The Useful Blackouts

The undisturbed supply of electricity depends on efficient operational strategies. The strategies should be updated concurrently with power system development. The current transition of many power systems into renewable and non-dispatchable production could be a reason for reconsidering and updating system security strategies.

Blackout Lessons Ignored

Most blackouts are followed by a report with observations, analyses and recommendations. In some cases the event causes an update of the operating rules, not only for the power system concerned, but for several other systems ready to share the experience. This is an essential reason for the high security of supply in most countries today.

In most cases it is possible to show that ignoring some previous recommendations has caused the event. Sitting afterwards at a desk identifying neglects is the easy part. However, for a system operator blackouts are so rare that reconsidering operating rules always seems to be less urgent. Besides, it can be a comprehensive and expensive procedure to implement and follow all rules and recommendations.

The transmission system is an infrastructure which is supposed to be efficiently utilised. Approaching capacity limits means reducing security margins and increasing risk of power failures. Therefore power system operation must be a balance on a knife edge between security and efficiency. New blackouts will occur sooner or later.

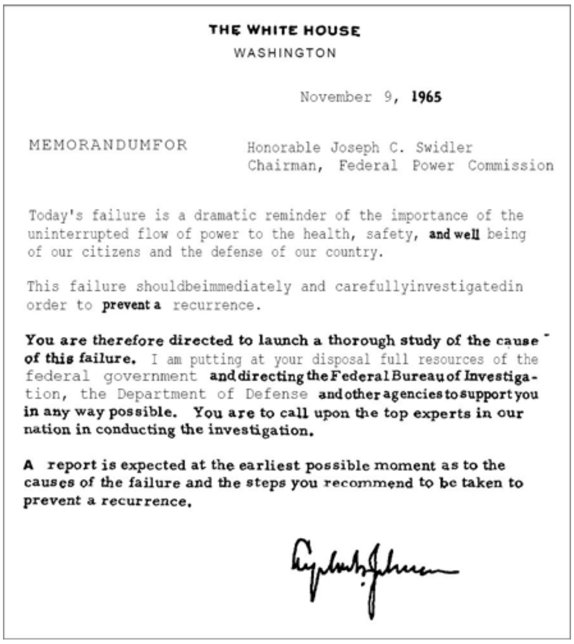
In this text these mechanisms will be demonstrated by some selected blackouts.

The Great Northeast Blackout, USA 1965

On 9th November 1965 at 5:16 pm power supply was cut off for 30 million people in the Northeastern United States and Ontario.

On the same day President Lyndon B. Johnson sent a letter to the chairman of Federal Power Commission (FPC), Joseph C. Swidler:

"Today's failure is a dramatic reminder of the importance of the uninterrupted flow of power to the health, safety, and well being of our citizens and the defense of our country.
- - -
A report is expected at the earliest possible moment as to the cause of the failure and the steps you recommend to be taken to prevent a recurrence."


THE WHITE HOUSE
WASHINGTON

November 9, 1965

MEMORANDUMFOR Honorable Joseph C. Swidler
Chairman, Federal Power Commission

Today's failure is a dramatic reminder of the importance of the uninterrupted flow of power to the health, safety, and well being of our citizens and the defense of our country.

This failure shouldbeimmediately and carefullyinvestigatedin order to prevent a recurrence.

You are therefore directed to launch a thorough study of the cause of this failure. I am putting at your disposal full resources of the federal government and directing the Federal Bureau of Investigation, the Department of Defense and other agencies to support you in any way possible. You are to call upon the top experts in our nation in conducting the investigation.

A report is expected at the earliest possible moment as to the causes of the failure and the steps you recommend to be taken to prevent a recurrence.

FPC's preliminary report was ready one month later [1]. The report states:

"Our study shows, first, that the cascading of the failure was not inevitable and should not recur if the precautions we recommend are observed – and most of them are already being implemented by the industry; and, second, that well-integrated power pools add strength and reliability to service from all

the interconnected systems. The so-called CANUSE network, within which the failure occurred, is not yet such an integrated power pool."

The initial event was the tripping of a line caused by a backup relay at Ontario Hydro's Beck power station. The backup relays had two functions and in order to serve both purposes they were set to disconnect at loads very close to the actual loads. Therefore there was an increased risk that a line would trip during the peak hour.

However, the real problem was that the tripping of a single component was able to cause a cascade of outages.

Besides, the failure and the long restoration process revealed massive problems in coordination, operating reserves, protection, and communication.

Course of events:

- On 9th November 1965 at 5:16 pm a backup relay at the Beck power station of Ontario Hydro disconnects a circuit supplying loads in the Toronto area.
- In a total of about 2½ second 4 remaining circuits to the north are successively disconnected for overload.
- Cascading outages of power lines
- The New York state backbone transmission system breaks up due to transient instability.
- Widespread load disconnections between 5:16 and 5:30 pm
- Last restoration of normal service next day at 7:00 am

The recommendations of the commission were "partial and tentative". In July 1967 FPC published a comprehensive report in three volumes [2]. The introductory letter to the President mentions the view that the interconnection of power systems itself implies an unreasonable risk of cascading outages. FPC says:

"The key lesson of the Northeast failure and the subsequent cascading outages, we believe, is that these interconnections and the coordination of diverse systems must be strong in order to be effective."

