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Date: August 18, 2003

To: McCullough Research Clients

From: Robert McCullough

Subject: A Matter of Seconds

At 6:30 P.M. Thursday, approximately 71,000 megawatts were interrupted.[1] We have almost no way to know how many individual Americans and Canadians lost their power to a massive cascading failure across Ontario, New York, Pennsylvania, New Jersey, Ohio, and Michigan, but a logical estimate would be on the order of 29 million.[2] New York City has estimated the economic cost as $1 billion. While a substantial effort will go into examining the incident, the fact is that FERC's new institutions, the centralized institutions of the Midwest ISO, New York ISO, New England ISO, and PJM (Pennsylvania, New Jersey, and Maryland), bore the brunt of the problem. Just as in the market failure of California, a number of utilities not involved in FERC's restructuring experiment were unaffected by the blackout.[3] The question that should be raised in New York is the same as that raised two years ago in California – is the centralization of the electric system good public policy?

The very preliminary indications that a series of problems in the Midwest ISO may have precipitated

[1] August 14, 2003 Power Outages, Update 8/15/2003, 12:00 a.m., North American Electric Reliability Council.
[2] NERC's 2003 summer assessment estimates a summer peak of 783,735 megawatts. This serves approximately 323 million U.S. and Canadian customers.
[3] When I appeared on NPR on August 15, 2003, the mayor of one of the cities served by municipal electric systems in Ohio mentioned that he was gratified that the blackout had spared his system, although he was fairly sure he was not the hero who had kept the lights on. In fact, he might well have been the hero who chose not to delegate his city's reliability planning to an Independent System Operator.

failures in the neighboring ISOs in Ontario and PJM and these in turn may have passed on the failure to the New York and the New England ISOs. If so, the blackout is unlikely to have been an engineering problem per se. Sequential failures at these new institutions would point to problems in communication and collaborative planning, not merely equipment failure.

A number of commentators have mentioned the speed of the incident. Electricity moves at the speed of light - 186,000 miles a second. Once a failure occurs, no computer currently available can react quickly enough to forestall the problem. Our solution is to contain the problem by shutting down transmission lines from the affected area. In theory, this means that a blackout is always a local event. The significance of the August 14th incident was not its speed, but its distance – the blackout affected states across the upper tier from Michigan to New York. Prudent planning should have localized the incident in the control area where it began. An ineffective response would have caused blackouts in neighboring control areas. On August 14th, blackouts apparently bridged four control areas. A blackout in one area is an equipment failure. A blackout in four control areas is a policy issue.

The 2003 Blackout

The North American Electric Reliability Council indicates that the blackout started at 4:11 P.M. EDT with lost loads of:[4,5]

PJM Interconnection	4,000	MW
Midwest ISO	18,500	MW
Hydro Quebec	100	MW
Ontario IMO	21,000	MW
ISO New England	2,500	MW
New York ISO	24,400	MW
Total	70,500	MW

A substantial amount of effort has been spent attempting to find the specific engineering source of the failure. As of this moment, the most authoritative information is from the NERC Preliminary Disturbance Report that cites a report of line and plant failures by the Midwest ISO:[6]

14:06 Chamberlain – Harding 345 kV line tripped – cause not reported
14:32 Hanna – Juniper 345 KV line sagged and tripped.
14:41 Star – S. Canton 345 KV line tripped

[4]NERC's August 14, 2003 Updated reported 61,800 MW lost, but the values cited add to 70,500.
[5]PJM serves the Pennsylvania, New Jersey, Maryland area. The Midwest ISO serves Michigan, Indiana, and Ohio.
[6]Preliminary Disturbance Report: August 14, 2003 Sequence of Events, NERC, August 15, 2003.

14:46 Tidd - Canton Ctrl 345 KV line tripped
15:06 Sammis – Star 345 KV line tripped and reclosed
15:08 Power swings noted in Canada and Eastern US.
15:10 Campbell # 3 Tripped ??[7]
15:10 Hampton – Thetford 345 KV line tripped
15:10 Oneida – Majestic 345 KV line tripped
15:11 Avon Unit 9 tripped[8]
15:11 Beaver – Davis Besse
15:11 Midway – Lemoyne – Foster 138(?) KV line tripped
15:11 Perry Unit 1 tripped[9]
15:15 Sammis – Star 345 KV line tripped and reclosed
15:17 Fermi Nuclear tripped[10]
15:17 - 15:21 Numerous lines in Michigan tripped

In past years, much attention has been focused on the operational and reliability problems concerning the "Lake Erie loop." The physics of electric power generation and transmission often do not match common-sense ideas. When they don't, operating problems are often a result. The lines surrounding Lake Erie have this characteristic. However, at this moment in time, attributing the engineering cause of the blackout in this way is the equivalent of Claude Rains' famous line "round up the usual suspects" in the movie Casablanca.

