

POWER SYSTEM BLACKOUTS – LESSONS LEARNED

Nasser Hossein-Zadeh
Faculty of Engineering and Physical Systems
Central Queensland University, Australia
n.zadeh@cqu.edu.au

ABSTRACT

In August 2003, large areas of the Midwest and Northeast United States and Ontario, Canada, experienced an electric power blackout. The outage affected 50 million people and about 62000 megawatts (MW) of electric load. The final report on the August 14, 2003 blackout by the US-Canada Power System Outage Task Force makes clear that this blackout could have been prevented! Similar events, but in a lesser extent, happened in Europe at about the same time. Some other major outages had occurred around the globe prior to the great blackout of 2003.

What are the lessons learned from these blackouts? This paper will partially address this question. It will also explore the relevance of these lessons to the electric power network in Australia.

1. INTRODUCTION

The interconnected electrical power system is a very complicated dynamic system. The North American electric grid has been referred to as the most complex machine ever built. This system delivers an enormous amount of energy to customers. If the system is not operated within defined operating parameters, that energy can be unleashed and result in severe equipment damage. Maintaining the stability of this complex dynamic system is of a paramount importance when disturbances or faults occur in the system. Although the system has many automated control systems, the system requires humans to operate it in a safe and stable manner. If the system is not well controlled, a cascade of outages may lead to a major blackout. Instability of power systems has been classified in a few categories, depending on the characteristics of the instability problem, such as transient instability, dynamic instability or voltage instability.

A review of blackouts of the electrical power grid of North America, published at the early stages of investigation into the blackout of August 2003, pointed out a few problems that could contribute to the blackout [1]. The historical power system blackout in **1965** was the biggest power system **transient stability event** at the time of its occurrence [2]. The speed of the events was so high that not much could be done by human intervention when the cascade of outages started. The cascade was triggered by tripping a single transmission line from the Niagara generating station. The Northeast power system became unstable and separated into isolated power systems (islands) within 4 seconds. Most islands went black within 5 minutes, due to imbalances between generation and load (generator

overspeed/underspeed tripping). The massive blackout left 30 million people without electricity for as long as 13 hours. After this event, power system authorities reviewed the American National Power Policy. They proposed studies and investigations into the inter-regional connections, a stronger national grid, and pumped-storage plants, which were supposed to represent a large reserve that could be put into operation on a short notice.

In contrast, the blackout of August 14, **2003** was apparently a '**voltage collapse**' [3]. Usually a voltage collapse is the consequence of lack of enough 'reactive power' injected to the system. Reactive power is the component of total power that assists in maintaining proper voltages across the power system. Customer loads such as motors and other electromagnetic devices consume reactive power, as do heavily loaded transmission lines. When reactive supply is limited, the increased loading will cause a voltage drop along the line. If reactive supply is not provided at the end of the line, the voltage could fall sharply.

The chain of events in the blackout of August 2003 was not as fast as the blackout of 1965. It seems that there was enough time, between what can be considered as the triggering event at about 1400 (2pm) (the U.S. eastern daylight time) and the actual start of the cascade at about 1609 (4:09pm); for the operators to react properly and contain the blackout. However, after the cascade started, it was a matter of a few minutes for the outages to spread out to a large area. At about 1612 (4:12pm) the cascading sequence was essentially complete, shutting down more than 100 power plants, including 22 nuclear reactors, in the United States and Canada and knocking out power to 50 million people over a big area stretching from New England to Michigan.

North American Electric Reliability Council (NERC) is in charge of developing reliability standards, which are designed to ensure that the electric system is operated so that it can withstand any single disturbance without resulting in the cascading failure of the system. The Preamble of the NERC Operating Policies states [4]:

All control areas shall operate so that instability, uncontrolled separation, or cascading outages will not occur as a result of the most severe single contingency. Multiple outages of a credible nature shall also be examined and, when practical, the control areas shall operate to protect against instability, uncontrolled separation, or cascading outages resulting from these multiple outages.

There is no way to prevent disturbances from occurring. However, a successful reliability process will ensure that the system will be operated in a reliable manner so that

even multiple events will be unlikely to cause a cascading outage.

