NORTHEAST POWER FAILURE

November 9 and 10, 1965

A Report to the President
by the
Federal Power Commissi[on]
December 6, 1965

U.S. Government Printing Office
Washington : December 1965

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C., 20402

THE WHITE HOUSE

WASHINGTON

November 9, 1965

MEMORANDUM FOR 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 should be immediately and carefully investigated in 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.

Lyndon B. Johnson

FEDERAL POWER COMMISSION

WASHINGTON

OFFICE OF THE CHAIRMAN

December 6, 1965

Dear Mr. President:

In response to your memorandum of November 9, 1965, we are pleased to submit this report on the Commission's investigation to date of the power failure which took place in the Northeastern United States and the Province of Ontario, Canada, on November 9-10.

We are happy to report that the Commission has had and continues to receive the fullest possible cooperation of the National Energy Board of Canada and The Hydro-Electric Power Commission of Ontario in carrying out its investigation.

Respectfully,

Joseph C. Swidler, Chairman

David S. Black, Vice Chairman

Charles R. Ross, Commissioner

Lawrence J. O'Connor, Jr.
Commissioner

Carl E. Bagge, Commissioner

The President
The White House
Washington, D. C. 20501

CONTENTS

	Page
Chapter I—The Story of the Blackout	1
Background	2
The CANUSE Area	2
The Cause and Spread of the Disturbance	4
The Tripping-Out of the Lines in Ontario	4
The Break-Up of the Transmission Lines in Upstate New York	8
The Shut-Down of the Generating Plants in the Niagara Area	11
The Breakdown in New England and Southeastern New York	12
Determining the Source of the Incident	17
General Description of Electric Systems	18
Chapter II—Protecting Against the Likelihood of a Recurrence	23
Measures to Strengthen the Grid	24
Measures to Confine Future Outages	26
Conclusion	28
Chapter III—The Problems of Restoring Service	29
The General Problem	29
Relative Difficulty in Generation Startup	29
Restoration of Service in Upstate New York	30
Restoration of Service in New England Areas	31
Restoration of Service in New York City	33
Nuclear Plants Nor in Operation	35
Chapter IV—The Impact of the Power Failure on the People in the Affected Area	37
Transportation	37
Hospitals	38
Communications	38
Public Services	39
National Defense	39
Commerce	40
Conclusion	40
Chapter V—Scope of Further Studies	41
Chapter VI—Recommendations	43
Acknowledgments	47
Appendix A—Summary of Events, November 9 and 10, 1965	51
Introduction—The System Operating Conditions Prior to the Disturbance	53
Sequence of Events in the System Split Up at the Beginning of the Disturbance of November 9, 1965	53
Power System Restoration, November 9 and 10, 1965	56
Appendii B—Electric Utility Planning Studies	61
Emphasizing Transient Stability Analyses of Transmission Network	63
Transient Stability Studies	63
Computer Simulation	64
Selection of Disturbances	64
System [illegible]	[illegible]

	Page
Appendix C-Summary of Events, January 28, 1965	67
The Missouri Basin Area Power Interruption of January 28, 1965	69
Report of January 28, 1965, System Disturbance on the Missouri Basin Interconnected System	71
Appendix D--Operation Guide No. 9	77
North American Power Systems Interconnection Committee	79
Appendix E-Summary of Utility Responses to FPC Questions of November 13, 1965	81
Appendix F-Recommendations of the Federal Power Commission Advisory Panel	93

LIST OF EXHIBITS

	Page
I-A: Map-h of Power Blackout in the Northeast	3
I-B: Table—Power Service Outages During November 9, 1965, Power Failure	4
I-C: Diagram-Load Control Areas in the Northeast	5
I-D: Map-Interconnected Systems in the United States	6
I-E: Map—Control Areas in CANUSE Interconnected System	6-7
I-F: Photograph-Ontario Niagara Power Facilities	7
I-G: Schematic Diagram-Beck No. 2 Station	8
I-H: Table-Power Loads and Resources in the Northeast	8
I-I: Diagram-Initial Transmission Line Outages During November 9 Disturbance	10
I-J: Photograph--Relays	11
I-K: Photograph--Circuit Breakers	11
I-L: Map—Transmission Lines and Outage Sequence in the Northeast	22
I-M: Map--Service Area Separations	11
I-N: Diagram—Power Flows at Time of Disturbance	13
I-O: Graph-Net System Load—Consolidated Edison	14
I-P: Diagram-Power Flows at 5: 16 and 5: 19 p.m.—Consolidated Edison	15
I-Q: Photograph--Control Center on Consolidated Edii System	16
I-R: Photograph—Recording Meters	18
I-S: Oscillogram for Ontario-Hydro Transmission Lines	19
I-T: Graph-Consolidated Edison Power Interchange with Niagara Mohawk	20
II-A: Map-Blackout Areas in Midwest and Northeast—1965	25
III-A: Map-Power Service Areas in New York City	34-35
III-B: Photograph-Substation-Consolidated Edison System	34
III-C: Photograph-Damage to Unit At Ravenswood Plant	35
A-l: Schematic-Sequence of Line Openings During November 9 Blackout	60-61
El: Graph Showing Stable Power System Conditions	65
B-2: Graph Showing Unstable Power System Conditions	65
Cl: Summary of Events—January 28, 1965 Power Failure in the Midwest	69

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

Chapter I
The Story of the Blackout

Immediately after the interruption of electric service throughout most of the northeast United States and the Province of Ontario on the evening of November 9, 1965, you directed the Chairman of the Federal Power Commission to launch a thorough study of "the causes of the failure and the steps you recommend to be taken to prevent a recurrence."

The Commission began its investigation on the same evening, and has been carrying it out on an urgent basis ever since. On the morning of November 15, with the assistance of The Hydro-Electric Power Commission of Ontario and all other parties concerned, the initiation of the disturbance was pinpointed as the operation of a relay at the Sir Adam Beck No. 2 Hydroelectric Plant (Beck) on the Niagara River in Ontario, which disconnected the transmission limes then moving power north from that plant, reversing the power flow from north to south and causing a massive surge of power into the northeastern United States. Our conclusion is supported by the investigating officers of the National Energy Board of Canada and by the officials of The Hydra-Electric Power Commission of Ontario who participated in the investigation and cooperated fully in all of its aspects.

There is no evidence whatever that sabotage was involved in any stage of the power failure.

We are releasing to the public at the Commission's offices in Washington the transcript of the statements made by the officials of the systems concerned in informal hearings conducted by the Commission on November 11, 12, and 15.

The power failure of November 9 and 10 has made a deep impression on the public because of its widespread nature and because of the difficulty and delay in discovering the origin. It should nevertheless be considered in perspective. The service standards of the industry are very high, and interruptions are, on the whole, short and infrequent. The problem arises not because service is poor but because the universal and increasing dependence of the American public on this form of energy makes any widescale interruption seriously disruptive. The prime lesson of the blackout is that the utility industry must strive not merely for good but for virtually perfect service.

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 arc already beiig 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 lesson of the blackout must not be lost. What is required now is an intensive reexamination of the service problem throughout the industry, based upon a realistic appraisal of the susceptibility of the particular supply facilities to interruptions from any cause.

This report will endeavor to describe the disturbance in more detail, to provide background information which we hope will be helpful to you, the Congress, and the American people, and to suggest both immediate and long-term measures which should be taken to minimize the possibility of a recurrence and to alleviate hardship to power consumers and the general public in the event of any widespread service outage in the future.

We are continuing our investigation in cooperation with all segments of the electric power industry to be sure that every conceivable step is taken to assure the highest possible standard of electric service to the American consumer. We believe the measures already taken, together with those we recommend, and the results of our further investigation on which we shall report to you at a later date, will go far toward eliminating the apprehensions which the recent blackout has created in the minds of the public.

We believe the public should recognize that the Federal Power Commission has no specific responsibiity for the reliability of service of the interstate electric power industry and has not approved the construction of the facilities or the operating practices of the systems affected by the power failure. The Commission has no licensing or certificating jurisdiction over generating or transmission facilities, other than hydroelectric projects. As a part of its National Power Survey, published in December 1964, the Commission has attempted to establii general guidelines for the coordinated growth of the industry in the future, but this activity was conducted under a provision of tbe Federal Power Act which liih the Commission to encouraging voluntary interconnection programs among utilities, and did not involve appraisal of the service reliability of the facilities or operations of any system or group. Whether to recommend additional legislation is a separate question which is now under active consideration.

We wish to acknowledge our indebtedness to the panel of technical experts from all segments of the electric power industry who joined in the investigation on short notice, many of whom worked virtually around the clock until the cause of the disturbance was pinpointed. The panel has also been of invaluable assistance to the Commission in formulating our recommendations for remedial action to prevent a recurrence. The cooperation of the Canadian power officials was, of course, vital in this joint effort to find a solution to a common problem. A list of those to whom the Commission is most indebted is appended.

Background

Beginning at approximately 5 : 16 p.m. on November 9, 1965, most of the northeastern United States experienced the largest power failure in history. The outage lasted from a few minutes in some locations to more than a half day in others. It encompassed 80,000 square miles and directly affected an estimated 30 million people in the United States and Canada. Occurring during a time of day in which there is maximum need for power in this area of great population density, it offered the greatest potential for havoc.

The geographic boundaries of the failure area included virtually all of New York State, Connecticut, Massachusetts, Rhode Island, and small segments of northern Pennsylvania and northeastern New Jersey. Substantial areas of Ontario were also without power. New Hampshire and Vermont were subject to spotty failures that lasted from three minutes to several hours. Maine did not experience any failure. Attached is a map outlining the affected areas (Exhibit I-A) and a table listing the outage periods for the various affected areas (Exhibit I-B).

The electric systems affected were some 28 utilities in the northeastern United States and The Hydro-Electric Power Commision of Ontario which together with a number of other systems are interconnected in varying degrees to make up the group of systems known generally as The Can&la-United States Eastern Interconnection (CANUSE). A diagram of the CANUSE interconnection is attached as Exhiiit I-C. CANUSE is in turn one part of an interconnected grid that operates in 39 states and the Province of Ontario. The rest of the grid functioned normally during the breakdown of service in the Northeast. Exhibit I-D is a diagram of these interconnected systems.

At the end of this chapter (page 18) there is included a general description of the way in which electric systems function which may be helpful in following the story.

The CANUSE Area

In the CANUSE area, 73 percent of the power is generated by steam-electric stations and 26 percent is produced by hydroelectric plants. The remaining one percent is generated by numerous internal combustion engines *and gas* turbines of relatively small size and by three nuclear plants[1] which have an aggregate capacity of about 515 mw.[2]

Most of the hydroelectric generating capacity in the CANUSE area is concentrated near Nii

[1] As it happened the two nuclear plants in the blackout area were not in operation on November 9 because of schedule outages. The third plant is located in Michigan outside the blackout area.