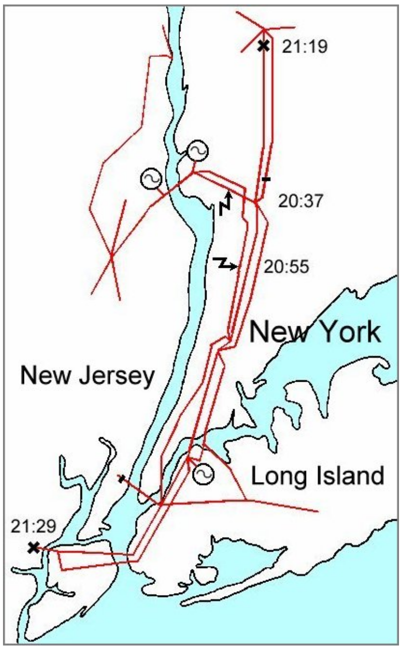
The letter also refers to the proposed "Electric Power Reliability Act of 1976". The bill would authorize the FPC to play a role in accomplishing a number of the recommendations of the report. The 34 recommendations are divided among

- Formation of Coordinating Organizations
- Interconnected System Planning
- Interconnected System Operating Practices
- Interconnected System Maintenance Practices
- Criteria and Standards
- Defense and Emergency Preparedness
- Manufacturing and Testing Responsibilities
- Increased Need for Technical Proficiency
- Power System Practices in Other Countries

Due to the comprehensive documentation the recommendations proved to be a list of useful guidelines for planning and operation of power systems, not only in USA, but also in several other countries.

National Electric Reliability Council (NERC) was established by the electric utility industry, in response to the 1965 blackout. Nine regional reliability organizations were formalized under NERC. Also formalized were regional planning coordination guides, which NERC maintained. Operations criteria and guides were maintained and practiced voluntarily.

The Con Edison Power Failure, USA 1977



On 13th July 1977 at 8:37 pm, during a thunderstorm, lightning struck two 345 kV circuits at the northern extreme of Con Edison's service area. At 8:56 pm two more lines were struck. Due to imperfect protection 3 systems of the 4 circuits remained open. The loss of transmission capacity left the New York City area without sufficient resources for maintaining the supply. The operators struggled for nearly an hour for keeping the lights on, but at 9:36 pm the Con Edison system was completely shut down.

9 million people were affected. The restoration took 25 hours.

A combination of the seriousness of the initial faults, equipment malfunctions and operator errors was the main reason for the magnitude of the power failure.

A report from the Federal Energy Regulatory Commission (FERC) was published in June 1978 [3]. The observations included "the usual neglects":

- improper relay circuit design
- equipment malfunctions
- operator failures:
    - failure to realize the unavailability of critical interconnection
    - failure to assure scheduled generator reserve
    - failure to pay attention to short-time ratings of critical facilities
    - failure to call for increased generation promptly
    - failure to shed load in response to repeated advice or directives
- delayed restoration:
    - insufficient pressure of insulating oil of underground transmission cables
    - inability to start generators designed for start without external power
    - difficulties in maintaining voltages within safe limits
    - damage to equipment due to attempt to rapid restoration
    - instances of inadequate coordination of restoration efforts

In the recommendations increased importance has been attached to operator training, load shedding and restoration.

It is difficult to prepare power system operators for extreme situations which most operators will never experience. Furthermore, the training must be maintained in order to have all necessary measures ready for very rare contingencies.

During an emergency there is an enormous strain on the operators. The report includes transcripts of telephone conversations from tapes in selected control centers. The conversations give an interesting insight in the situation of the operators while struggling to understand the situation and to find resources for restoration of normal operating conditions.

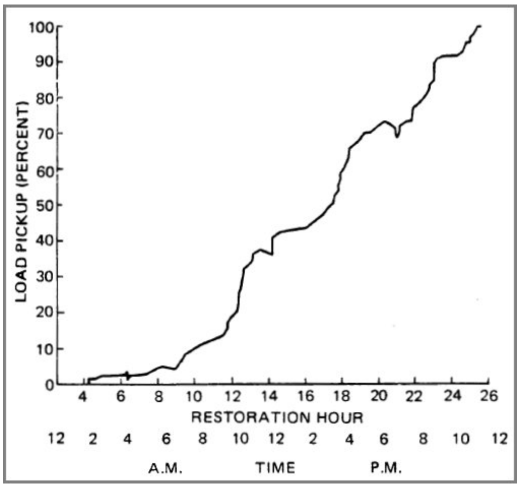
The failure to perform a manual load shedding in this case is enigmatic. The frequency was normal until the very last minutes when the automatic load shedding proved to be insufficient. The failing manual load shedding was never explained:

20:56:54	NYPP SPD	Bill, you better shed some load until you get down below this thing because I can't pick anything up except from the north, see?
	CE SO	Yeah.
	NYPP SPD	So, you'd better do something to get rid of that until you get yourself straightened out.
	CE SO	I'm trying, I'm trying.
	NYPP SPD	OK, fine.
20:59:15	CE SO	Yeah, Bill.
	NYPP SPD	Bill, I hate to bother you, but you'd better shed about 400 MW of load or you're going to lose everything down there.
	CE SO	Bill, I'm trying to.
	NYPP SPD	You're trying, all you got to do is hit the button there and shed it and then you worry about it afterwards, but you got to do something or they're going to open up that Linden tie on you.
	CE SO	Yeah, right. Yeah, fine.
21:02:22	NYPP SPD	Hello.
	CE SO	Look any better?
	NYPP SPD	No. You still got to get rid of about 400, Bill, because you're 400 over the short-time emergency on that 80 line.
	CE SO	Yeah, that's what I'm saying. Can you help me out with that?
	NYPP SPD	I can't do nothing because it's got to come from the lower part of the State, and there's nothing there to help you with. You got to do it in—
	CE SO	There's no GT to put on because they went home.
	NYPP SPD	OK, then you're going to have to shed load because that's the only way that thing is going to save you til you get them . . . things on because I told Long Island to pick up everything he had, and that's the only place that I can get into you.
	CE SO	Can you help me?
	NYPP SPD	There's no way I can help you, see? OK, Will?
21:27:08	CE PD	Yes, sir, Bill.
	NYPP SPD	OK, I'm going to tell you one more time. If you don't shed about 600 MW of load immediately—.
	CE PD	He's doing it as fast as he can, pal.
	NYPP SPD	All you got to do is punch a button to get rid of it.
	CE PD	That's what he is doing, right now.
	NYPP SPD	Shed 600 MW immediately or you'll lose that Linden and you're out of business. That's the only thing you have left, John.
	CE PD	I know that.
	NYPP SPD	OK, fine.
	CE PD	Right.

These extracts of the conversation between New York Power Pool Senior Power Dispatcher (NYPP SPD), Con Edison System Operator (CE SO) and Con Edison Power Dispatcher (CE PD) are illustrative. Was CE SO paralyzed?

The report stresses three main problems in restoring a power system which is completely closed down:

1. The system must be synchronized with neighboring systems through interconnections.
2. Time must be allowed for large steam turbine generators to be brought up to full output.
3. The generator output must be matched by gradually increasing the connected load.



An attempt at rapid restoration with a limited sectionalizing of the grid was made immediately after shutdown. The attempt was unsuccessful due to overload of major transmission facilities.

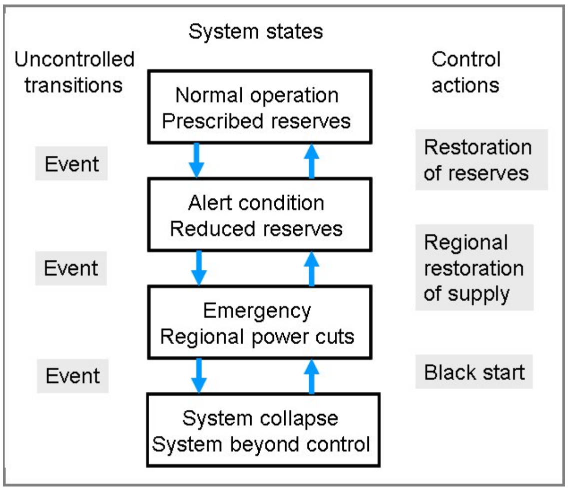
A number of “black start” combustion-turbine generators did not perform as expected. As a result the early parts of the plan took longer to implement than expected, and the first significant customer load pickup did not occur until shortly before 2:00 am on 14th July.

Difficulties continued. A reasonably steady load pickup did not begin until about 10:00 am, more than 12 hours after the initial events).

New Operating Strategies in the Wake of the Con Edison Blackout
Blackout recommendations are based on hindsight. Meeting all requirements in daily operation can be both difficult and expensive. The recommendations must be transformed into a strategy for power system operation.

In 1978 seven articles in IEEE Spectrum (the "blackout series" [4]) gave an overview of the course of a blackout and laid down principles, which still form the basis of power system development in many countries.

The second article by Lester H. Fink and Kjell Carlsen defines possible system states together with uncontrolled events causing transitions into a worse state and possible control actions in order to improve the situation.

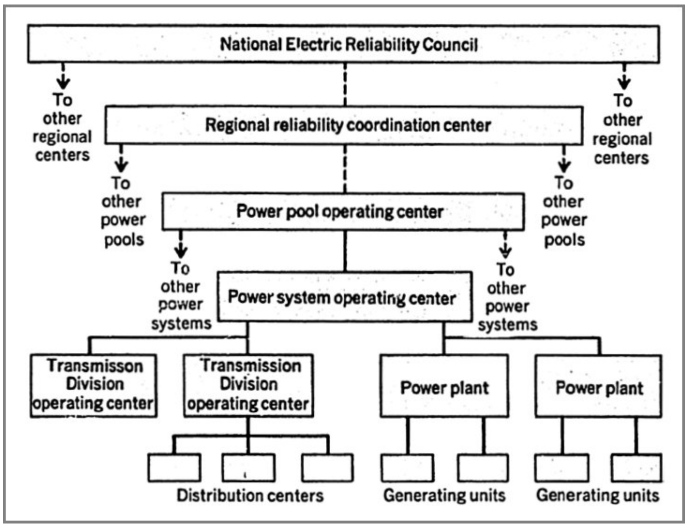


It is important to analyze initial situations together with more or less likely events in order to understand the risk of transitions into less safe states.