The eastern half of North America is a single interconnected system that stretches from Montréal to New Orleans and it is known as the "eastern interconnection." (Texas and the Pacific coast are separate systems.) The eastern interconnection comprises 2,772,555 square miles. This area is served by 206,485 miles of high voltage transmission at 230 kV and above.

In such a large system, the question is not whether a failure will occur. Failures are occurring continuously. Plants face forced outages of one sort or another; transmission lines are knocked down by drunk drivers, tornadoes, ice storms, and lightning. This is why the entire system is planned on a redundancy basis. The twenty percent reserves on the system are designed to address equipment failure on an ongoing basis.

The easiest portion of reliability planning to understand is capacity sufficiency. The industry ensures that at least ten to twelve percent more equipment is always available than should be needed.

[7]Consumers Energy
[8]First Energy
[9]First Energy
[10]Detroit Edison

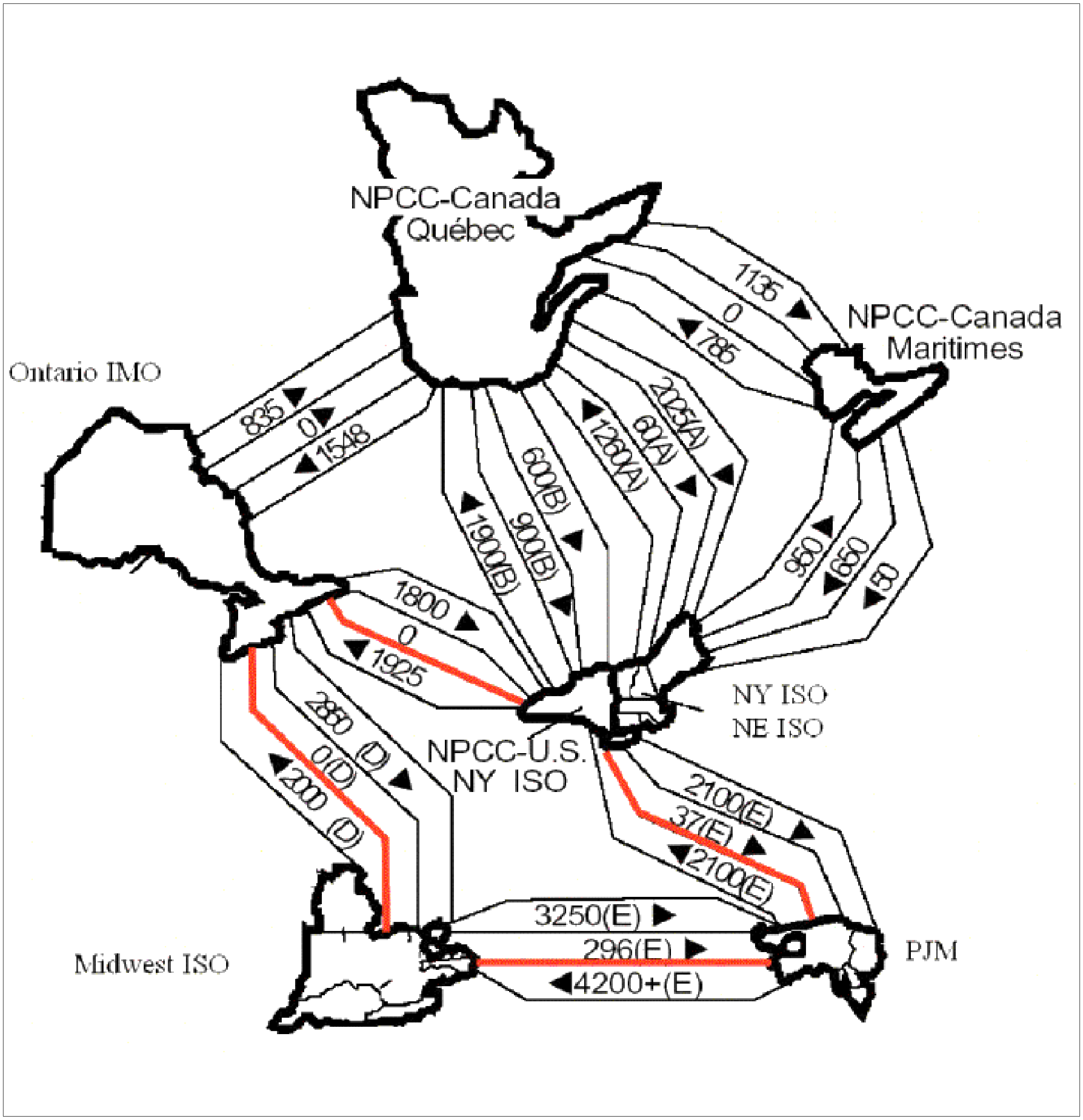
On August 14th, reserve margins in the affected areas were quite high – 31.5% at the New York ISO, 35.8% at the New England ISO, and 26.3% at the Ontario IMO[11].