[2] An mw (or megawatt) is equal to 1000 kw (or kilowatts). Tbe kilowatt is the common measure of electrical capacity, roughly equal to 1⅓ horsepower. For relative purposes, the total installed capacity of the power system in the United States is now in the order of 235,000 mw.

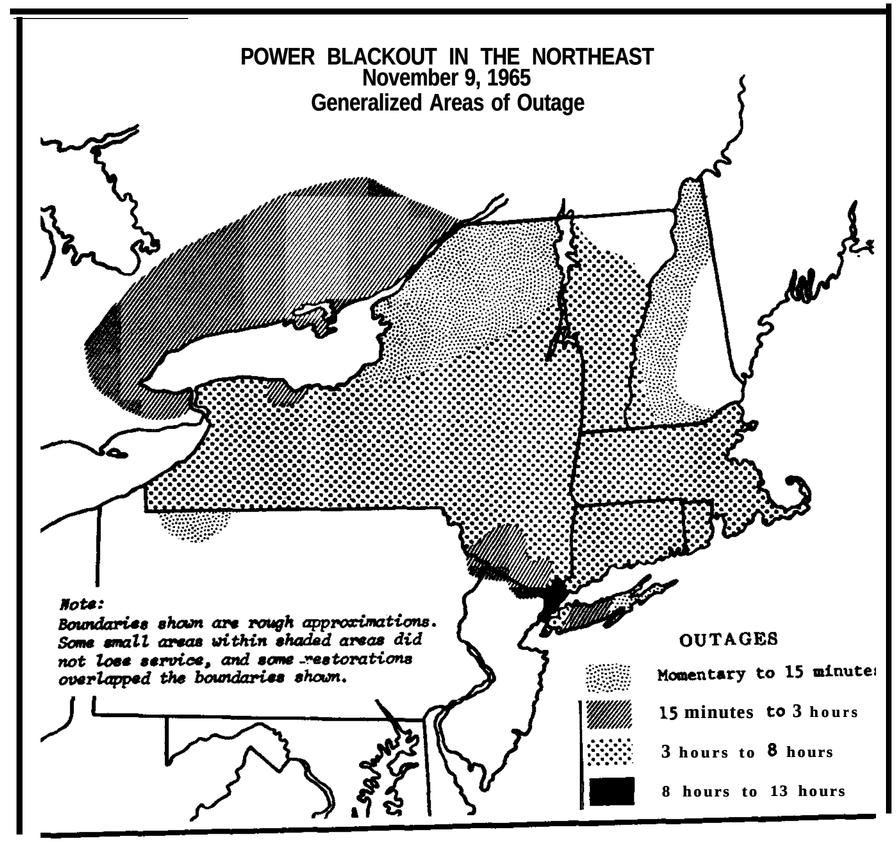


EXHIBIT I-A

Falls on the Niagara River. Ontario Hydro's Beck plant has a dependable capacity of 1485 mw including the pumped storage units and the Niagara Plant of the Power Authority of the State of New York (PASNY) has a dependable capacity in the range of 2400 to 2500 mw including the pumped storage units. Combined, these developments constitute the largest concentration of generating capacity in one locality in North America. Near Massena, New York, east of Lake Ontario on the St. Lawrence River, PASNY, and Ontario Hydro have dependable capacities of 700 to 800 mw each in a hydro plant which was jointly planned and constructed.

Much of the power generated by the large hydroelectric projects at Niagara and St. Lawrence is utilized at load centers which are located some distance from these plants. The principal load center of Ontario Hydro's system is in the vicinity of Toronto. Power developed by PASNY's large hydroelectric plants is transmitted over twin 345-kv transmission lines[3] extending across New York State from Niagara to Albany and south to New York City and over a number of 115-kv and 230-kv

The size and capacity of transmission lines is usually indicated by their voltage. A kv is a kilovolt or 1000 volts. The capacity of a transmission line increases roughly as the square of the voltage. 345 kv lines are the heaviest in the CANUSE area, and are the heaviest in extensive use in the United States, although some 500 kv lines have recently been built and more are under construction.

EXHIBIT I-B

Power Service Outages, Northeastern United States & Ontario, Canada, November 9 and 10, 1965

Utility	*Time of Outage*	*Time Service Restored* Partial	*Time Service Restored* Completed
Niagara Mohawk Power Corp	5:16 p.m.	5:37 p.m.	10:30 p.m.
Rochester Gas & Electric Corp	5:16 p.m.	7:45 p.m.	11:44 p.m.
PASNY [1]—Moses-Niagara	5:16 p.m.	....	6:10 p.m.
PASNY [1]—Moses-St. Lawrence	5:16 p.m.	....	....
New York State Electric & Gas Corp	5:16 p.m.	5:38 p.m.	11:14 p.m.
Central Hudson Gas & Electric Corp	5:22 p.m.	7:30 p.m.	10:00 p.m.
Consolidated Edison Co.	5:28 p.m.	10:36 p.m.	7:0o a.m.
Long Island Lighting Co.	5:30 p.m.	7:09 p.m.	1:00 a.m.
Orange & Rockland Utilties	5:20 p.m.	5:20:30 p.m.	9:12 p.m.
Hydro-Electric Power Commission, Ontario	5:16 p.m.	....	8:30 p.m.
CONVEX [5]	5:17 p.m.	5:30 p.m.	11:15 p.m.
Vermont Electric Power Co., Inc	[2]5:18 p.m.	6:16 p.m.	7:20 p.m.
New England Electric System	5:17 p.m.	6:03 p.m.	10:00 p.m.
Public Service Co. of New Hampshii	5:21 p.m.	([4])	5:25 p.m.
Boston Edison Co	5:21 p.m.	8:14 p.m.	1:00 a.m.
Central Vermont Public Service Co.	5:16 p.m.	5:33 p.m.	7:58 p.m.
Pa.-N. J.-Md. Interconnection	([3])	....	([3])
Detroit Edison Co	0	....	....
Consumers Power Co.	0	....	....
Central Maine Power Co	0	....	....

[1] Power Authority State of New York.
[2] Wholesale supplier.
[3] Power interrupted in the W-, Pa. area for about 15 minutes.
[4] Loss of service generally in southwestern New Hampshire area.
[5] Connecticut Light and Power Co., Hartford Electric Light Co., United Illuminating Co., Western Massachusetts Electric Co.

transmission lines originating at both the plants of PASNY at Niagara and near Massena. Transmission lines which interconnect systems of New York with New England include a single 345-k" line from a point north of New York City to near Hartford, Connecticut, a 230-kv line and four others at 115 kv.

The CANUSE system is bordered on the south by the utilities of the PJM pool (Pennsylvania-New Jersey-Maryland interconnection). The CANUSE area and the PJM pool are interconnected by six transmission lines including two 230-kv lines and others at voltages of 115 and 138 kv. One of these ties links Consolidated Edison's system in New York with the systems of the PJM pool in northern New Jersey.

The largest of the 28 principal utilities operating in the CANUSE area include Ontario Hydro, serving almost the entire Province of Ontario, and PASNY, which generates large amounts of power at its two hydroelectric plants at Niagara and Massena and sells it in bulk to utilities in New York, New England and Ontario. Three utilities-The Niagara Mohawk Power Corporation (Niagara Mohawk), Rochester Gas and Electric Corporation (Rochester) and New York State Electric and Gas Company (NYSEG)—serve the largest areas in upstate New York. Consolidated Edison Company (Consolidated Edison) serves the City of New York. The CONVEX power pool, an association of four utilities in Connecticut and western Massachusetts, supplies the largest load in the New England area, followed by the New England Electric System and the Boston Edison Company. The locations of the principal utilities in the CANUSE area appear on Exhibit I-E.

The Cause and Spread of the Disturbance

The Tripping-Out of the Lines in Ontario

The disturbance was initiated on one of the main transmission lines taking power north from the