The events can be anything from sudden disturbances to effects of design errors and imperfect equipment.

The control actions must be carefully prepared and the staff must be regularly trained in carrying out the actions.

A clear distribution of responsibilities is a decisive factor. The third article by Donald N. Ewart defines a control hierarchy.



The structure is clear and simple. Nevertheless, later blackouts have demonstrated that the structure has not been properly implemented.

For instance, the interconnected AC system in the European continent has been extended several times without the establishment of a corresponding control level.

Visions for the future were presented by Fred C. Schweppe in the article "Power systems '2000': hierarchical control strategies". The visions include more customer generation and/or energy storage, including solar heating, cogeneration, and eventually solar photovoltaic, the energy marketplace, environmental considerations of air and thermal pollution, increased weather dependence, models for forecasting weather and environmental impacts, mathematical models that approximate actual behavior of power plants, loads, etc., in real-time operation and data-network communications and mini- and microcomputer technology.

Fred Schweppe's vision for the energy marketplace demonstrates how far-sighted he was:

The energy marketplace

The utility's role in furnishing power, the customer's attitude toward the use of power, and the nature of electric power control systems are closely coupled and interrelated. A major shift in the relationships that exist among these three will occur by 2000 with the establishment of the "energy marketplace." Today the relationship between customer and utility is one of master to slave. The customer is the master who demands power from the utility, his slave. The slave is expected to provide as much power as the master wants, any time the master wants it. The control systems reflect this relationship because they are designed to help the slave do everything possible to meet the master's demands. When control systems push the slave beyond its limits, the slave collapses and the master is left on his own. Unfortunately, in our present society, the customer has become so dependent on the utility that the master is not able to function without the slave.

But by 2000, the relationships between the customer, the utility, and the control systems will have changed significantly. By then, the utilities and customers will be equals who deal with each other through the energy marketplace.

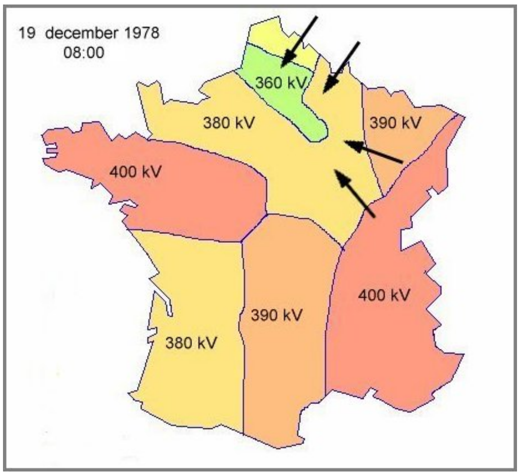
The utility's generation and storage systems will offer power for sale to the customers, and customers will buy most of their power from the utilities. However, some customers will generate their own power and offer any extra for sale. All of these transactions will take place via an energy marketplace, which will consist of the transmission/distribution grid that does the "physical" distribution, and the control systems that enable the "market transactions" to take place. Thus, in addition to providing central-station generation and storage facilities, utilities will also maintain the energy-marketplace mechanism. The energy-marketplace economics will operate both long-term contracts (where the rate is prespecified for one to two years in advance and depends on time of day, season of year, energy use, and peak demand) and spot-price rates (which are not specified in advance, and depend on actual market conditions as determined by demand, plant outages, and weather, on an hour-by-hour basis). There will be long-term contracts and spot contracts for both buying from and selling to the grid (marketplace). There will also be the interruptible versions of both kinds of rates, interruptible rates for buying power will be lower because the utility has bought—by applying lower rates—the right to disconnect part of the customer's load when it chooses.

The ability to build sophisticated control-communication systems is necessary for the energy-marketplace concept to work, and the evolution of that concept will have a major impact on the control systems. Relative to blackouts, the key change is in the ability of the utility to exercise load control ("soft" load control via the economics of spot pricing or "hard" load control via the disconnecting of interruptibles).

Fred Schweppe 1978

Fred Schweppe also presented a list of controversial issues. The dilemmas are still valid. Therefore his "Anatomy of a blackout: 2001" is also remarkably realistic.