2. ANALYSIS OF THE BLACKOUT OF AUGUST 2003

Figure 1 shows the region where the big blackout of August 14, 2003 initiated. Reliability Coordinators and Control Areas are also shown in the Figure. Of special interest, is the area covered by First energy (FE), in Northern Ohio and specifically the area in the vicinity of Cleveland. FE is the fifth largest electric utility in the United States. It operates several control centres in the Ohio territories. Each of these control centres performs different functions. The generation management system (GMS) handles the unregulated generation business, including automatic generation control and wholesale transactions. Another control system, the energy management system (EMS), monitors the entire FE control area. The control centre has two groups: one is responsible for real-time operations and the other is responsible for transmission operations support. This group has several dispatchers who conduct day-ahead studies. The real-time operations group, on the other hand, is composed of two sub-groups: control area operators and transmission operators, who are responsible for monitoring the system on line and providing proper actions [4].

August 14, 2003 was expected to be a normal summer day. Electric loads were expected to be high, but not at peak levels. Significant inter-regional power transfers were expected, but nothing beyond the normal summer power flows. As day progressed, operators observed low voltages in the FE territory, but they did not consider the voltages to be “particularly bad”. FE operators requested additional reactive support from the plants under their control that morning.

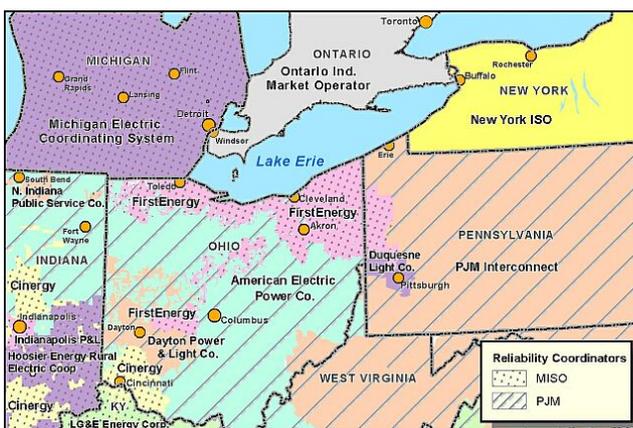


Figure 1: Reliability Coordinators and Control Areas in the region where blackout initiated [4]

The events that ended up with the blackout of 2003, are summarised as follows, [4] and [5].

- Temperatures were high in the Midwest area;
- First Energy’s 870 MW nuclear plant located in North-East Ohio was down for maintenance;

- The 597 MW Eastlake generating unit in Northern Ohio (Cleveland area) went offline at about 1400 (2pm). It is interesting to note that this unit tripped because of an attempt to provide more reactive power to support the scheduled voltage;
- At about 1414, the FE EMS system experienced a software failure that resulted in the loss of alarm processing. This was unfortunate since the operators relied almost exclusively on audible and on-system alarms to reveal any significant changes in system conditions;
- One of the transmission lines feeding the city of Cleveland went out of service at about 1505. This line tripped due to a tree contact. However, this outage did not change the status of the power flows over Michigan’s interstate connections;
- A second line feeding Cleveland went out of service and transmission system near Cleveland experienced low voltage. The power flows on Michigan’s interstate connections was still normal;
- Two more transmission lines feeding Northern Ohio went out of service and the transmission system in that region experienced severe low voltage. The power flows were still steady, about 200 MW from Ohio to Michigan, about 2000 MW from Indiana to Michigan and about 400 MW from Michigan to Ontario (Canada);
- The FE operators were so dependent on alarms to provide an indication of the system’s health that they were not aware of the emergency situation. They even discounted the information being provided from outside their system;
- At about 1606 the Sammis-Star transmission line feeding Northern Ohio from within Ohio went out of service; this was a critical event as the power flow on the Michigan-Ohio interstate connection reversed and FE started pulling 200 MW through Michigan. Voltages on the Michigan Grid began to decline in order to support Northwest Ohio. At this time, Indiana was exporting 2300 MW to Michigan and Ontario was importing 500 MW from Michigan;
- Three minutes later, at about 1609, two more transmission lines went out and Northern Ohio became isolated from the rest of Ohio; The flow of power from Michigan to North Ohio jumped suddenly to 2200 MW (a jump of 2000 MW in less than 10 seconds!); Power flow on the Michigan – Ontario interconnection reversed, too; Michigan was then importing 200 MW from Ontario and also 3700 MW from Indiana; Voltages on the Michigan Grid declined more under the strain;
- About 30 seconds later, one power plant in mid-Michigan tripped and another one 15 seconds later, due to the declining voltage. As a result, 1800 MW went offline; This put more pressure on the network and voltage began to collapse starting in mid-Michigan;