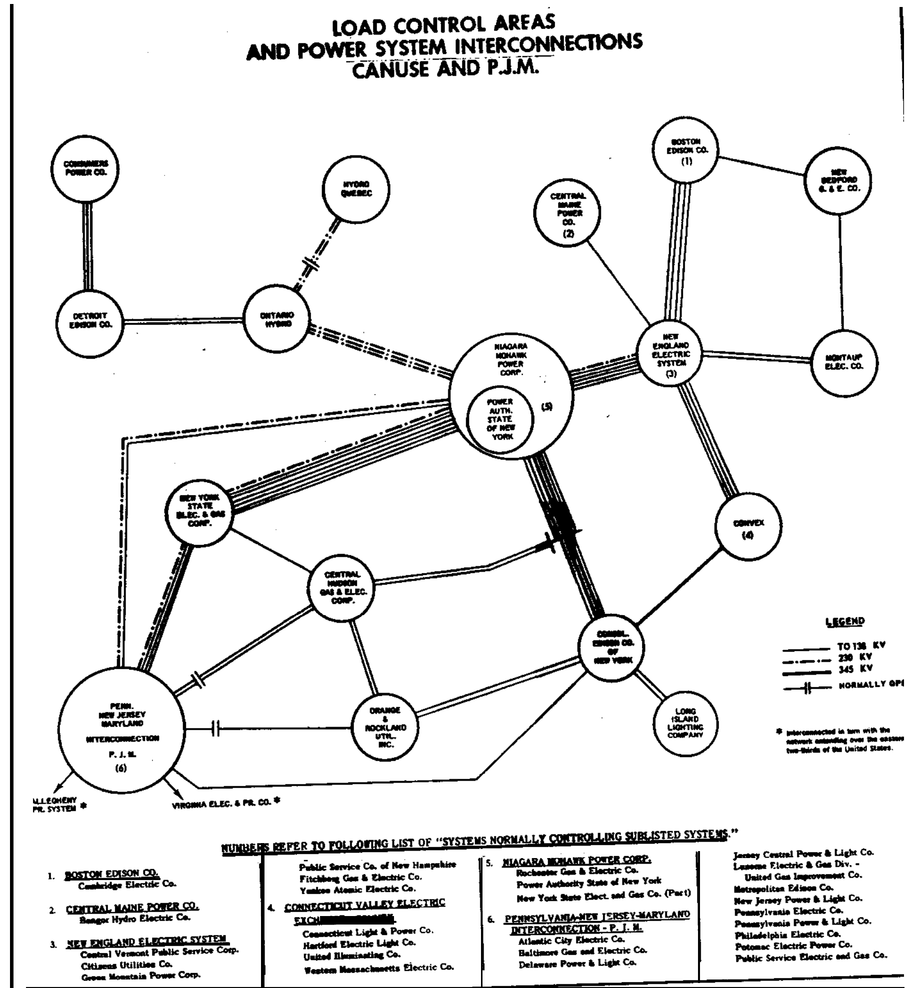


EXHIBIT I-C

MAJOR AREAS SERVED BY INTERCONNECTED SYSTEMS

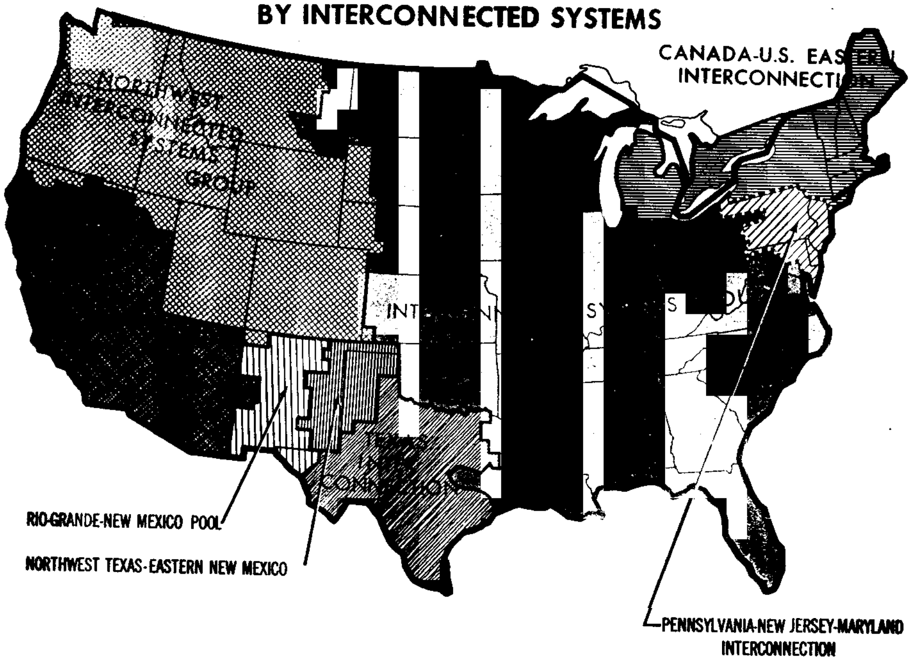


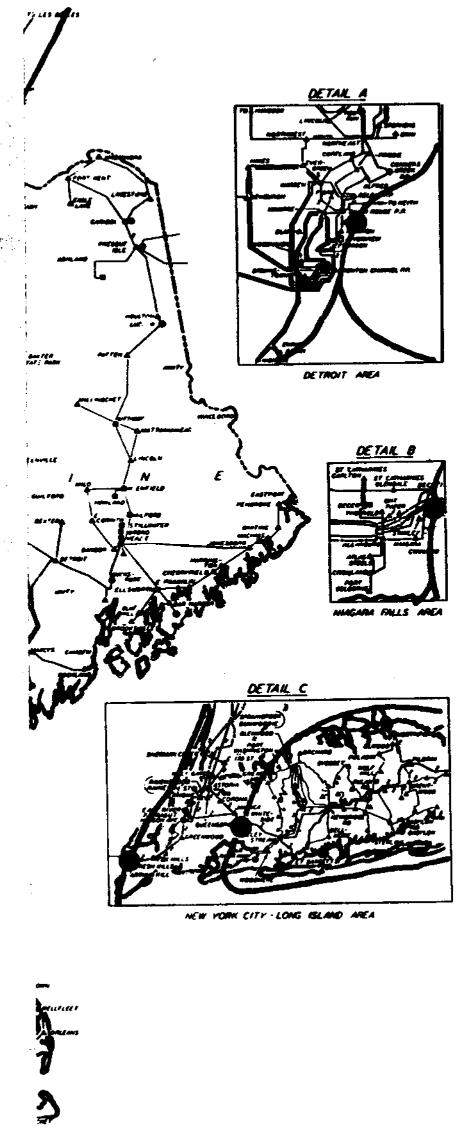
EXHIBIT I-D

Beck station of Ontario Hydro on the Nii River.' Exhibit I-F is a photograph of the Niagara facilities of Ontario Hydro. The power flows north from the Beck station over five 230-kv lines connecting the plant with loads in the Toronto area of Ontario. Exhibit I-G is a schematic diagram of the facilities at the Beck plant. There are two 230-kv lines from the Beck station which cross the river to the south and interconnect with the power systems in the United States.

At 5:16:11 p.m., a backup protective relay on one of the five 230-kv transmission lines taking power north from the Beck plant of Ontario to the Toronto area operated and caused the circuit breaker to disconnect the line. The flow of power on the disconnected line was thus shifted to the remaining four lines going north from the Beck plant, each of which was then loaded beyond the level at which its protective relay was set to operate. They tripped out successively in a similar manner in a total of about 2½ seconds.

The relay which caused the disturbance was one of five which had been installed in 1951 as backup protection for the primary relays at Beck. We are informed by the Ontario Hydro officials that following the occurrence of a fault on one of these lines in 1956 in which the breaker failed to open, all of Beck's generation was lost causing a power outage in Ontario and northwestern New York during which load shifted from Beck to PASNY and Niagara Mohawk plants. As a result of a reevaluation of its requirements for backup protection, Ontario Hydro in January 1963 modified these relays to broaden their protection. The relay settings imposed in 1963 were in effect at the time of the power failure on November 9. The modified relays served two purposes. One purpose was to

'A step-by-step account of the sequence of events which should be of interest to the engineering community is attached as Appendix A.



CANUSE CONTROL AREAS
AFFECTED BY MSTURBANCE • NOV. 9, 1965

NUMBERED SYSTEMS NORMALLY PROVIDE LOAD CONTROL FOR **SUBLISTED** SYSTEMS

1. **Consumers Power** co.
2. **Detroit Edison** Co.
3. Hydm **Electric** Power Commission of Ontario
4. Consolidated Edison Co.
5. Long **Island** Lighting
6. **Central** Hudson **Gas** and **Electric** Co.
7. **Orange and Rockland** Utilitia
0. **New York** State **Electric and Gas** Co.
9. Nor **Bedford Gas & Edison Light** Co.
10. **Montaup Electric** Co.

Systems Normally Controlling Sublisted Systems

11. Boston Edison
    Cambridge Electric Co.
12. Central **Maine Power** Co.
    Bangor **Hydro** Electric Co.
13. Now England Electric System
    Central Vermont Public **Service Corp.**
    Citizens Utilities Co.
    Green Mountain **Power** Corp.
    Public **Service** Co. of Nor **Hampshire**
    Fitchburg **Gas** and Electric Co.
    Yankee Atomic **Electric** Co.
14. **Connecticut** Volley **Electric Exchange-Convex**
    Connecticut Light and **Power** Co.
    Hartford Electric Light Co.
    United Illuminating Co.
    Western **Massachusetts** Electric Co.
15. Niagara Mohawk Power **Corp.**
    Rochester Gas and Electric Co.
    Power Authority State of New York
    Now York **State** Electric **and Gas** Co. **(Part)**

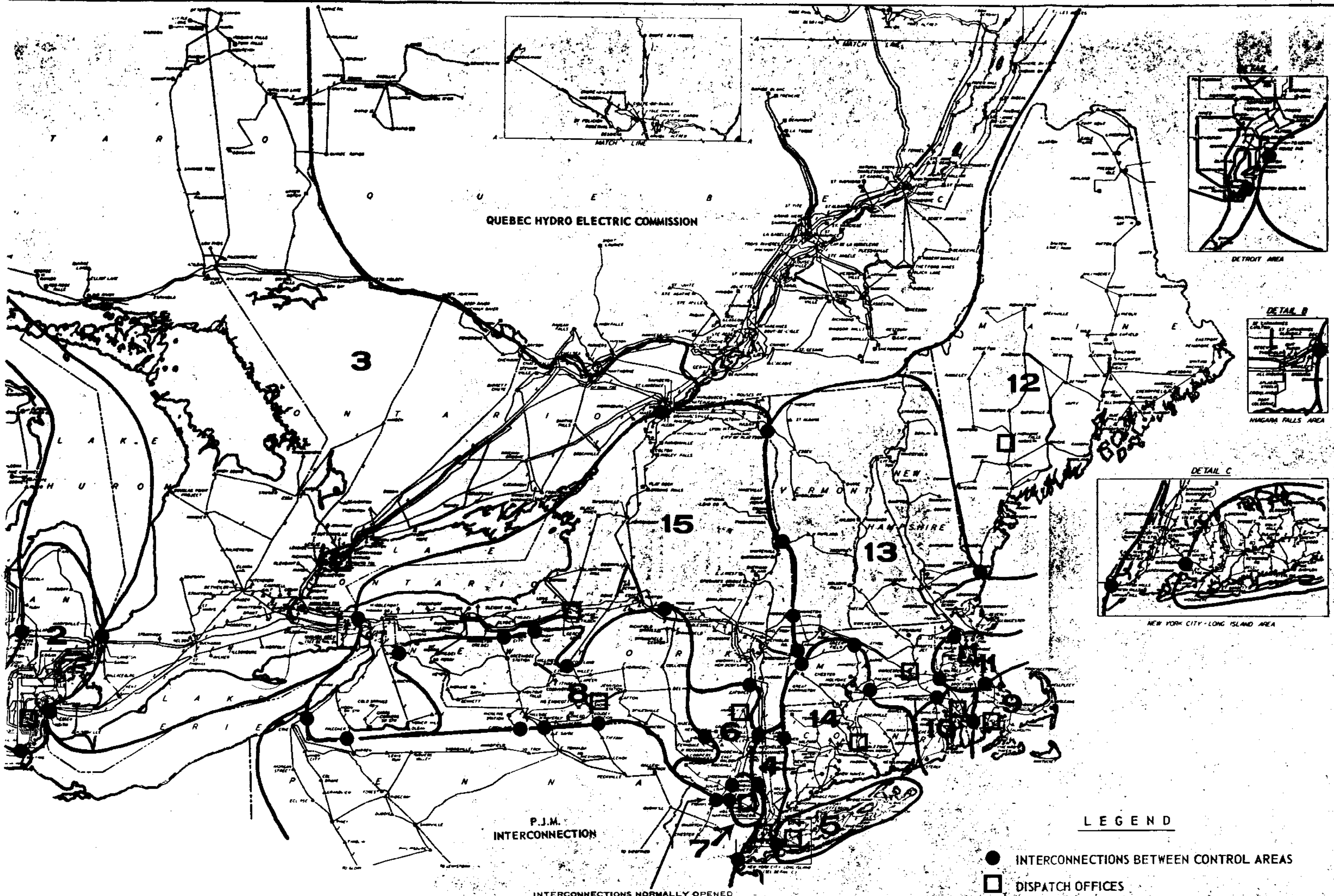
794-080 O-65 (Face p. 6)