Voltage Collapse in France 1978

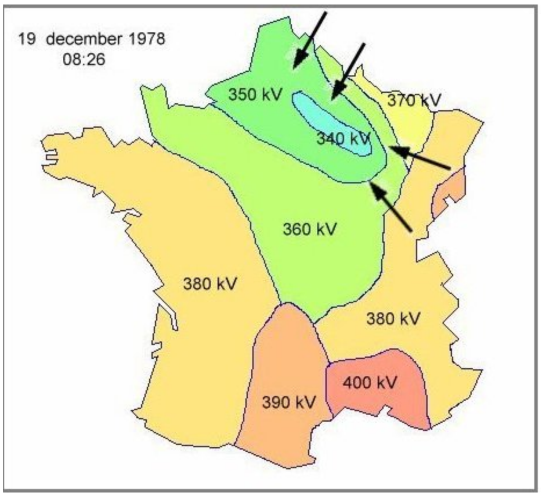


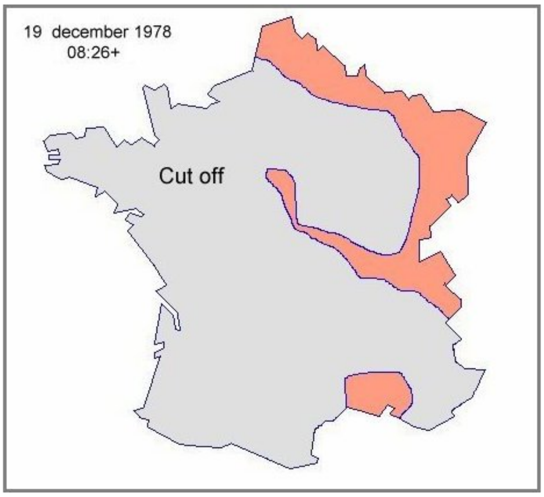
The French voltage collapse on 19th December 1978 is different from the previous cases in the sense that an initial event cannot be identified. The problems are developing gradually and it is difficult to tell when a control action must be taken.

At 08:00 there was a heavy flow of electricity from north and east toward Paris. The voltage of the transmission grid was low in the capital area.

At 08:06 there was an overload warning for the 400 kV line Bézaumont-Creney east of Paris

The morning peak would soon be over and the grid conditions would turn into something more comfortable. An intervention would require a manual load shedding in the capital area.





Decreasing voltages mean increasing currents. At 08:26 the voltage had decreased another 20 kV and protecting relays disconnected the overloaded 400 kV line Bézaumont-Creney. The disconnection started a cascade of disconnections and within seconds 75% of the French electricity demand was cut off.

The reconnection of customers took between 30 minutes and 10 hours.

The blackout was caused by the lack of intervention in due time. It is a heavy burden for an operator to be responsible for a decision on manual load shedding. In order to relieve that burden the best policy seems to be very clear operating procedures requiring a specified manual load shedding at predefined minimum voltages.

The San Francisco Bay Cutoff 2000

This type of procedure was in force in California on 14th June 2000 when very low voltages occurred in the San Francisco Bay area. The service interruptions were limited to 97,000 consumers for between 65 and 82 minutes.

Though this case was handled perfectly and according to rules Pacific Gas and Electric Company and California Independent System Operator (CAISO) were publicly blamed for the interruption.

U.S.-Canada Power System Outage 2003

On 14th August 2003 temperatures were hot but in a normal range throughout the northeast region of the United States and in eastern Canada. Several large operators in the Midwest consistently under-forecasted load levels. Unavailability of certain critical reactive resources within the Cleveland-Akron area was not known at MISO[1].

From noon the lack of resources created grid problems, but due to a software bug FE[2] did not realize until late that anything was wrong. Between 14:02 and 16:05 several 345 kV lines tripped after tree contact.

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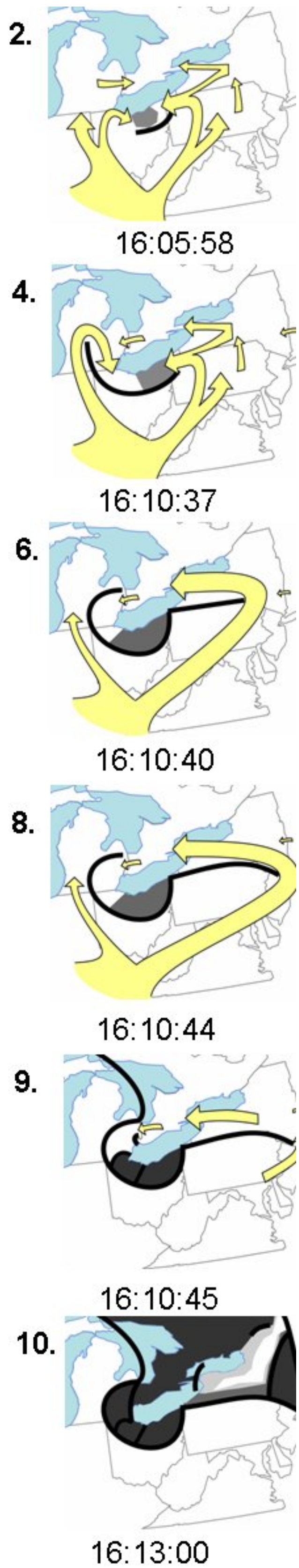
[1] Midwest Independent Transmission System Operator
[2] FE: First Energy (energy company, based in Akron, Ohio)

After 16:05 interruptions occurred in the Cleveland area.



As more lines tripped for overload the flow had to find new and longer paths, voltages decreased, currents increased, and after a few minutes cascading outages caused a blackout in an area with an estimated 50 million people and 61,800 megawatts (MW) of electric load in the states of Ohio, Michigan, Pennsylvania, New York, Vermont, Massachusetts, Connecticut, New Jersey and the Canadian province of Ontario.

A joint US-Canada task force published a final report [5] in April 2004. The long list of causes is organized in four groups:

1 Inadequate System Understanding
- A FE failed to conduct long-term planning studies and extreme condition assessments.
- B FE did not conduct sufficient voltage analyses for its Ohio control area.
- C ECAR[3] did not conduct an independent review or analysis of FE's voltage criteria and operating needs.
- D Ambiguous NERC rules were leniently interpreted by FE.