- 30 transmission lines in Michigan went out of service in less than 8 seconds;
- Connections between Michigan Electric Transmission Company (METC), which is in charge of West and North Michigan, and International Transmission Company (ITC), which is in charge of South-East Michigan, opened, isolating ITC from the rest of Michigan; FE was still pulling power through Michigan, but the flow of power was now only possible through Ontario; Thus, flow of power from Ontario to Michigan suddenly jumped to 2800 MW affecting Ontario, New York and other states;
- During the next minute, nearly all generation units in south-East Michigan – in the vicinity of the border with Ontario – went offline; The Ontario system stayed interconnected to support both Michigan and Ohio for nearly 2 minutes, but then collapsed itself. By 1612, there was a blackout, which affected about 50 million people and about 62000 MW of electric load in the states of Ohio, Michigan, Pennsylvania, New York, Vermont, Massachusetts, Connecticut, New Jersey and the Canadian Province of Ontario.

NERC has made it clear that system operators have been at the centre of every blackout investigation since the 1965 Northeast blackout [4]. In almost every instance, had system operators taken appropriate actions, these blackouts would not have occurred. The August 14/2003 was no exception. For illustration, NERC summarised the investigations into past major blackouts as follows:

November 9, 1965 – Northeast U.S./Canada Blackout:

Summary of recommendations

- System control centres should be equipped with displays which provide the operator with as clear a picture of system conditions as possible;
- Coordinated programs of automatic load shedding should be established and maintained;
- Schedules for operator training and retaining should be administered.

July 13, 1977 – New York City Power Failure:

Summary of investigations

- The single most important cause of the power outage was the failure of the system operator to take necessary action;
- It is recommended to make a thorough reevaluation of the selection and training of system operators;
- A full-scale simulator should be made available to provide operating personnel with hands-on experience in dealing with possible emergency conditions.

July 2, 1996 – Western U.S. Blackout:

Summary of recommendations

- The need for a security monitor function to monitor operating conditions on a regional scale;

- The need for on-line load flow and stability programs and real-time data monitors;
- Review the current processes for assessing the potential for voltage instability and the need to enhance the existing operator training programs..

August 10, 1996 – Western U.S. Outage:

Summary of recommendations

- Coordination among regional members and with neighboring systems should be increased;
- Develop communications systems and displays that give operators immediate information on changes in the status of major components in neighboring systems;
- Strongly encourage operators to exercise their authority to take immediate action if they sense the system is starting to degrade;
- Train operators to make them aware of system conditions and changes.

NERC's investigations into the blackout of 2003 confirmed these findings, which were also endorsed by the U.S.-Canada Power System Outage Task Force [6]. The Task Force has basically summarised the causes of the Blackout's initiation into four groups, i.e. 'inadequate system understanding', 'inadequate situational awareness', 'inadequate tree trimming', and 'inadequate diagnostic support from reliability councils'. The Outage Task Force has explained these in their final reports as follows.

Cause 1:

FE and ECAR (First Energy's Reliability Council) failed to assess and understand the inadequacies of FE's system, particularly with respect to voltage instability and the vulnerability of the Cleveland-Akron area.

Cause 2:

Inadequate situational awareness at First Energy. FE did not recognise or understand the deteriorating condition of its system.

Cause 3:

FE failed to manage adequately tree growth in its transmission rights-of-way.

Cause 4:

Failure of the reliability organisations to provide effective real-time diagnostic support to system operators and control areas.

The Task Force has also compared the blackout on August 14, 2003 with previous major North American outages [6]. The Task Force has found that all these blackouts had several causes or contributory factors in common, including:

- Failure to identify emergency conditions and communicate that status to neighboring systems;

- Inadequate operator training;
- Inadequate vegetation management;
- Failure to ensure operation within secure limits;
- Inadequate regional-scale visibility over the power system;
- Inadequate coordinating of relays and other protective devices or systems.

