The Electricity Journal 29 (2016) 42–49

Contents lists available at ScienceDirect

The Electricity Journal

journal homepage: www.elsevier.com/locate/electr

Analysis of major blackouts from 2003 to 2015: Classification of incidents and review of main causes

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ARTICLE INFO

Article history:
Available online 25 September 2016

Keywords:
Power systems
Power system blackouts
Power system reliability
Power system security

ABSTRACT

An analysis of severe worldwide blackouts classifies the events according to defined indices and establishes common causes among them. Among the conclusions is that a voluntary system of compliance with reliability regulations is inadequate to the needs of current power systems.

1. Introduction

After serious blackouts occurred in Iran, London, Denmark and Sweden, Italy, and North America in 2003, bringing with them important economic, social, and political consequences, the necessity of reviewing the reliability standards in these regions to avoid a reoccurrence or minimize the impact of new blackouts was clearly established. The UCTE (Union for the Coordination of Transmission of Electricity) reviewed its rules and introduced the Operation Handbook (UCTE, 2015) and the NERC (North American Electric Reliability Council) performed improvements in its Reliability Standards (NERC, 2015). The reviews and improvements were done in order to maintain a reliable operation and took into account lessons learned from those incidents about their prevention and management. Despite efforts like these, major blackouts continue happening, affecting electric systems worldwide. This article reviews blackouts with worldwide repercussions that have occurred since those 2003 incidents.

The updated case analysis follows almost the same structure of those performed for the 2003 incidents included in (Veloza and Cespedes, 2006), establishing a similar comparison base and drawing relevant conclusions. However, this article also presents a description of the root causes of each incident, groups them accordingly, and addresses a matter of special interest, the causes of new blackouts affecting areas where enhancements in standards were implemented.

The analysis focuses on transmission system reliability, since big blackouts are mainly related to high-voltage grids, and the major impact of the transmission activity on power systems.

2. Case study

The main characteristics of 14 major blackouts occurred in the world in the past 13 years are presented in this section (European Regulators' Group for Electricity and Gas ERGEG, 2007; FERC and NERC, 2012; FRCC Florida Reliability Coordination Council, Inc, 2008; Gaikwad and Srivastava, 2013; ISA, 2007; Ministry of Power, 2012; ONS, 2011; Ruiz et al., 2008; TEIAS and ENTSO-E, 2015; Tribunal de Contas da União, 2011; UCTE, 2007a; Vournas et al., 2005; XM Compañía de Expertos en Mercados, 2007; Younas and Qureshi, 2007), starting with the five serious events of 2003 (Veloza and Cespedes, 2006). Incidents caused by extreme weather conditions were not considered for the analysis.

2.1. Characteristics of the analyzed blackouts

The review of the characteristics of the incidents was performed based on five significant indices: number of people who lost service, lost load (in MW), duration, affected population (percentage), and severity (in system-minutes).

Table 1 shows the indicators corresponding to the first three mentioned indices for the 14 important events included in the analysis. These figures were mainly obtained from the final investigation reports issued after each blackout.

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http://dx.doi.org/10.1016/j.tej.2016.08.006
1040-6190/

Table 1
Indicators (Part I).

Blackout	People without Service (Number)	Lost Load (MW)	Duration
Turkey March 31, 2015	70.000.000	32.200	More than 7 h
India July 31, 2012	670.000.000	48.000	2–8 h
Arizona and Baja California Sept. 8, 2011	8.100.000	7.835	6–12 h
Brazil Feb. 4, 2011	40.000.000	8.884	More than 3 h
Florida Feb. 26, 2008	3.000.000	3.650	1–3 h
Colombia April 26, 2007	41.160.000	6.644	4,5 h
UCTE Nov. 4, 2006	45.000.000	14.500	Less than 2 h
Pakistan Sept. 24, 2006	160.000.000	11.160	5–6 h
Athens July 12, 2004	5.000.000	4.500	Up to 5 h
Italy Sept. 28, 2003	57.000.000	24.000	5–9 h
Denmark and Sweden Sept. 23, 2003	4.000.000	6.550	5 h
London Aug. 28, 2003	410.000	724	0,62 h
North America Aug. 14, 2003	50.000.000	61.800	16–72 h in USA and up to 192 h in Canada
Iran March 31, 2003	22.000.000	7.063	8 h

From Table 1, the blackout that affected the largest amount of people occurred in India (2012), followed by the event in Pakistan, then the incident in Turkey. Two of these blackouts occurred in the last five years, and the India event affected more than 9% of the world population in 2012 (World Bank, 2012). The blackout in North America (2003) is still the event reporting the longest duration and with the largest amount of lost load, followed by the India and Turkey incidents, while the London blackout (2003) is still the least serious event. The average duration of the blackouts was about five hours, excluding the long restoration time observed for the event of North America.

Two other indices used to study the events were affected population (%) by the incident (1), and severity (system-minutes) (2) (Gomes, 2004). These are calculated as:

$$Affected\ population\ (\%) = \frac{Number\ of\ costumers\ without\ service}{Population\ of\ affected\ countries} x100 \quad (1)$$

$$Severety(System-minute) = \frac{Energy\ not\ served\ (MWh)}{Base\ of power\ (MW)} x60 \quad (2)$$

The base of power was taken as the peak load in the system. The classification of blackouts according to their severity level is presented in Table 2 (Gomes, 2004):

Table 2
Disturbance Severity Classification.

Classification (Level)	Severity (System – minute)	Interpretation
0	<1	Acceptable
1	1–10	Not severe
2	10–100	Severe
3	100–1000	Very severe
4	>1000	Catastrophic

Table 3 shows the two calculated indices for each incident, and the blackout classification according to Table 2. The UCTE blackout shows low values in this table, but it should be noted that as the event affected most of the European countries in the UCTE system, the indices for that incident were obtained using the population and the base of power corresponding to the whole system.

From Table 3, the calculated indices show that the incident in Turkey (2015) had the highest severity in system-minutes. Almost half of the blackouts (6 events) had a severity level of 3, defined as very severe. Two of these incidents occurred in the last five years. Between the very severe incidents, the events that occurred in Italy (2003) and Pakistan (2006) affected 100% of population in their countries, closely followed by the blackout in Colombia, where 98% of its population was affected. The blackouts of London, Florida, and UCTE, with a severity level of 1, were not severe by the measurement of the disturbance severity classification.

A graphical presentation of the incidents is presented in Fig. 1, where severity vs. affected population is presented. A color code was used consisting of a transition from white for the lowest-impact event towards black for the most serious incident (Table 4). Fig. 1 allows quickly and easily identifying the blackouts located in each zone, and pays special attention to the four blackouts in the high-impact zone, the events in Turkey, Pakistan, Italy, and Colombia.

2.2. Previous conditions

Table 5 shows some of the conditions before the incidents. Common pre-existing conditions among several blackouts were high load and interchange levels, causing an operation closer to security limits, and maintenance outages of transmission lines and/or generation units weakening the systems. Two of the blackouts started due to errors during maintenance procedures.

This suggests that transmission system planning and operation as well as the planning and execution of power system maintenance activities should be carefully developed.