	August				August 14, 2003 4:00 P.M.		
	Resources	Load	Capacity Margin	Reserve Margin	Load	Capacity Margin	Reserve Margin
	(MW)	(MW)	(%)	(%)	(MW)	(%)	(%)
ECAR (Eastern Mid-west)	125,786	97,046	22.8%	29.6%			
ERCOT (Texas)	77,563	56,945	26.6%	36.2%			
FRCC (Florida)	46,459	38,823	16.4%	19.7%			
MAAC	65,308	53,337	18.3%	22.4%			
MAIN (Illinois)	63,136	53,544	15.2%	17.9%			
MAPP	34,755	27,885	19.8%	24.6%			
NPCC (NY and NE)	69,465	56,550	18.6%	22.8%			
NYISO	37,756	31,430	16.8%	20.1%	28,709	24.0%	31.5%
ISO NE	31,709	25,120	20.8%	26.2%	23,347	26.4%	35.8%
SERC	177,248	150,411	15.1%	17.8%			
Entergy	30,418	25,194	17.2%	20.7%			
Southern	51,422	44,404	13.6%	15.8%			
TVA	31,884	27,368	14.2%	16.5%			
VACAR	64,455	53,445	17.1%	20.6%			
SPP	47,590	38,706	18.7%	23.0%			
WECC	152,976	117,499	23.2%	30.2%			
NWPP	48,251	32,732	32.2%	47.4%			
RMPA	11,531	9,584	16.9%	20.3%			
AZ-NM-S. NV	30,827	24,923	19.2%	23.7%			
CA-Mexico	62,367	50,260	19.4%	24.1%			
Total - U.S.	860,286	690,746	19.7	24.5			
Canada							
MAPP	6,912	5,251	24.0%	31.6%			
NPCC	61,205	45,657	25.4%	34.1%			
Maritime	4,476	2,736	38.9%	63.6%			
IMO (Ontario)	28,102	23,021	18.1%	22.1%	22,258	20.8%	26.3%
TransÉnergie	28,627	19,900	30.5%	43.9%			
WECC	21,812	15,513	28.9%	40.6%			
Total - Canada	89,929	66,421	26.1%	35.4%			
Eastern Interconnection	775,427	624,155	19.5%	24.2%			

More complex is transmission reliability planning. As mentioned above, the Lake Erie loop issues reflect the underlying physics of electricity. Flows around Lake Erie do not follow the simple contract paths that humans assume they might. A considerable amount of planning goes into the analysis of potential reliability issues with transmission. The following chart, taken from NERC's summer reliability analysis, describes the transmission capability in the upper Midwest and New England.[12]

[11] 2003 Summer Assessment: Reliability of the Bulk Energy Supply in North America.

[12] 2003 Summer Assessment: Reliability of the Bulk Energy Supply in North America.



Each region has three numbers describing its transmission capacity – the maximum capacity in, the maximum capacity out, and the expected use of the capacity. The lines of interest in the blackout are marked in red. Recent high natural gas prices will have made generation from coal and hydroelectricity attractive – even over long distances. It is logical that ECAR, a region with substantial coal generation, would be selling to MAAC and through MAAC (PJM) to the New York and New England ISOs.

This chart shows two very important facts:

1. Transfer capability into New York and New England is very small compared to loads. Flows from Ontario and MAAC (PJM) should have been less than 3,900 megawatts – less than 8% of total loads – and well within the capacity reserves available in New York and New England.

