. Ajjarapu, G. Andersson, A. Bose, C. Canizares, N. Hatziargyriou, D. Hill, A. Stankovic, and C. Taylor, "Definition and classification of power system stability IEEE/CIGRE joint task force on stability terms and definitions," *Power Syst. IEEE Trans. On*, vol. 19, no. 3, pp. 1387–1401, 2004.

[11] P. Kundur, *Power system stability and control*, vol. 12. 中国电力出版社, 2001.

[12] B. M. Weedy, *Sistemas eléctricos de gran potencia*. Reverte, 1978.

[13] P. M. Anderson and B. K. LeReverend, "Industry experience with special protection schemes," *IEEE Trans. Power Syst.*, vol. 11, no. 3, pp. 1166–1179, Agosto 1996.

[14] D. Rodríguez, R. Ramirez, and J. C. Pino, "Esquemas Especiales de Protección del Sistema Eléctrico Interconectado Nacional (SEIN): Esquemas de Rechazo Automático de Carga y Desconexión Automática de Generación-Año 2007," 2007.

[15] M. Zima, "Special protection schemes in electric power systems," *Lit. Surv. Swiss Fed. Inst. Technol. Zurich EEH-Power Syst. Lab.*, pp. 1–22, 2002.

Authors

José Quintana nació en Quito Ecuador, el 13 de Julio de 1982. Se graduó en la el Colegio Salesiano Don Bosco "La Tola", obteniendo el título de Bachiller Técnico Electrónico. Actualmente se encuentra en el décimo semestre de la Carrera de

Ingeniería Eléctrica en la Universidad Politécnica Salesiana.

Víctor H. Orejuela nació en Quito, Ecuador, el 16 de abril de 1946. Es ingeniero eléctrico graduado en la Escuela Politécnica Nacional de Quito, Ecuador; y tiene un título de Master otorgado por la Universidad Politécnica Salesiana de Quito, Ecuador. También ha participado en el Power Systems Engineering Course, de la General Electric Co, en Schenectady, N.Y.; y, el curso Relays and Protection Techniques, en la Brown Bovery & Co, en Suiza.

Su experiencia profesional incluyen el Instituto Ecuatoriano de Electrificación (INECEL), desde 1970 a 1988; en la planificación de sistemas eléctricos de potencia; y, en el diseño de sistemas de distribución, transmisión y generación. Desde 1988 viene ejerciendo su profesión, como Consultor Independiente, también trabajó en el Fondo de Solidaridad. Se ha desempeñado como profesor en la Escuela Politecnica Nacional, desde 1975 y actualmente en la Universidad Politécnica Salesiana, ambas en Quito, Ecuador.

Ha recibido varios premios, entre ellos, la Medalla de Oro al Mérito de la Ingeniería, otorgado por la Sociedad de Ingenieros del ecuador. Además ha recibido primeros premios por los mejores artículos técnicos presentados; y, por mejores desempeños académicos.