LEGEND

?CONNECTIONS BETWEEN CONTROL AREAS

.TCH OFFICES

Exhibit I-E



CANUSE CONTROL AREAS AFFECTED BY DISTURBANCE - NOV. 9, 1965

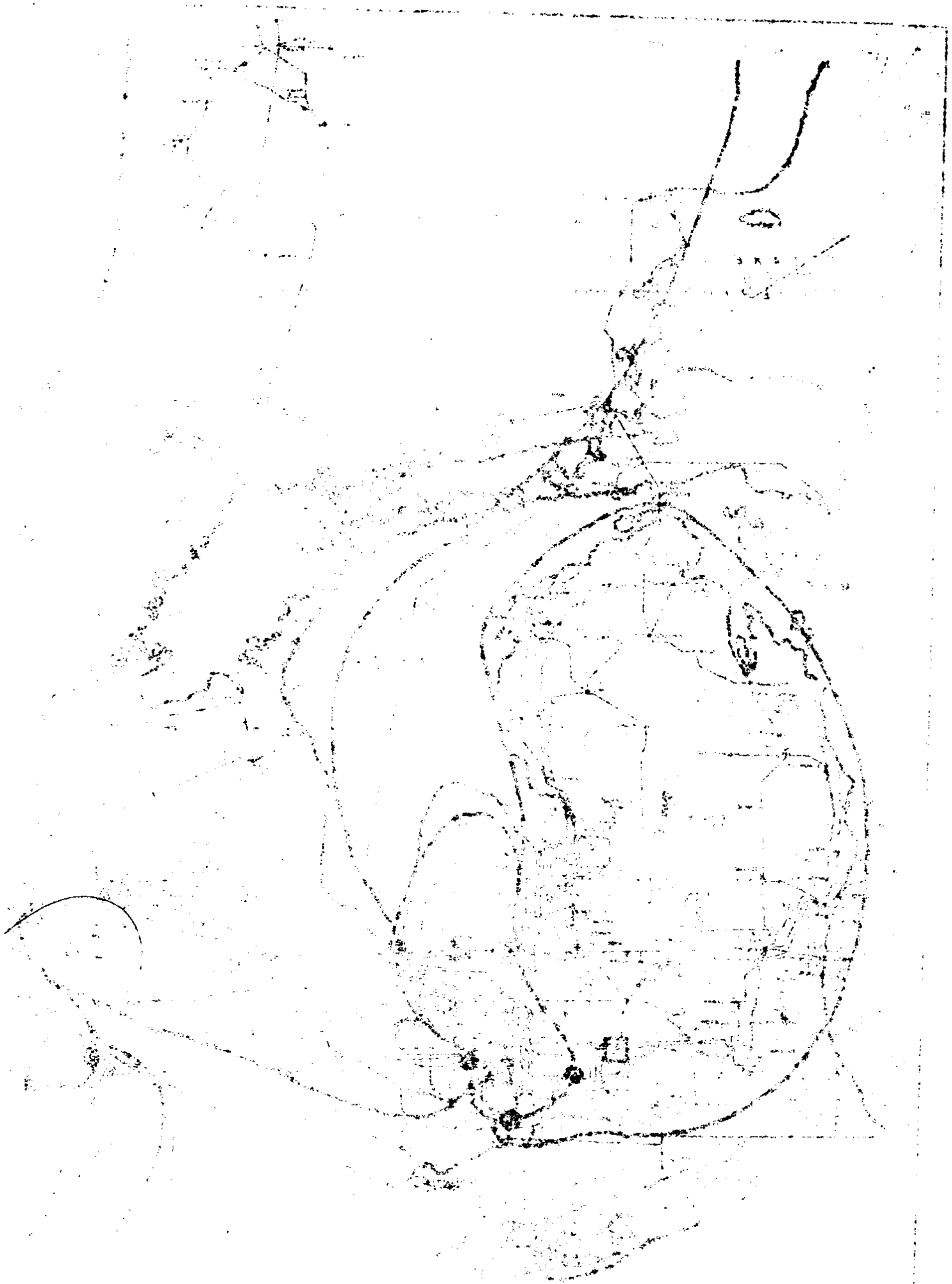
NUMBERED SYSTEMS NORMALLY PROVIDE LOAD CONTROL FOR SUBLISTED SYSTEMS

1. Consumers Power Co.
2. Detroit Edison Co.
3. Hydro Electric Power Commission of Ontario
4. Consolidated Edison Co.
5. Long Island Lighting
6. Central Hudson Gas and Electric Co.
7. Orange and Rockland Utilities
8. New York State Electric and Gas Co.
9. New Bedford Gas & Edison Light Co.
10. Montaup Electric Co.

Systems Normally Controlling Sublisted Systems

11. Boston Edison
    - Cambridge Electric Co.
12. Central Maine Power Co.
    - Bangor Hydro Electric Co.
13. New England Electric System
    - Central Vermont Public Service Corp.
    - Citizens Utilities Co.
    - Green Mountain Power Corp.
    - Public Service Co. of New Hampshire
    - Fitchburg Gas and Electric Co.
    - Yankee Atomic Electric Co.
14. Connecticut Valley Electric Exchange-Convex
    - Connecticut Light and Power Co.
    - Hartford Electric Light Co.
    - United Illuminating Co.
    - Western Massachusetts Electric Co.
15. Niagara Mohawk Power Corp.
    - Rochester Gas and Electric Co.
    - Power Authority State of New York
    - New York State Electric and Gas Co. (Part)

Exhibit I-E



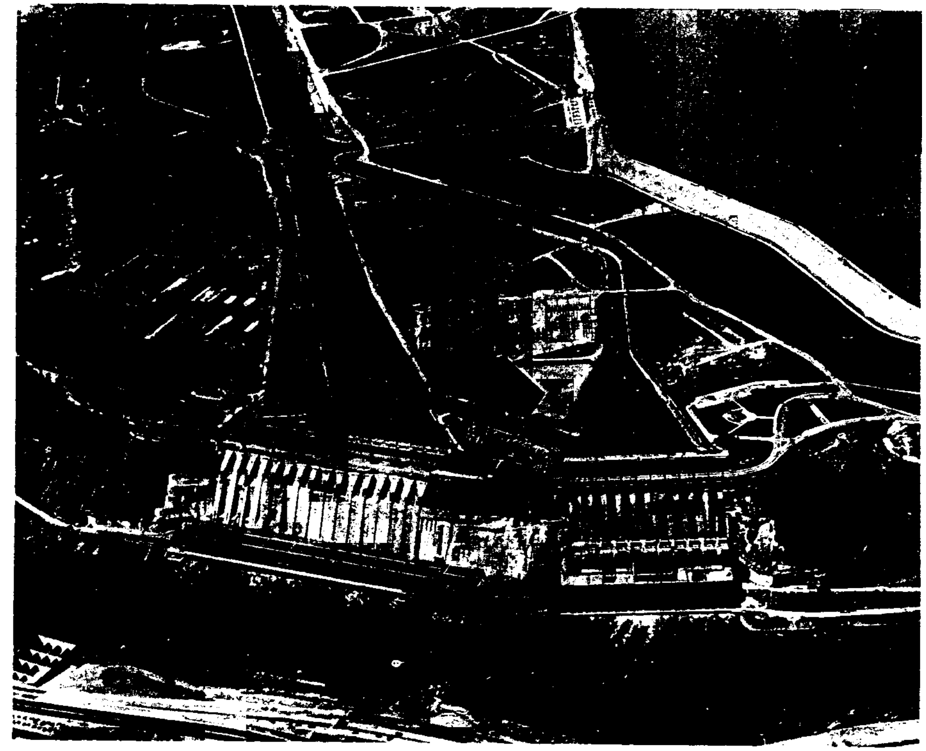


Exhibit I–F. Ontario Hydro's development at Niagara Falls includes the Sir Adam Beck Plant No. 2 (Beck) at left, with an installation of 1,223.6 megawatts, the Sir Adam Beck Plant No. 1 at right, with an installation of 403.9 megawatts, the Pumped Storage Plant and Reservoir at upper center, with an installation of 176.7 megawatts, and the substation, center.

backup the primary short circuit relays at Beck in the event one of them failed. The second purpose was to ensure that any of the five lines moving power to the north would be disconnected in the event its circuit breaker at Beck failed to operate or should there be a stuck breaker at Burlington, Ontario, down the line. With the installation of these backup relays there were in existence two sets of relays protecting the five 230-k" lines going north from the Beck station, one the basic short circuit relays and the other the backup relays which initiated the disturbance.

The backup relay which triggered the blackout was set in 1963 to operate at approximately 375 mw. The load-carrying capacity of each of the lines is considerably above 375 mw, but it was necessary to set each backup relay to operate at a power level well below the capacity of the line because its function was to detect faults beyond the next switching point from the Beck plant on the Ontario Hydro system.

In 1963 when the backup relays were modified and the power levels set, the load on the lines north out of Beck was much lower than the 375 mw setting of the backup relay. The loadings on the transmission lines in recent months have been unusually heavy due to emergency outages in Ontario Hydro's new steam plant at Lakeview, which has created a general deficiency of generation reserves in Ontario and resulted in heavier imports of power from the United States. Ontario Hydm officials have informed us that the personnel operating the Ontario Hydm system were not aware that the relay was set to operate at the 375 mw level.

With the winter peak in Ontario approaching, the loads on the lines going north from Beck have steadily increased. According to the Ontario Hydro officials, at the time of the initial disturbance the average flow in the line that tripped out first bad reached 356 mw, but flows arc not absolutely constant, and some fluctuation from moment to moment is normal. With this normal fluctuation, the flow of power at 5: 16: 11 p.m. on November 9, 1965, reached the level at which the backup relay was set and it operated to disconnect the line, with the consequences already mentioned, and the further consequences we shall now describe.