2. The Midwest ISO does not interconnect to New York or New England.

If the blackout started by a failure in the Midwest ISO, the failures in PJM and Ontario constitute a planning error, rather than an operational failure. The capacities displayed above, 2000 megawatts to Ontario and 3,250 megawatts to PJM, were values calculated to be reliable even if a major failure had taken place. Correspondingly, the transmission capacity between Ontario and New York – 1,800 megawatts – and between PJM and New York – 2,100 megawatts was theoretically calculated to be reliable after a major failure took place.

The 1965 Blackout

George Santayana was the author of the frequently repeated statement that to forget history is to risk repeating it. A more cynical writer once remarked that we repeat policy errors frequently in the hope that practice will make perfect. There are several points to be learned from the 1965 blackout.

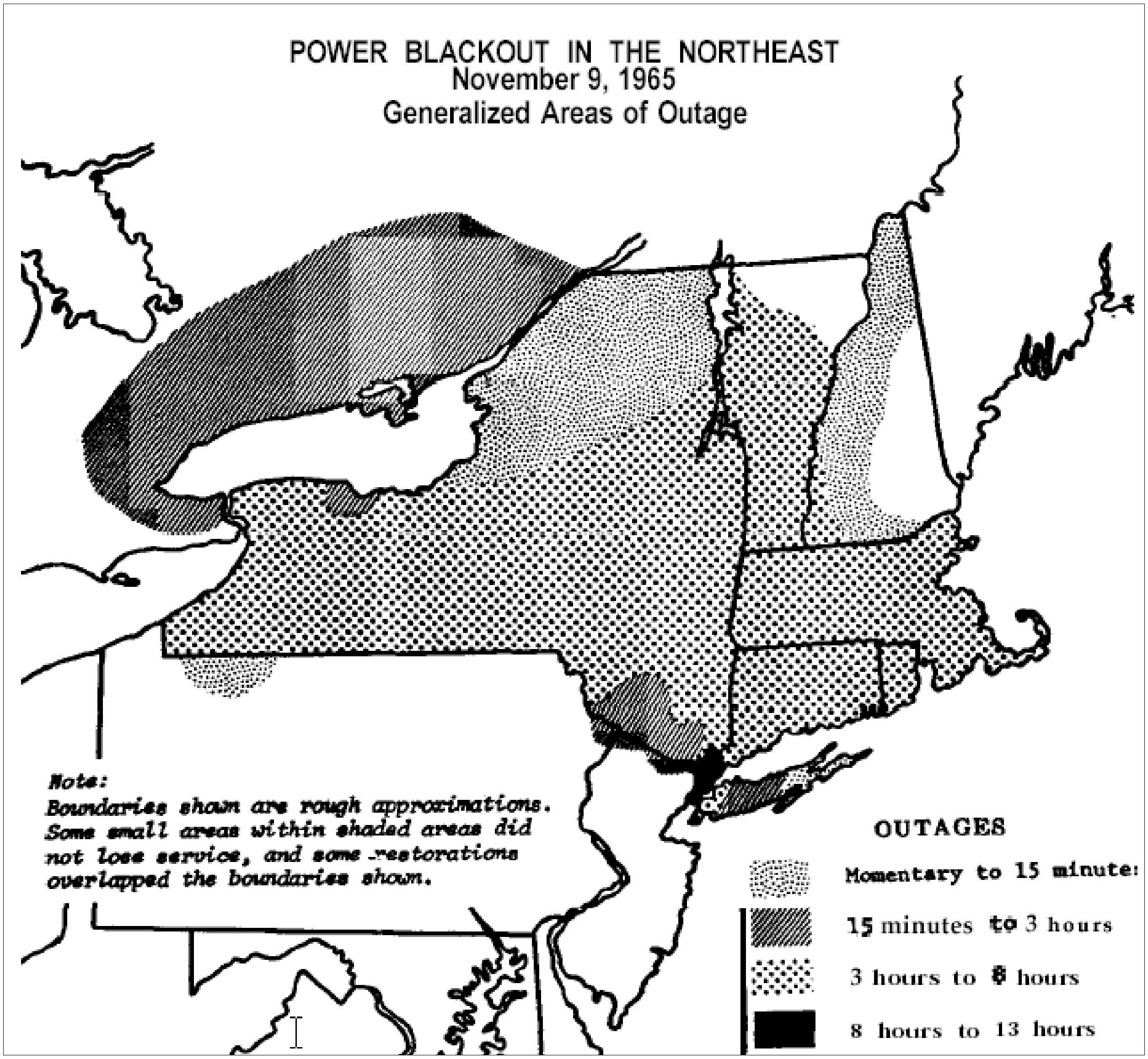
First, the cascade of failures is a common facet of complex interrelated systems. Even the smaller outage in 1965 was a function of a number of different events. We cannot expect a quick resolution of the initial equipment failure or its subsequent impacts. The FPC investigation into the 1965 blackout developed this brief statement of the events leading up to the 1965 blackout.[13]