2 Inadequate Situational Awareness
- A Inefficient contingency analysis capability at FE.
- B FE unable to check functional state of critical monitoring tools
- C Lack of effective internal communications procedures between computer support staff and operations staff at FE
- D FE unable to test functional state of critical monitoring tools after repair
- E Lack of backup monitoring tools at FE

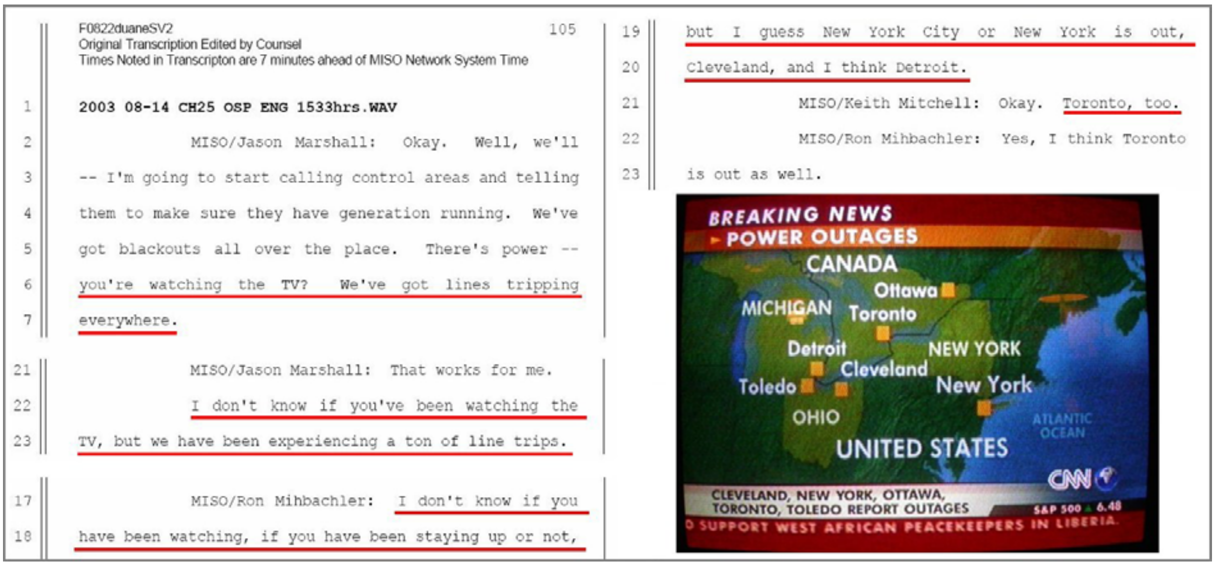
3 Inadequate Tree Trimming

4 Inadequate RC Diagnostic Support
- A MISO's state estimator did not have real-time data from the Stuart-Atlanta 345-kV line.
- B MISO's reliability coordinators were using non-real-time data to support real-time "flowgate" monitoring.
- C MISO lacked an effective way to identify the location and significance of transmission line breaker operations reported by their Energy Management System.
- D PJM[4] and MISO lacked joint procedures or guidelines on when and how to coordinate a security limit violation.

A remarkably large part of the neglects were found at FE (First Energy), but also neglects at MISO (Midwest Independent Transmission System Operator) played a decisive role.

[3] ECAR: East Central Area Reliability Council
[4] PJM Interconnection

Grid operators are supposed to have very robust monitoring equipment and a very good overview of their grids. It is obvious from the telephone transcripts that MISO had to rely on the TV stations for information on the power system condition.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2003 08-14 CH25 OSP ENG 1533hrs.WAV

MISO/Jason Marshall: Okay. Well, we'll -- I'm going to start calling control areas and telling them to make sure they have generation running. We've got blackouts all over the place. There's power -- you're watching the TV? We've got lines tripping everywhere.

MISO/Jason Marshall: That works for me. I don't know if you've been watching the TV, but we have been experiencing a ton of line trips.

MISO/Ron Mihbachler: I don't know if you have been watching, if you have been staying up or not, but I guess New York City or New York is out, Cleveland, and I think Detroit.

MISO/Keith Mitchell: Okay. Toronto, too.

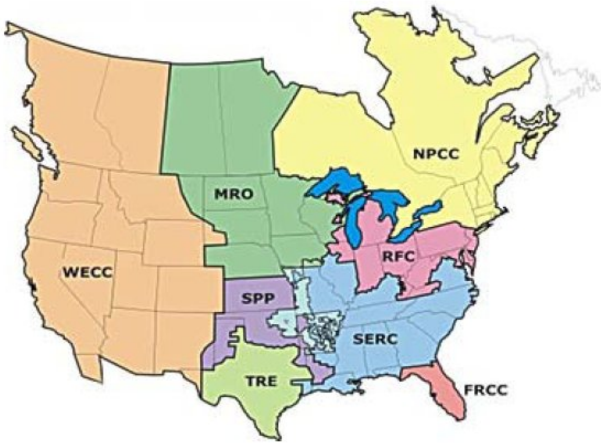
MISO/Ron Mihbachler: Yes, I think Toronto is out as well.