The Break-Up of the Transmission Lines in Upstate New York

The disconnection of these five major lines created a separation of the Ontario generation at Niagara

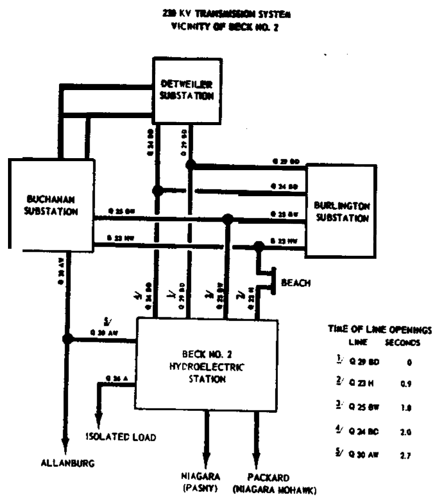


EXHIBIT I-G

EXHIBIT I-H

Northeast power loads and resources just prior to electric power disturbance, Nov. 9, 1965

Utility	System load, Mw.	Generating capability, Mw.	Resources used to meet load		
			Generation, Mw.	Net received, Mw.	Total, Mw.
Niagara Mohawk Power Corp	3, 405	2,681	2,556	+849	3, 405
Rochester Gas & Elec. Corp	500	350	296	+204	500
PASNY [1]—Moses-Niagara	0	2, 500	2,274	−2, 274	'0
PASNY [1]—Moses-St. Lawrence	480		700	−220	'480
New York State Elec. & Gas Corp.	1,035	5 %	547	+501	1,046
Central Hudson Gas & Elec. Corp.	335	309	282	+53	335
Consolidated Edison Co	4,770	5, 896	4,555	+215 [4]	4,770
Long Island Lighting Co.	1,289	1,442	1,197	+90	1,289
Orange & Rockland Utilities.	232	144	121	+117	238
Hydm Elec. Pwr. Comm. Ont.	6, 400	6, 750	6,100	+300	6, 400
CONVEX.	2,626	2,685	2,583	+43	2,626
Vermont Elec. Pwr. Co., Inc. [3]	306	0	0		[3] 0
New England Elec. System.	1,300	1, 804	1, 642	-34;	1, 300
Public Service Co. of N.H.	410	385	370	+40	410
Baton Edison Co.	1,222	1,578	1,405	-154	1,351
Central Vermont Public Service Co	150	36	26	+124	150
Pa.-N.J.-Md. Interconnection...	13,600	14, 451	13, 355	+245	13,600
Detroit Edison Co	3,196	3,280	3,050	+146	3,196
Consumers Power Co	2,161	2,668	2,294	-121	2,173
Central Maine Power Co	471	581	490	-19	471
Total.	43,582	48,909	43,843		

[1] Power Authority State of New York.
[2] Wholesale supplier.
[3] Distributes PASNY power in Vermont. Not included in totals to avoid duplication.
[4] Outflow to Long Island not deducted.

from the loads in Ontario. Just prior to the disturbance then? were some 1800 mw of generation originating at PASNY's Nii plant that was flowing over the transmission system to the south and east in the United States. With the dropping of the lines to Toronto, the power being generated at the Beck plant and at PASNY's Niira plant, which had been serving the Canadian loads around Toronto, amounting to approximately 1500 mw, reversed and was superimposed on the lines to the south and east of Niagara. It was thii tremendous thrust upon the transmission system in western New York State which exceeded its capability and caused it to break up. Exhibit I-H tabulates power loads and resources for major utilities affected at the time of the disturbance.

The instantaneous result of the tripping of the lines from Beck to the Toronto area was the acceleration of the generators at Beck and PASNY-Niagara, with a sharp drop in their electrical output, but as the speed increased the electrical power output at the two plants rapidly increased. The instantaneous drop in generation at Beck and PASNY, followed by the rapid buildup, resulted in putting the Beck and PASNY generation out-of-phase with most of the other generation attached to the interconnected transmission system and this situation of "transient instability" was directly responsible for the breakup of the New York State backbone transmission system. Appendii B contains a technical discussion of the transient stability phenomenon in the context of the planning of power systems.

The first line to fail was the interconnection east of Lake Ontario between PASNY and Ontario Hydro at Massena on the St. Lawrence River which became overloaded one-half second after the last of the five lines out of Beck tripped out and was opened by automatic relays. As a result the Ontario system was separated from the New York systems, except at Niagara.

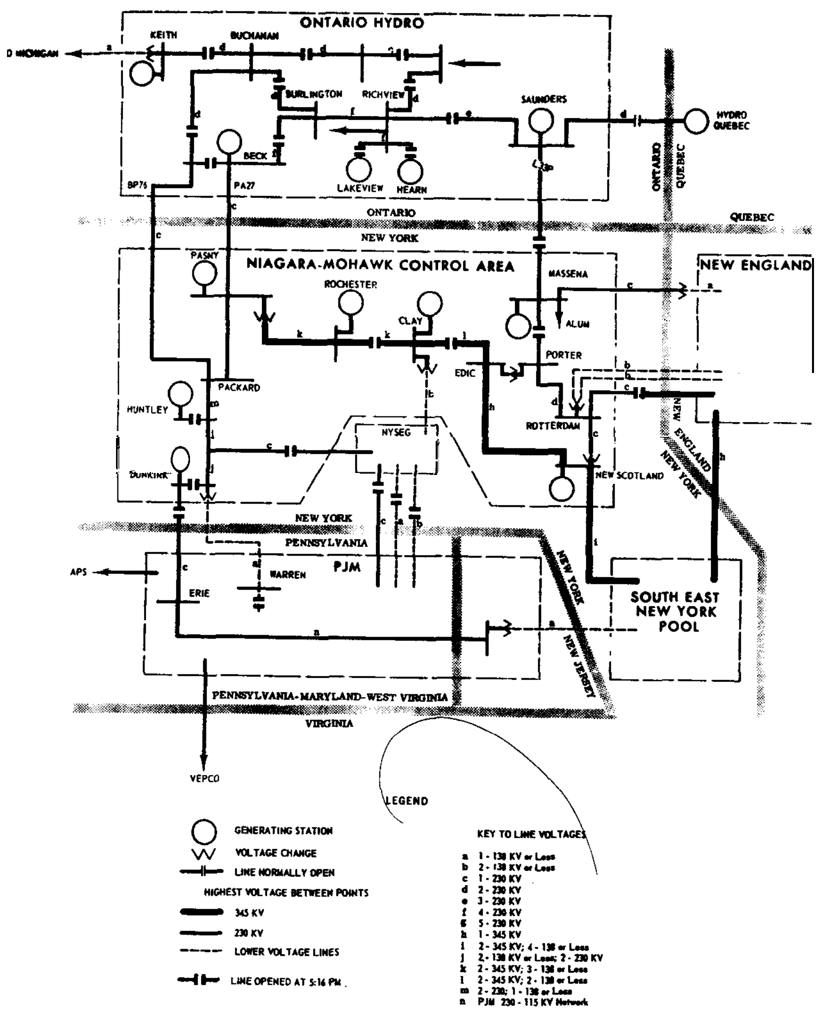
Since the output fmm the two Niagara hydroplants could not be accommodated by the remaining transmission system, at 0.9 seconds after the final tripout of all five Ontario lines the backbone transmission system broke apart electrically with the opening of the two 345-kv lines between Rochester and Syracuse, New York (the Clay substation) as well as the opening of several 115 and 230-kv circuits in the southwest Niagara Mohawk area. Also at this time ties to the PJM pool were broken both in the Niagara Mohawk area and in Brooklyn at the Consolidated Edison side of a connection with PJM through Staten Island. Exhibit I-I shows the lines that went out of service as a result of the initial disturbance. Exhibits I-J and I-K show typical relays and circuit breakers used in modem systems. Exhibit I-L, a map of the transmission systems in the Northeast, is included at the end of this chapter.

At $1\frac{1}{3}$ seconds after the separation of the Beck generators from their loads, the two 230-kv lines connecting the PASNY plant at St. Lawrence with the main 345-kv lines running from Niagara to downstate New York and New England tripped out. Thii operation simultaneously tripped out five of the 16 generators at the St. Lawrence (Massena) plant of PASNY. The automatic trip-out of the generators took place in accordance with predetermined operating procedures. The St. Lawrence hydroplant was designed so that the remaining generators could continue to function in supplying the large industrial loads in the vicinity of Massena. Had all of the generators remained on the tine this would probably have created a surge on this system which would have taken out all service in the vicinity of Massena.

The generators at the Beck plant were not designed with relays to trip them out under these circumstances. While at PASNY's St. Lawrence plant the breaking of the transmission lines to the loads in Canada had been considered to be a reasonable contingency and provision was made for its occurrence, at Niagara the contingency of the five lines to the north being lost simultaneously was unanticipated.

Within four seconds after the initial relay operation at the Beck Plant, the CANUSE area was broken into four isolated sections, plus Maine and a part of New Hampshire which did not lose service. First, the Ontario system was completely separated from New York and was badly deficient in generation. Second, the area around PASNY's St. Lawrence plant was isolated, but the plant continued to carry the loads of the Aluminum Company of America, Reynolds Metals Company, General Motors, City of Plattsburg and Plattsburg Air Base. Third, the region around Niagara on the United States side (the Niagara-Dunkirk area), was separated from the remainder of the interconnection and now had large excesses of generation. Fourth, the remainder of the CANUSE area including a portion of upper New York State, the New Eng-

794-080 O-65-3



INITIAL TRANSMISSION LINE OUTAGES
NORTHEASTERN BLACKOUT NOVEMBER 9, 1965

EXHIBIT I-I

land systems and the systems in the southeast New York area, was separated from the rest of the group but remained interconnected within itself. Exhibit I-M shows the areas of separation. The area in Maine and New Hampshire where service was not affected is being designated as No. 5.

As to the first area (the Canadian area) the Ontario system split into three sections, dropping some 3800 megawatts of load in the process. Since it was separated from New York it no longer had any impact on the systems in the affected U.S. area. With the assistance of power flows from Michigan,. service was maintained in the western sector of Ontario.

The second area around PASNY's St. Lawrence plant continued in operation as described above.

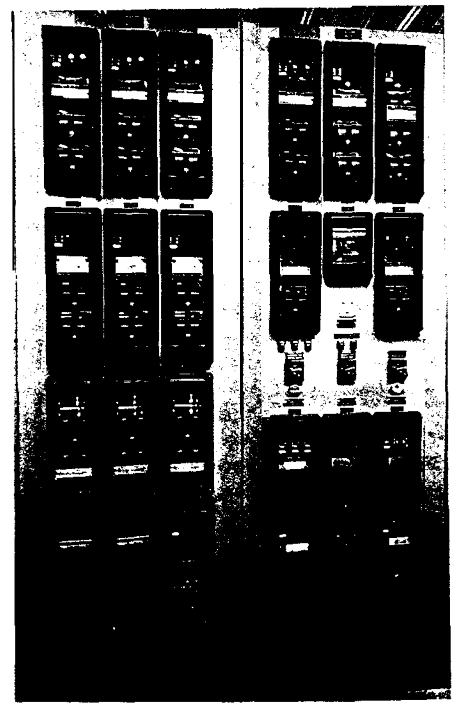


Exhibit I-J. These relays on the Clay-Edic 345 kilovolt transmission line of Niagara Mohawk Power Corporation are typical of those used throughout the area. When changes in the characteristics of the power flows exceed preset limits, the relays operate and activate the circuit breakers that open the line.