Time (h:m:s)	Events
5:16:11	The first of the S-230 kv lies (Q29BD) from the Beck hydroelectric plant to Toronto opened by relay action. The loss of this line caused the remaining 4-230 kV lines to open in rapid succession. The last of these lines tripped out in less than 2.7 seconds after the initial line opening. Beck generation was instantly fed to Niagara Mohawk and PASNY through the main east-west 345 kV lies and other paralleling networks to Syracuse and back to Ontario via 230 kV lines to Massena on the St. Lawrence.
5:16:14	The 230 kV line connecting PASNY and Ontario at Massena opened by over current relay action.

[13]Report to the President By the Federal Power Commission On the Power Failure in the Northeastern United States and the Province Of Ontario on November 9-10, 1965, page 22.

5:16:15	The 115 kV and 230 kV network in New York opened by protective relay action at seven locations (two reclosed automatically) resulting in severing the CANUSE area from the PJM pool to the south.
5:16:15	Both circuits of the main east-west 345 kV grid opened east of Rochester as the result of line instability and all of the 115 kV circuits of Niagara Mohawk and New York State Electric & Gas in parallel with the 345 kV Lies tripped open.
16:14.6	Consolidated Edison Co. separated from PJM system at its Greenwood Substation in Brooklyn by relay action caused by excessive power flow.
5:16:14.4	Four segments of the 230 kV network of the Ontario system opened. One line reclosed almost instantly and two others within one-fourth of a second. The result was a subdivision of the Ontario system into three separate parts.
5:16:15.8	After a number of rapid openings and closings, the two 230 kV lines extending from Maasena to their junction with the cross-state 345 kV grid tripped out at Adirondack and remained open. This resulted in tripping out 5 of the 16 generation of the Massena plant of PASNY.
5:16	Two 115 kV intersystem ties in New England tripped open. Two 115 kV ties from New York to Vermont and one 230 kV tie from New York to Massachusetts tripped open because of instability.
5:17:03 to 5:18:01	Ten units at Beck were automatically shut down by low governor oil pressure and five pump generating units in PASNY's Niagara station were closed down by over speed governor control.
5:17:30 to	The two 230 kV ties between Ontario and PASNY at Niagara opened by under frequency relay action.
5:17 to 5:21	CONVEX manually opened its ties to the rest of New England.

Second, the geographic breadth and the scale of the interruptions were considerably greater in 2003 than in 1965. The following chart is taken from the third page of the Federal Power Commission report.



Finally, the problem is not insoluble, nor even terribly difficult to solve:

> 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.[14]

As today, our standard solution is to derate the capacity of the line to a level where transfers do not pose a threat to the stability of the system.

[14]Ibid., page 1.