New causal features of the blackout of 2003 include:

- Inadequate inter-regional visibility over the power system;
- Dysfunction of a control area's SCADA/EMS system;
- The lack of adequate backup capability to the SCADA/EMS system.

3. TASK FORCE RECOMMENDATIONS

The U.S.-Canada Power System Outage Task Force has provided a total of 46 recommendations for preventing future blackouts and reducing the scope of any that may occur. In order to have a general awareness of these recommendations, with an emphasis on the broad recommendations that may be applicable to other power grids, such as the Australian National Grid, only a summary of main points are provided in this paper.

The recommendations are classified in four groups, as follows.

3.1. GROUP 1 – INSTITUTIONAL ISSUES

The Task Force has 14 recommendations in this group. A summary of main points are as follows.

- Make reliability standards mandatory and enforceable;
- Shield operators who initiate load shedding from liability or retaliation;
- Integrate a 'reliability impact' consideration into the regulatory decision-making process;
- Establish an independent source of reliability performance information;
- Establish requirements for collection and reporting of data needed for post-blackout analyses;
- Expand the research programs on reliability-related tools and technologies;

3.2. GROUP 2 – ACTIONS REQUIRED

The Task Force has 17 recommendations in this group. A summary of main points are provided here as follows.

- Correct the direct causes of the blackout;
- Establish enforceable standards for maintenance of electrical clearances;
- Improve training and certification requirements for operators, reliability coordinators, and operator support staff;

- Establish clear definitions for normal, alert and emergency operational system conditions. Clarify roles, responsibilities, and authorities of reliability coordinators and control areas under each condition;
- Make more effective and wider use of system protection measures;
- Adopt better real-time tools for operators and reliability coordinators;
- Strengthen reactive power and voltage control practices;
- Improve quality of system modeling and data exchange practices;
- Re-evaluate the existing reliability standards development process;
- Tighten communications protocols, especially for communications during alerts and emergencies;
- Require use of time-synchronised data recorders;

3.3. GROUP 3 – CYBER SECURITY REQUIREMENTS

The Task Force has 12 recommendations in this group. A summary of main points are as follows.

- Develop and implement IT standards, IT management procedures, and IT security governance and strategies;
- Implement controls to perform network monitoring and incident management;
- Improve IT forensic and diagnostic capabilities;
- Establish clear authority for physical and cyber security;

3.4. GROUP 4 – NUCLEAR POWER SECTOR

The Task Force has 2 recommendations in this group.

- The requirement of installation of backup generation equipment for the nuclear power sector;
- Review of operating procedures and operator training associated with this sector.

As it is clear from the recommendations, roles of system operators and the requirement for proper training of them are evident.

4. BACKGROUND PROBLEMS

Some background problems that existed for a long time contributed to the blackout, too. .

4.1. RESTRUCTURING THE GRID

As correctly pointed out by the Consortium for Electric Reliability Technology Solutions in 1999, "The U.S. electric power system is in transition from one that has been centrally planned and controlled to one that will rely increasingly on competitive market forces to determine its operation and expansion. Unique features of electric power, including the need to match supply and demand in real time, the interconnection of the network through which power flows, and the rapid propagation of disturbances throughout the grid pose unique challenges for ensuring the reliability of the system" [7].

The disturbances of summer 1999 brought the critical situation to light and were the subject of a special investigation by the department of energy (DOE). Performed by 19 experts and the Post Outage Study Team (POST) identified many characteristic local elements, and also drew attention to fundamental commonalities [8].

In 2000, ICF Consulting mentioned, "Because of the structural changes in the operation of power systems, the current transmission system is being used in a way not intended by its design. Very little investment has been made to upgrade the grid over the past 25 years. There is a competitive pressure on existing transmission grid operations. The sometimes conflicting goals of providing reliability, moderating power prices, deferring transmission investments, and avoiding the economic liabilities associated with third-party power transactions can cause transmission operators to take greater risks with the grid than they would take in the past" [9].