The Shut-Down of the Generating Plants in the Niagara Area

The breakdown of the transmission grid in the third area, around Niagara-Dunkirk, left it, alone of the four areas, with an excess of generation. Thii caused all the generators in the area to speed up and the frequency to rise. The steam plants in the area including the major plants of Niagara

*Exhibit I-K. These oil circuit breakers at the Clay Sub-*station of *Niagara Mohawk* Power *Corporation were activated* by *the relays shown* in Exhibit *I-J, and opened the lines they serve about 3½ seconds after the initial disturbance.*

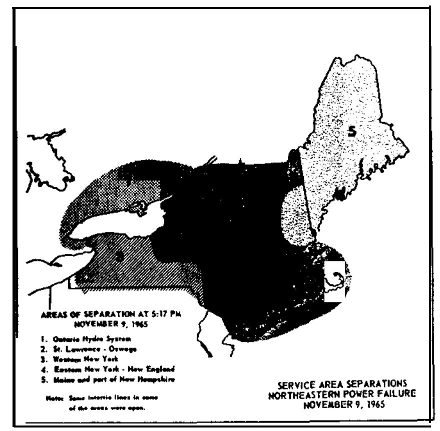


EXHIBIT I-M

Mohawk at Huntley and Dunkirk were then shut down by automatic governors because, unlike a hydrostation, high frequency in a steam turbine risks serious damage to the turbine blades.

The shutdown of the steam plants in the Niagara-Dunkirk area was followed in less than one and one-half minutes by the tripping off of the generators at the Beck plant. The reason for the shutdown at Beck was that the hydraulic mechanisms positioning the turbine gates attempted to adjust to the violent load fluctuations and in the process their hydraulic oil supply was depleted to the point that the oil pressure was too low to permit the gates to function properly. The protective relays that were designed to detect such an emergency then operated to close the gates and thus shut down the units.

With the load in the area now exceeding remaining power supply the frequency began to fall. The frequency continued to fall and when it dropped to 58½ cycles two 230-kv lines connecting the PASNY Niagara and Ontario Beck plants disconnected as dictated by the settings of the underfrequency relays controlling these lines. The two lines had remained closed during the initial surge of power from the United States because, while they were protected by overload relays set to trip out at 864 megawatts, these relays were time relays and could not have operated during the less than one-second interval before the breakup of the main transmission system. After the initial disturbance, the flow south from the Beck plant did not exceed 864 megawatts for the required time to operate the relays.

The Breakdown in New England and Southeastern New York

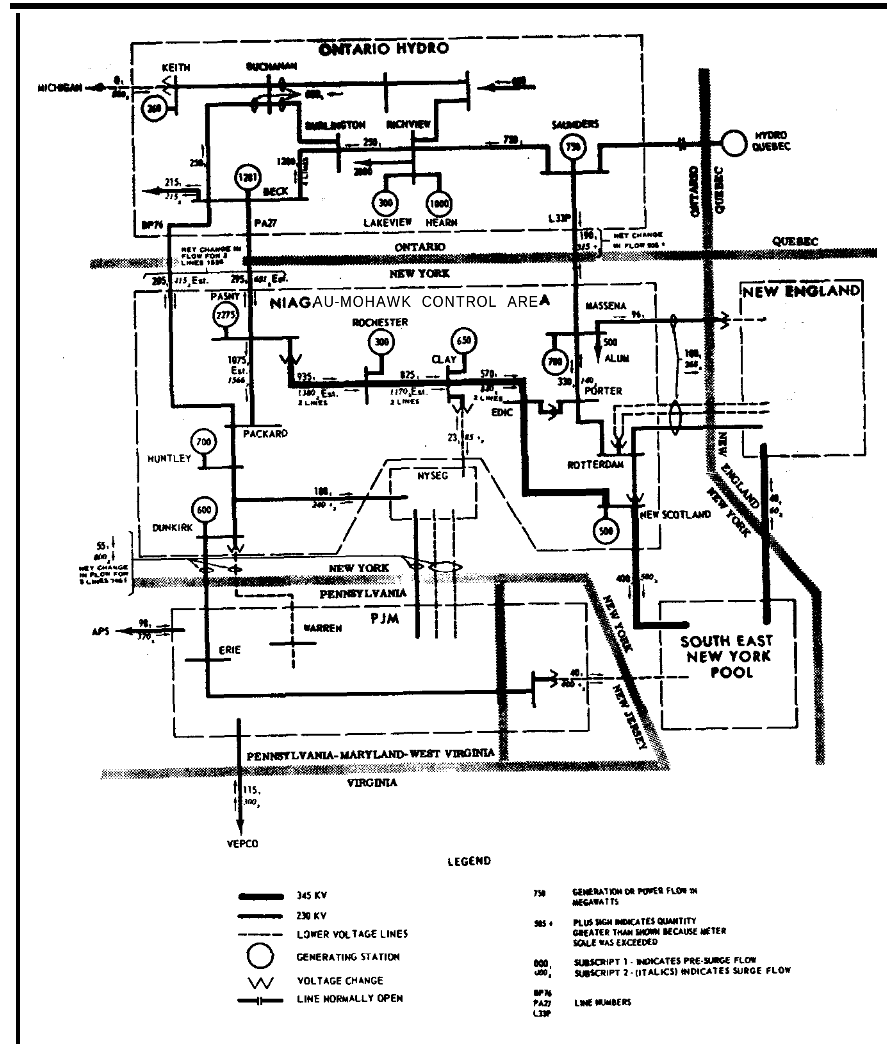
Before the disturbance, New England was importing 140 mw and the downstate New York State area 400 mw, a total of 540 mw from the upstate New York systems. (The power flows in the CANUSE area at this time are shown on Exhibit I-N.) Within four seconds, the upstate New York area east of the point where the PASNY and Niagara Mohawk systems had split, which was still tied to the New England and southeast New York areas, had a deficiency in generation in the order of 1100 mw. This deficiency created a drain on the power resources in New England and the southeast New York area. However, the deficiency in generation in upstate New York could still have been supplied if there existed sufficient spinning reserves (capacity on the line but not generating power) in the New England and New York City areas over and above the generation which was already being used to meet their own loads.

The spinning reserve capacity on the line in these areas was adequate in total, adding up to some 1650 mw, but the problem was whether the spinning reserve could respond quickly enough. The spinning reserve was mostly in steam plants and there is an inherent time lag in the response of steam generators to large changes in output. Time was required to increase fuel consumption and steam output. Responsive capability of the spinning reserve also was significantly affected by the way in which the total amount of spinning reserves was distributed among the various generating units and plants at the time.

It developed that the reserves on the systems in the New England and the southeast New York area were not adequate in responsive capability to meet the drain imposed upon them. Accordingly the frequency on these systems continued to fall. This created a cascade effect within the steam plants since the reduced frequency further restricted the output of the pumps and other auxiliary equipment required for steam generation. One by one the steam plants were shut down to prevent destruction.

Consolidated Edison was operating at 5: 16: 11 p.m. on November 9 with a system load in the range of 4800 mw. (The net loads are shown on Exhibits I-O and I-P.) The capacity of the 47 steam units it had on the line at the time was approximately 5900 mw, the difference representing spinning reserve. It was receiving power, according to schedule, from Niagara Mohawk (360 mw) and the PJM pool (40 mw), and transmitting power to the CONVEX pool (35 mw) Long Island Lighting (80 mw), Orange and Rockland (115 mw), and to Central Hudson (35 mw) as shown on Exhibit I-P.

Within seconds after the initiation of the incident, Consolidated Edison found itself in a situation in which the flows into its system from both Niagara Mohawk and PJM had ceased. While the intertie with PJM in Brooklyn had broken, the 345 and 138-kv circuits to Niagara Mohawk remained intact, with the result that Consolidated Edison at once began to feed upwards of 560 mw of power to the



POWER FLOWS IN NORTHEASTERN SYSTEMS AT TIME OF NOVEMBER 9, 1965 POWER FAILURE

EXHIBIT I-N

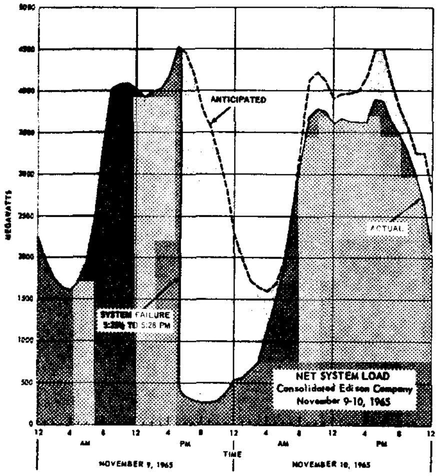


EXHIBIT I-O

now isolated eastern segment of the Niagara Mohawk system. At the same time its transmission to CONVEX reversed and for a period of 2 to 3 minutes Consolidated Edison received an average flow of 180 mw. Likewise Long Island Lighting instead of receiving 80 mw began to send about 20 mw into the Consolidated Edison system for 2 to 3 minutes. This transfer dropped for a minute to zero and then ascended to an input to Consolidated Edison which ranged between 50 and 120 mw for a period of 3 minutes. In net effect, the total load upon Consolidated Edison's generation equipment increased instantaneously by something between 600 and 800 mw, was sustained in this range for about 2 minutes, and then increased to well over 1000 mw when the inflow from CONVEX of 180 mw rapidly changed at about 5: 19 p.m. to an outflow in excess of 240 mw. The added burden on Consolidated Edison again increased at about 5:23 when Long Island severed its tie, in a fruitless effort to save itself, interrupting the power which it had been sending into the Consolidated Edison system.

There were only two basic ways in which this increased demand on the Consolidated Edison system could have been met: by shedding some of its own load or by increasing generation by its own units. The company had no large industrial customers whose loads could be dropped in an emergency, but it was possible to close down particular sections of its system, and this was belatedly attempted in at least one area. In retrospect it seems likely that a timely shedding of the load in some sections of New York might have avoided a city-tide blackout in New York and the breakdown of service elsewhere, as well as facilitating restoration of service.