Tragedy of the Commons – August 2003

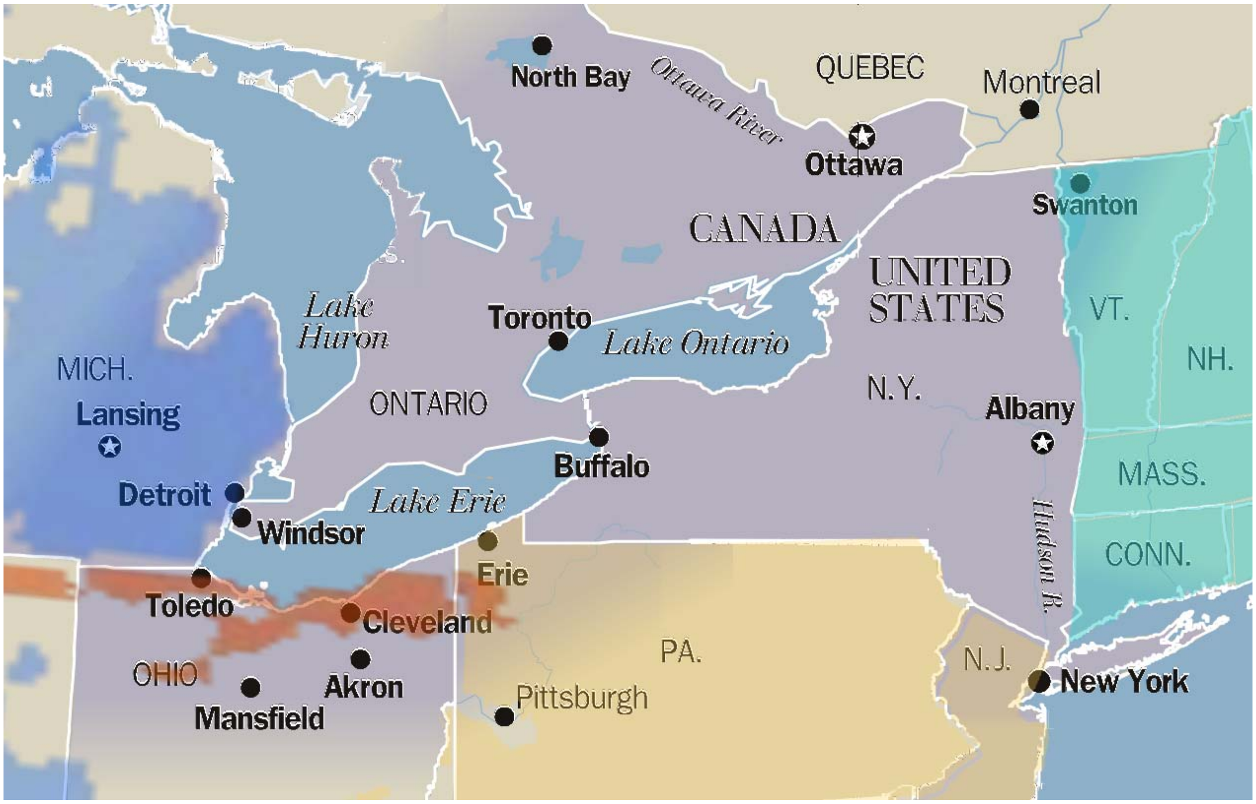
The following chart superimposes the Independent System Operators over the geographical area of the blackout. New York state is served by the New York Independent System Operator. The New England ISO is superimposed in light blue, PJM is superimposed in yellow, the Midwest ISO in dark blue, and GridAmerica, soon to merge with the Midwest ISO, in red. Ontario operates its own system, the Ontario Independent Market Operator.

A major issue in the creation of this centralized system is the "seams" between the independent system operators. The relationship between the New York ISO and PJM has often been difficult. The relationship between the Midwest ISO and its neighbor, GridAmerica, will change with the merger planned this fall.

One of the concerns held about the principle of centralizing the electric system is the question of responsibility in joint ownership. The industry's experience with joint ownership has not always been positive. The most egregious example was the Washington Public Power Supply System, a grandiose effort in the 1980s to build five nuclear stations without clear ownership. Cost overruns and operational problems were a natural result of this large project because it lacked carefully delineated incentives and responsibilities.

The problems of the California Independent System Operator (CAISO) have also served to underscore the question of how effective an institution these centralized projects actually are. In the case of the CAISO, a number of management failures added to problems during the California crisis of 2000-1. The California Senate Select Committee to Investigate Price Manipulation of the Wholesale Energy Market has identified extensive periods during which CAISO chose to artificially congest parts of its system and to dispatch energy to imaginary customers. CAISO has defended these actions, arguing that it was acting in the best interest of consumers in California, but such practices would have been unacceptable in systems subject to more oversight and traditional operational standards[15].

[15]The Select Committee held hearings on November 29, 2002 and January 21, 2003 on California ISO artificial congestion and imaginary load issues.



In the case of Thursday's blackout, problems in the blue and red areas – Midwest ISO and GridAmerica – apparently spread to the areas in gray, yellow, and light blue – Ontario, New York, New England, and PJM. The affected area is also the center of the movement toward system centralization and administration by entities without direct responsibilities and incentives to customers.

Logically, the investigation of the blackout should ask why the transfer limits between the newly formed ISOs were set higher than the failures they were equipped to handle.

Economists call the attenuation of responsibility that accompanies joint ownership the "tragedy of the commons." The phrase reflects a problem of incentives in the operation of farming land owned in common by English villages before the industrial revolution. Villagers tended to overgraze the village common because no single farmer had control of the asset or bore the costs of overgrazing. To solve this problem, the enclosure movement decentralized ownership of the commons assigning it to specific farmers. Historical evidence strongly suggests that this improved output and resource management. In some ways, our experience with the movement to centralized ISOs has been the opposite – we appear to be experiencing lower levels of efficiency and reliability due to the different incentives inherent in collective ownership.