The task force presented 46 recommendations organized in four groups:

1. Institutional Issues Related to Reliability
2. Support and Strengthen NERC's Actions of February 10, 2004
3. Physical and Cyber Security of North American Bulk Power Systems
4. Canadian Nuclear Power Sector

NERC's[5] Readiness Audit Program

One outcome of the 2003 blackout was NERC's Readiness Audit Program which was planned to ensure that operators of the bulk electric system had the tools, processes, and procedures in place to operate reliably. The evaluations were conducted on a three-year cycle. Each round was supposed to include all balancing authorities, transmission operators, reliability coordinators, and other entities that support the operation of the bulk power system in North America.



In 2007, there was a shift from voluntary compliance with industry-developed reliability standards to mandatory compliance with FERC-approved NERC Reliability Standards in the United States. NERC and the industry have transformed decades of industry criteria, guides, policies, and principles into mandatory and enforceable NERC Reliability Standards.

Every year NERC presents an annual report

[5] NERC: Now North American Electric Reliability Corporation

with results of the Compliance Monitoring and Enforcement Program (CMEP). It describes a wide range of NERC activities with the purpose of keeping every responsible body in compliance with the current NERC rules.

This work is important to the complex North American power systems with eight reliability councils and numerous control areas. In Europe the corresponding work is conducted by ENTSO-E.

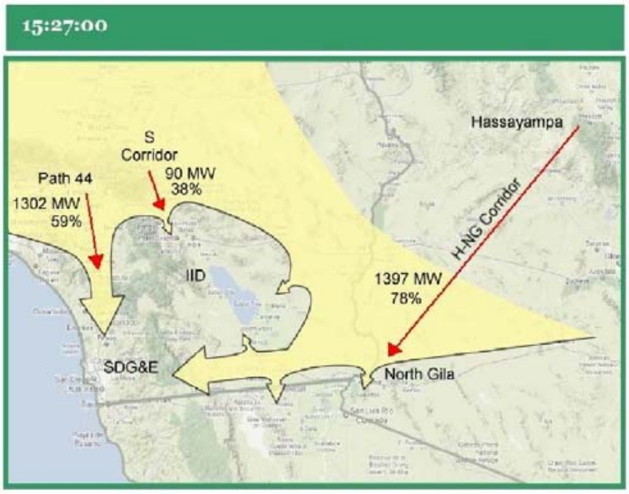
The San Diego Blackout 2011

The blackout on 8th December 2011 affected the following areas: San Diego Gas & Electric (SDG&E), Comisión Federal de Electricidad (CFE), Imperial Irrigation District (IID), Arizona Public Service (APS) and Western Area Power Administration – Lower Colorado (WALC).

Interruptions of service were between 6 and 12 hours.

The Bulk Power System in the western part of North America is coordinated by WECC (Western Electricity Coordinating Council).

The power systems concerned are planned and operated in accordance with current operating standards. Nevertheless a routine switching to isolate a capacitor bank could start cascading outages which after 11 minutes had caused the loss of nearly 8 GW load. The investigation report [6] explains the complex combination of circumstances which undermined the defence lines of the operational security.



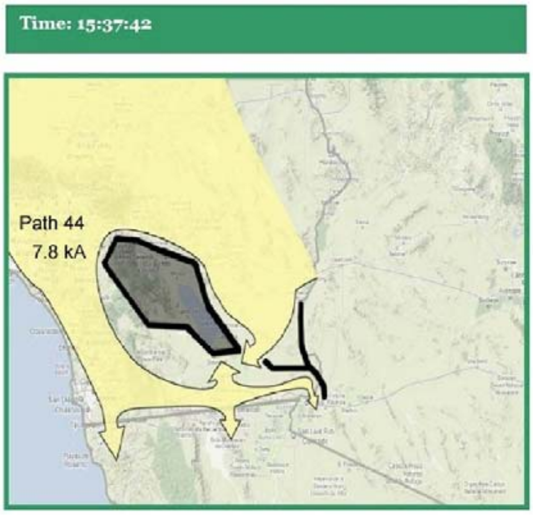
September is generally considered a "shoulder" season, when demand is lower than peak seasons and generation and transmission maintenance outages are scheduled.

8th September was a rather normal, hot day. The SDG&E import was 2539 MW or 89% of system operating limits. The transport corridors were operated well within safe limits.

The initiating event was a routine switching to isolate a capacitor bank at North Gila in Arizona. The switching was carefully planned. The technician had completed step 6, but was distracted by other communication and wrote the time on the line for step 8 in his check list. Therefore he skipped two steps and continued with step 9. The result was an arc over the switch and the automatic disconnection of the 500 kV line Hassayampa-North Gila (H-NG).

After the disconnection of H-NG the flows were redistributed. Flow on path 44 increased by 84% to 2,362 MW or 5.9 kA. At 8.0 kA the SONGS[6] separation scheme would be initiated.

Some transformers and capacity banks tripped for overload. During this phase the current on path 44 peaked at 7.8 kA, but stabilised at 7.2 kA.



CAISO (California Independent System Operator) attempted to bring path 44 back within its limit of 2,500 MW by redispatch. It would have taken 30 minutes.

About 8 minutes after H-NG tripped two 161/61 kV transformers tripped in the Yuma area. The path 44 current increased to 7.4 kA.