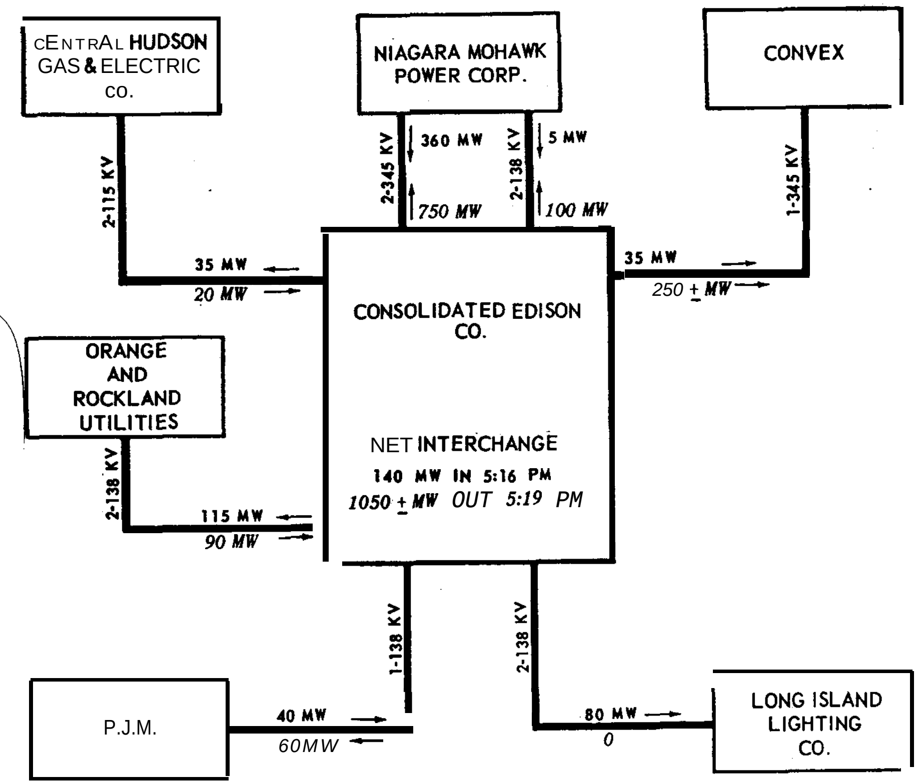
Load could also have been reduced by severing the ties with the interconnected systems. This, Consolidated Edison's system operator eventually attempted to do, insofar as the major drain towards Niagara Mohawk was concerned. It is not clear whether this action was completed before the system went dead; in any event it was not successful.

Consolidated Edison placed its principal reliance, during the brief period before the system went dead, upon the ability of its 47 steam plants then in operation to take advantage of their reserve capacity of about 1100 mw. As we have stated it proved impossible to load this capacity quickly enough. The problem was complicated by the fact that a very large percentage of the reserve capacity (some 350 mw) was in one unit, the 1,000 mw Ravenswood No. 3 generator. Within a matter of four or five minutes this unit was able to increase its power by about 80 mw, and it had reached a peak increase of 110 mw just prior to system breakdown. Thii was a good performance under the circumstances, but nevertheless, it appears that in this unit alone some 240 mw of spinning reserve was never brought into service.

Thus, despite an initial increase there was not enough generation to carry the increased load. The frequency on the system fell lower and lower, and the auxiliary electrical equipment on the steam boilers became less and less operable. A situation was rapidly reached in which one after the other the steam plants were taken off the line in order to avoid permanent damage. The result was that after a few minutes of affirmative but inadequate response to its increased load demands, the system reached a point at which it started to disintegrate at an increasingly rapid rate and finally was closed down altogether.

The decision whether to separate from other systems, insofar as Consolidated Edison was concerned, was left to the system operator on duty. Exhibit I-Q shows a typical control center and some of the multitude of instruments involved in system operation decisions. Under the emergency operating instructions which are the general guidelines set forth

CONSOLIDATED EDISON CO.
APPROXIMATE POWER TRANSFERS WITH OTHER UTILITIES
BEFORE AND DURING THE DISTURBANCE OF
NOVEMBER 9, 1965



POWER FLOWS AT 5:16 PM (BEFORE SURGE)
POWER FLOWS AT 5:19 PM (PEAK OF OUTFLOW)

EXHIBIT I-P

for all interconnected systems by the North American Power Systems Interconnection Committee (NAPSIC) (the full text of which is attached as Appendix D) a system operator is instructed that:

"When a system disturbance occurs, a prime consideration is to maintain parallel operation throughout the interconnected system if at all possible. This will permit rendering maximum assistance to the system in trouble and may prevent cascading of trouble to other parts of the interconnection and assist in restoration of normal operation."

The guide also provides that :

"If an overload persists on a tie toward a neighboring system or pool:

a. The affected system or pool shall notify the neighboring system or pool of the magnitude of the overload and request immediate relief.

b. If intolerable overload continues and equipment is endangered, the affected system or pool may open the overloaded ties."

System operators must give serious weight to both these instructions. Of course the whole concept of the interconnected system depends upon mutual support in time of trouble. It is also important that a system operator should not be overly quick to separate in the case of low frequency since it may be possible to hold the *system* together, as was done by Consolidated Edison in a previous case.

There were no outstanding instructions by CANUSE or Consolidated Edison specifying, in terms of frequency loss or otherwise, under what particular circumstances particular interconnections should be severed or particular load segments of Consolidated Edison's system temporarily disconnected in order to save the remainder.

The Consolidated Edison system operator on duty had full authority and responsibility both with respect to load shedding and severing ties with other systems. Whether because of lack of clarity in the control room instrumentation or for other reasons,

EXHIBIT I-Q. *The 65th Street control center of Consolidated Edison is typical of operations centers in large systems.*

the system operator did not make an immediate clear-cut decision in this emergency. Availability of clear indications of system frequency together with standing instructions setting a minimum frequency at which the operator should open ties which were draining power from his system or shed some of his system's loads might have prevented the collapse of the Consolidated Edison system.

It must be recognized that premature opening of ties will work to the detriment of other systems which are in trouble, and the criteria or standards under which pooled systems will abandon mutual assistance and try to save themselves must be coordinated throughout the group. Efforts should be made to shed load within systems when necessary to maintain the integrity of ties between systems.

The circumstances which faced all of the electrical systems in New England as well as the smaller systems in the New York area appear to have been somewhat similar, but we do not yet have sufficient facts to describe in detail their response to the emergency. While the facts varied somewhat from case to case, in general each company was faced with a sudden increase in load of substantial proportions and a drop in frequency. For one reason or another they were not able to shed loads and maintain interconnected service or to separate their systems from their interconnections and to rely on their own generation to meet their loads. In most systems, by 5:28 p.m. at the latest, operations had ceased except for some remote areas served by hydro facilities. Most of lower New England and southern New York was blacked out some 12 minutes after the initial disturbance in Canada.

The transmission system map included as Exhibit I-L, is keyed to a sequence of events listed on the page facing the map. A more detailed description of the sequence of events is given in Appendix A.

Determining the Source of the Incident

Unravelling a *mystery* is intriguing. It may be of interest, therefore, to describe the procedures used by the Commission staff and experts and by Ontario Hydro to locate the origin of the failure.

This disturbance was unique in the magnitude of its consequences. It was most uncommon in that the origin of the disturbance was not betrayed by equipment failure or other external evidence.

An outage caused by a short circuit, by a break in a transmission line resulting from storm or other casualty, by a broken insulator or an exploded transformer or circuit breaker, leaves tangible evidence. When this outage first occurred there was no obvious cause of thii kind. Each system, therefore, checked its equipment and no faulty equipment was found. Thii situation create-d a need for deeper research than would normally be necessary. The widespread effect of the incident and the enormous range of possibilities within such a large group of interconnected companies complicated the task of data collection and analysis.

On the morning of November 10, while some of the companies were still struggling with the problems of restoration of service, the Commission and its staff met with a group of power system analysts assembled from all parts of the country to begin the task of piecing together the initial fragments of information which were being telephoned in bit by bit. At that time, in addition to negative information on equipment damage, it became clear that the incident was precipitated at approximately 5:16 p.m. on November 9, but the reasons and the location of the initial disturbance were largely speculative. It was thought that it resulted from the loss of a major source of generation or load by one of the CANUSE systems. Therefore, the effort was devoted largely to making arrangements for securing the additional information which was essential before proceeding further with the analysis.

The next day: November 11, the Commission and its experts began the interrogation of the operating officials of the principal companies involved, who presented a great deal of pertinent information. On the basis of this information the Commission and its advisory panel of experts were able by the evening of November 11 tentatively to reconstruct a pattern of power flow before and after the disturbance as well as the frequency conditions over the entire affected area. Some difficulty in interpreting the data, particularly as regards changes in frequency, left several avenues of speculation open to the experts. To eliminate each of them was time consuming. In the end, to pinpoint the source of the initiating cause it was necessary to reconstruct a pattern of frequency changes and load flows on the affected systems.

The experts continued to assemble and analyze the mass of recording charts which the companies had provided until in the early morning of November 15 it became apparent that the only possible explanation which would fit the pattern of disturbance was the sudden reversal at Niagara at

5: 16 p.m. on November 9 of a large block of power, in the order of 1.5 million kilowatts. This conclusion was reached by plotting on a schematic dim of the CANUSE area the generation plant outputs, transmission line power flows at the instant prior to the disturbance, at the time of the first significant change in these quantities when increments of power flowed outward from the Niagara area across the affected transmission systems and into adjoining interconnections, and at the time of the second significant change when increments of power flowed back toward the Niagara area from the interconnected systems.

While the above approach gave almost conclusive evidence that the disturbance was initiated in the Niagara area, it was not readily evident, in view of the arrangement of transmission facilities in the Niagara-Reck area, how a large block of generation external to the PASNY Niagara plant could have been transferred from the Ontario Hydro system to the New York systems. It was still impossible with the evidence at hand for the experts to determine at this time the nature of the triggering event which caused the disturbance.

It should be explained here that the chart data, which provide information on frequencies, power flows on transmission lines and power outputs of generating plants, are automatically recorded at various key locations on the power systems but, of necessity, this information is recorded on a compressed time male. The chart material, therefore, does not show clearly the variations which occurred during fractions of a second. (Exhibit 1-R) Considering that power flows at the speed of light, 186,000 miles a second, the sequence of power reactions may take place on a split-second basis. In addition to chart data the utilities maintain oscillographic equipment which provides a record of data during periods of disturbance on a magnified time scale so that changes are recorded in terms of cycles (1/60 of a second). Oscillograpbic information did not become available to the Commission and its experts until Monday, the 15th, at which time it was possible to develop a chronological sequence of the tripping out of various transmission lines and generating plants on the New York State and Ontario Hydro systems.