Competition and Reliability

A substantial debate has begun about whether competition (also known as deregulation or electricity restructuring) could have caused the August 14th blackout. The debate is appropriate, but the factual basis of the debate to date is sketchy.

Flows of electricity are largely unaffected by the economic organization of ISOs. As mentioned above, recent increases in the price of natural gas have changed the optimal location of natural gas in the dispatch order and the distance over which it is appropriate to carry less expensive generation to New England. This has nothing to do with the creation of centralized institutions like the New York ISO. The same economics were present before a move to centralized administration.[16]

Our experience with ISO-oriented gaming in California indicates that few of these schemes were actually designed to affect real operations. Fat Boys, Death Stars, Ricochets, and wash transactions all tended to create a fraudulent illusion that elicited additional payments from the centralized system operator. There is no evidence that CAISO's operators ever were fooled into believing that the schemes actually were effecting the flows of kilowatt-hours.[17]

Centralized system operators are, in general, less transparent and more complex than the utilities they are replacing. The information flow ("paper trail") is often congested at the ISO – typically interrupted for months until the ISO's confidentiality rules have been met.

Specific ISO rules tend to discourage longer-term transactions and provide a focus for short term or real-time schedules. This makes the system more complex and difficult to manage, but is not, per se, a problem with competition. It is only an arbitrary focus on shorter and shorter operational durations. In effect, the ISOs tend to drive ahead of their headlights when compared to the utilities that they are replacing.

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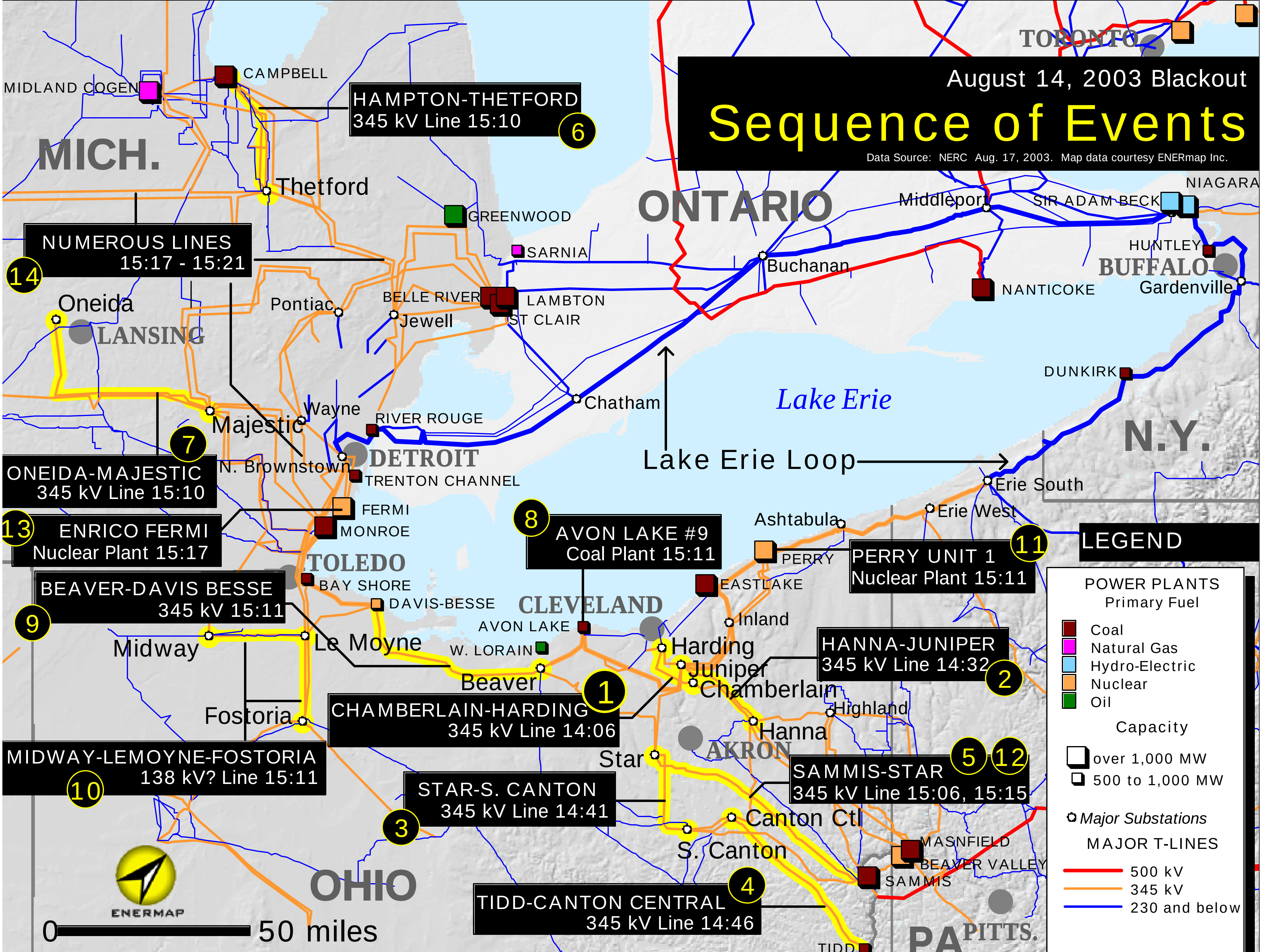
[16]Low natural gas prices in the late 1980s and 1990s effectively reversed the traditional order of dispatch. Before this point, coal units were regarded as the first units to be dispatched in most systems. Low natural gas prices and highly improved technology inverted the dispatch order in many areas as natural gas became cheaper than distant coal units.