Several other lines and generators tripped and at 8.0 kA the SONGS separation scheme operated (11 minutes after H-NG tripped). The operation effectively separated SDG&E from the rest of the Western Interconnection. It created an island consisting of the SDG&E system, the remaining Yuma-area load, and CFE's California Control Area.

The SDG&E/CFE/Yuma island had a significant imbalance between generation and load. The activation of the Under Frequency Load Shedding (UFLS) programs was not able to prevent the island from collapsing.

A selection of the 27 findings in the San Diego blackout investigation report is presented below.

No	Finding	Comment
1	Failure to Conduct and Share Next-Day Studies	It is important to analyze system security for each time step of the day-ahead planning, but it is equal important to share the details with neighboring system operators. This problem has also been an issue for disturbances in Europe.
2	Lack of Updated External Net-works in Next-Day Study Mod-els	As above: is the data on neighboring grids sufficient and updated every day?
3	Sub-100 kV Facilities Not Ade-quately Considered in Next-Day Studies	In West Denmark we avoided parallel loops via 60 kV grids. The cost of this policy was a small risk of brief local inter-ruptions of service.
6	External and Lower-Voltage Facilities Not Adequately Con-sidered in Seasonal Planning Process	Shortage of reactive resources plays an important role in practically every blackout.
8	Not Sharing Overload Relay Trip Settings	This problem was decisive in the European power failure in November 2006.

[6] SONGS: San Onofre Nuclear Generation Station

11	Lack of Real-Time External Visibility	“External” could be neighboring systems or local sub-100 kV systems
12	Inadequate Real-Time Tools	The tools should be adequate “and run frequently enough to provide their operators the situational awareness necessary to identify and plan for contingencies and reliably operate their systems”
13	Reliance on Post-Contingency Mitigation Plans	This case is interesting because the contingency was considered, but the mitigation plan was based on manual procedures for which the time was insufficient in this case.
17	Impact of Sub-100 kV Facilities on BPS (Bulk Power System) Reliability	It is the most robust solution to avoid parallel loops in the sub-100 kV systems. If such loops cannot be avoided they should be efficiently included in the seasonal and daily planning and in the real time control. This measure could have prevented the collapse.
18	Failure to Establish Valid SOLs (System Operating Limits) and Identify IROLs (Interconnection Reliability Operating Limit)	The investigation team says that the cascading events show that an IROL was violated on 8 September, but not recognized by WECC.
24	Not Recognizing Relay Settings When Establishing SOLs	Some protective relays were set to trip below the established emergency rating. The transformers concerned tripped during the restoration process and delayed the restoration to the Yoma load pocket.
25	Too Narrow Margin Between Overload Relay Protection Settings and Emergency Rating	A narrow margin between emergency rating and overload relay protection setting does not allow the operator time to take relevant control actions. Both CV transformers tripped at 127% of their normal rating.[7]
27	Phase Angle Difference Following Loss of Transmission Line Not Measurable	WECC was informed that H-NG line would be restored quickly. However, due to a 72 degrees phase angle difference this was not possible because the synchro-check relay was set at 60 degrees. The problem was that the operator had no idea of the phase angle. The case suggests widespread use of PMUs (Phasor Measurement Units).

The discussion does not include design of equipment. The fatal operation of the disconnect switch at the capacitor bank could have been blocked if essential conditions for the operations were not fulfilled. It is an open discussion to which degree such preventing precautions should be installed, but the investigation report does not mention the question.

The same neglects as in 2003

On August 14, 2003, the Midwest and Northeast United States and Ontario, Canada, experienced an electric power blackout.

Appendix C of the San Diego investigation report is an interesting comparison of the two events. It concludes:

> “First, affected entities in both events did not conduct adequate long-term and operations planning studies necessary to understand vulnerabilities on their

[7] PRC-023-1 R.1.11 requires relays to be set to allow the transformer to be operated at an overload level of at least 150% of the maximum applicable nameplate rating, or 115% of the highest operator established emergency transformer rating, whichever is greatest.

> systems. Second, affected entities in both events had inadequate situational awareness leading up to and during the disturbances. In addition to these two underlying causes, both events were exacerbated by protection system relays that tripped facilities without allowing operators sufficient time to take mitigating measures."

The detailed comparison of findings is alarming evidence that previous recommendations to a large extent have been ignored.

50 Years' Experience

In 1965 President Johnson would prevent a recurrence of the Great Northeast Blackout. He did not succeed.

The large AC power systems are vulnerable. A delicate balance between demand and supply must be maintained every second. The rare occurrence of blackouts demonstrates that the first lines of defence (spinning reserves and N-1 grid redundancy) are efficient in most power systems.

However, black start capabilities and procedures (the last line of defence) have often proved to be inefficient. It was for instance the case in East Denmark and in Italy in 2003.

Officially all power systems maintain a high security standard, but a NERCC audit on the European power systems could be an interesting experiment.

It is hard to justify the cost of facilities and staff for observing all rules and for the ability to conduct a black start when an average power system experiences less that one blackout per decade. Therefore the current security levels could be considered as reasonable from a socio economic point of view.

The system operators will face new challenges from the massive introduction of un-dispatchable power plants (wind turbines) in several countries. We have not yet seen the last blackout.

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