The POST report also indicates that, "Inter-regional inter-connections are under greater pressure to supply emergency power when one or another region is short, as the transmission system itself continues to become increasingly constrained. Transmission capacity has remained flat in the most recent years, yet the number of transactions involving bulk transfers of electricity over transmission grid has soared astronomically. As the demand on the transmission system continues to rise, the ability to deliver remote resources to load centers will deteriorate. The transmission system is being subjected to flows in magnitudes and directions that have not been studied or for which there is minimal operating experience."

4.2. POWER SYSTEM EDUCATION

The prospects of the power system education had also declined substantially for at least a decade prior to the blackout of 2003. The long term impact of this decline is normally ignored in the investigations about power system blackouts. Professor Badrul Chowdhury, in his paper published in the IEEE Spectrum in 2000 wrote, "The electric power industry in the United States is facing a disquieting shortage of trained engineering personnel. For decades, things have gone downhill. The salaries paid to power engineers have been lower than those of virtually all other electrical engineers. Student enrolments have steadily declined. University programs have atrophied. Considering how excessively the prestige of power engineering has dropped in the United States, there is hardly any way to go but up." [10]

"Although power engineering has not retained the status it once enjoyed among students and the faculty who train them, it remains the lynchpin of a huge industry on which virtually all other industries rely. Reversing the trend of diminishing U.S. student interest in electric power will not be easy."

4.3. AVAILABILITY OF ON-LINE TOOLS

There is a need for sophisticated (dynamic) models of power systems to plan the operation of power systems during contingencies and to put stability constraints on

some parts of the network operation. Large interconnected systems require proper and accurate system simulation tools.

Power System Engineering Research Centre in a paper analysing the blackout events of 1996 stated, "The models that were used by the utilities in their planning studies before the blackouts were overly optimistic. When we carried out the simulations using the standard planning models, the model showed the system to be operating normally while the actual system had experienced the blackouts." [11]

5. CONCLUSIONS

Some main causes of the blackouts of large interconnected power systems have been reviewed in this paper. A summary of recommendations proposed by the North American Electric Reliability Council (NERC) and the U.S.-Canada Outage Task Force have been discussed. There is a common agreement among the experts that system operators have been at the centre of every blackout investigation since the 1965 Northeast American blackout. In almost every instance, had system operators taken appropriate actions, these blackouts would not have occurred.

Some background problems have also been pointed out. Especially, the importance of power system education and its long-term impact on the management and operation of power systems has been discussed.

It is suggested that the power system operators in Australia review the causes of the blackouts of interconnected power systems elsewhere and also review the recommendations made by the professional organisations for preventing such blackouts from happening. Then, they should implement some of the relevant recommendations, especially those that are related to the planning and development of the network.

REFERENCES

- [1] N. Hossein Zadeh and A. Kalam, "The Blackouts of the Power Grid of North America – A Review", The International Conference PowerCon 2003 – Special Theme: Blackout, IASTED, New York, USA, 10-12 December 2003, pp 81-86.
- [2] B. McCaw, "The great blackout", *Power Engineering*, December 1965, 36A–36C.
- [3] U.S.-Canada Power System Outage Task Force, "August 14, 2003 Outage Sequence of Events", September 12, 2003.
- [4] North American Electric Reliability Council, "A review of system operations leading up to the blackout of August 2003", 12 January 2004.
- [5] International Transmission Company (ITC), "Analysis of Grid Collapse", 20 August 2003.
- [6] U.S.-Canada Power System Outage Task Force, "Final Report on the August 14, 2003 Blackout in the United States and Canada", April 2004.
- [7] Consortium for Electric Reliability Technology Solutions, "Grid of the future white papers – Project executive summary", Prepared for *the Office of Power Technology, U.S. Department of Energy*, December, 1999.
- [8] Report of the U.S. Department of Energy's Power Outage Study Team, "Findings and recommendations to enhance reliability from the summer of 1999", Final Report, March 2000.
- [9] ICF Consulting, "Cascading blackout: why wasn't the power outage contained?", 19 August 2003.
- [10] B. H. Chowdhury, "Power education at the crossroads", *IEEE Spectrum*, *WEBONLY*, October 2000.
- [11] M. V. Venkatasubramanian, "Analyzing blackout events: experience from the major western blackouts in 1996", *Power System Engineering Research Center (PSERC) Background Paper*, August 20, 2003.