[17]Most of the Enron schemes simply cancelled out in the real world. They were designed to fool the ISO's accountants, not their engineers. Some of the CAISO's measures – such as the artificial congestion of transmission lines – could have affected reliability, if the management of the ISO had not informed the operators that the assumed schedules were imaginary. All evidence shows that the management of the ISO did not keep this information from its own operators – only from operators of neighboring systems.

A Final Word

The Internet is based on a decentralized model where no central traffic cop is wanted, or required. Natural gas was deregulated without a desire for centralization. The 2003 blackout is the second major failure of the centralization movement in the last three years. The fact that the blackout affected areas that have been centralized under FERC's guidance may well be a coincidence, but even a coincidence should receive a careful review when the failure is this massive. So the question is: Is centralization really valuable or is it exposing us to increasing risks?


August 14, 2003 Blackout
Sequence of Events
Data Source: NERC Aug. 17, 2003. Map data courtesy ENERmap Inc.
HAMPTON-THETFORD
345 kV Line 15:10
6
NUMEROUS LINES
15:17 - 15:21
14
ONEIDA-MAJESTIC
345 kV Line 15:10
7
ENRICO FERMI
Nuclear Plant 15:17
13
BEAVER-DAVIS BESSE
345 kV 15:11
9
MIDWAY-LEMOYNE-FOSTORIA
138 kV? Line 15:11
10
AVON LAKE #9
Coal Plant 15:11
8
CHAMBERLAIN-HARDING
345 kV Line 14:06
1
HANNA-JUNIPER
345 kV Line 14:32
2
STAR-S. CANTON
345 kV Line 14:41
3
TIDD-CANTON CENTRAL
345 kV Line 14:46
4
SAMMIS-STAR
345 kV Line 15:06, 15:15
5
12
PERRY UNIT 1
Nuclear Plant 15:11
11
Lake Erie Loop
Lake Erie
MICH.
ONTARIO
OHIO
N.Y.
PA
TORONTO
BUFFALO
DETROIT
TOLEDO
CLEVELAND
AKRON
LANSING
PITTS.
MIDLAND COGEN
CAMPBELL
Thetford
GREENWOOD
SARNIA
BELLE RIVER
LAMBTON
ST CLAIR
Jewell
Pontiac
Oneida
Majestic
Wayne
RIVER ROUGE
N. Brownstown
TRENTON CHANNEL
FERMI
MONROE
BAY SHORE
DAVIS-BESSE
Midway
Le Moyne
Fostoria
Beaver
AVON LAKE
W. LORAIN
Chatham
Buchanan
Middleport
SIR ADAM BECK
NIAGARA
HUNTLEY
Gardenville
NANTICOKE
DUNKIRK
Erie South
Erie West
Ashtabula
PERRY
EASTLAKE
Inland
Harding
Juniper
Chamberlain
Highland
Hanna
Star
S. Canton
Canton Ctl
MASNFIELD
BEAVER VALLEY
SAMMIS
TIDD
ENERMAP
0
50 miles
LEGEND
POWER PLANTS
Primary Fuel
Coal
Natural Gas
Hydro-Electric
Nuclear
Oil
Capacity
over 1,000 MW
500 to 1,000 MW
Major Substations
MAJOR T-LINES
500 kV
345 kV
230 and below