When the Commission's hearing resumed on November 15 the remaining area of uncertainty was cleared up by the Ontario Hydro spokesmen. Over the weekend they had made an intensive study of their own records. These demonstrated, as already described in some detail in this report, the original tripping mechanism on one d the Ontario-Toronto lines and the subsequent tripouts on the other four lines which isolated the Reck Plant from the Ontario system and transferred its generation south. (See Exhibit I-S.) The oscillograms also made clear the precise time sequence of the tripouts of the various other transmission lines and power plants so that the interrelationships between them could be determined and the successive events described. Exhibit I-T is a reproduction of Consolidated Edison's meter record of its 345-kv lines' interchange with Niagara Mohawk.

Geneml Description of Electric Systems

A few words of explanation concerning the business of furnishing electric service may be helpful by way of background.[5] Providing electric service in-

[5]For a more detailed description of the electric power industry and guidelines for its coordinated growth in the future see the FPC's National *Power* Survey, December *1964.*

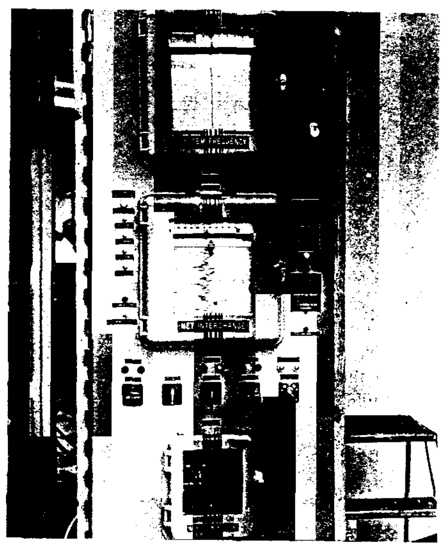


Exhibit I-R. These recording meters, at the Syracuse Area Control Center *of Niagara Mohawk Power Corporation, gioc the system* operators an *instantaneous graphic view of the performance Of their system. Similar meters provide visual and permanent records of operations on each major component of the system.*

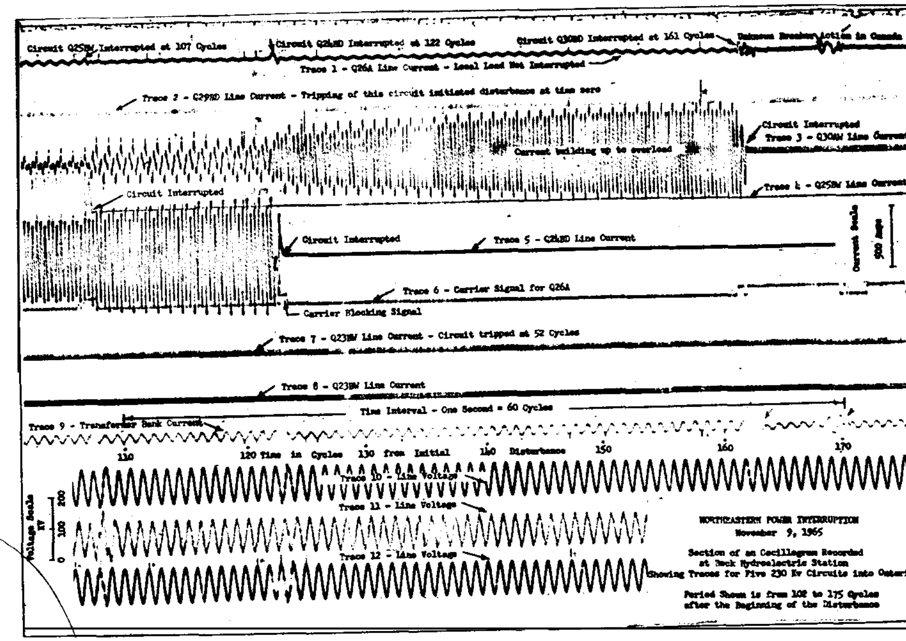


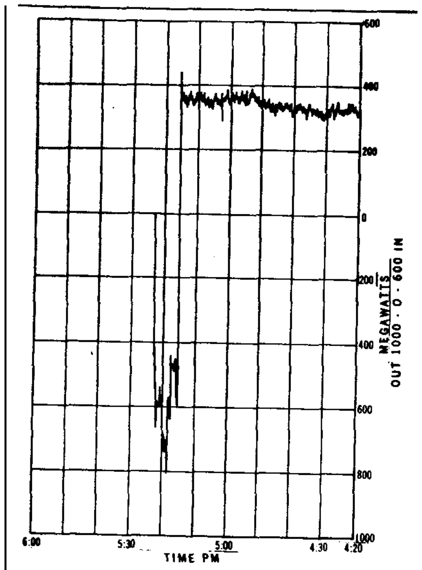
EXHIBIT I-S

volves three functions: generation, transmission and distribution. They are roughly equivalent to the manufacture, shipment to market and retailing of any product. The generation and transmission functions, combined, are referred to as "bulk power supply," and distribution is the final leg of the journey to the ultimate consumer.

While a failure in distribution may cause a local service interruption, this was not the type of problem which caused the power failure of November 9, but rather a failure in the bulk power supply for the New York-New England-Ontario area.

The general characteristic of all electric utility systems is a widespread distribution of electric loads supplied with power from a limited number of electric generators. These generators may be remote from the load areas because of their location at waterfalls, near coal supplies or adjacent to large supplies of cooling water. The connection between the loads and generators is through high voltage transmission lines which provide a path on which the electric energy flows. The path however, is not a single toad between a specific generator and a specific load, but is a network of lines with loads supplied at many intermediate points called substations, from which distribution lines may radiate.

Some substations are terminal points for lines which bring power in at transmission voltage and which reduce the voltage to that required in the distribution area. Other substations serve only a switching function, and provide facilities to permit isolation of portions of the system in the event of trouble and the transfer of power from one line to another. Most large substations serve both the switching and transformation functions. Since them may be many lines connected to a substation, the failure of one line only requires its removal from service in the network so that the remaining lines



CONSOLIDATED EDISON ,COMPANY
POWER INTERCHANGE
NIAGARA MOHAWK 345 KV LINES
November 9, 1965

EXHIBIT I-T

can continue to function and avoid a stoppage of the electric flow.

The removal from service of a faulty line in a transmission system is accomplished by pieces of equipment called circuit breakers which can switch the lines on and off. The device that determines when a circuit breaker should operate is called a relay. The relays on a power system are complicated devices which continuously measure electric quantities and determine when the power system is in trouble and where the trouble is located. These instruments then relay this information (hence the name) to the circuit breakers which open to isolate the faulty line or other equipment from the rest of the power system.

During storms them may be many short circuits but the operation of the relays and circuit breakers and related equipment prevents the shutdown of the power system. The failure of a circuit breaker to operate during system disturbances causes an extremely hazardous condition, and while circuit breaker failure is a rare occurrence, the consequences are so severe that utility systems provide additional relays called back-up relays that sense this condition and operate other circuit breakers to clear the faulty facility.

Transmission lines both carry electric energy from the generators to the loads within a single utility and provide paths for electric energy to Row between utilities. These latter lines are called interconnections and enable the utilities to operate as a team to obtain benefits which would otherwise not be available.

When power systems are electrically connected by transmission lines they must operate at the same frequency, that is, the same number of cycles per second, and the pulsing of the alternating current must be coordinated. As a corollary, generator speeds, which determine frequency, must also be coordinated. The various plants are then said to be operating "in parallel" or "in synchronism", and the system will be said to be "stable". A sharp change in loading at a plant will affect the frequency, but if the plant is strongly interconnected with other plants they will normally help to absorb the effect of the changed loading so that the change in frequency will be negligible and system stability will be unaffected. Since each interconnected generating unit helps to cushion the effect of a disturbance anywhere on the system, a large system, if it has ample generating capacity and is solidly interconnected, has great strength in meeting emergencies. Conversely, if generating capacity is inadequate for system support or transmission interties are weak, the tendency of each generating unit to support the others could result in system instability and a consequent cascading of trouble.

Interconnected operation requires coordination in system planning and operation since the failure of any part of the electric system can affect much larger geographic areas. It is of particular importance to determine that the loss of a generator or a transmission tie will not cause the cascade failure of other equipment ending in the eventual shutdown of the interconnected system. Planning studies using computers to simulate the operation of the electric system am conducted before new interconnections are made. In a fully coordinated system or pool, these studies will cover the consequences of all credible incidents in order to determine that they will not cause a massive failure. In the same studies a determination is made as to the additional facilities, including those internal to the individual

systems, required to assure continuous service under all foreseeable conditions.

To permit effective interconnected operation requires the development of strong transmission networks capable of handling heavy flows of power during both normal and emergency conditions. This requites the use of extra-high-voltage lines. Many such lines are being added to networks today, having capabilities which are commensurate with the large-size generating units being installed and with the increasing growth in electric loads.

Them are great economies of scale in bulk power supply. These economies are part of the reason the power companies operate their own systems as a unit and interconnect with each other to form power pools.

The term "power pool" is sometimes used rather loosely to describe any group of companies that are interconnected. The label can be misleading. The mere fact that utilities are interconnected does not mean that they have achieved the economies of scale or the increased reliability of service which is afforded by a fully integrated power system or pool.

Power pooling is but an extension of one of the basic characteristics of electric utility service. In the early days of the industry service to a community might be dependent upon a single generating station and in those days service was subject to frequent and extended interruptions. As loads grew, service was provided from more than one generating station and they were tied together. It then became possible to assure more dependable service since each station backed up the other.

Each large utility thus constitutes in effect a pool in itself, and interconnections among neighboring systems are no different in principle than the ties among the stations of a single utility. However, the prerequisite for the establishment and satisfactory performance of such a pool is a reliable and adequately developed transmission system in each of the utilities making up the pool.

The first step in power pooling is interconnection by means of transmission lines with sufficient capacity to permit automatic emergency assistance. Such interconnection lowers the Cost of producing electricity by permitting each participant to utilize larger and mom efficient units and to reduce the total amount of generating capacity necessary to meet its load including its maintenance requirements and reserve for forced outages. It also provides much greater flexibility in the location of generating stations. For one example power networks permit location of plants at a distance from heavily populated areas and thus minimize the growing air pollution problem in our metropolitan centers.

The two advantages already cited, ability to use large plants and relative flexibility in locating them, enable power pools to utilize nuclear plants to advantage where the smaller independent systems could not. Capital and operating costs of small nuclear plants are high compared to those of equivalent steam plants, but the costs fall rapidly with increases in size.

Power pools have been instrumental in increasing the reliability of electric service. Equipment failures occur from time to time on power systems throughout the nation without causing any interruption in service. For example a large generating plant in Indiana failed on November 1 of this year with no interruption in service. Usually all that a customer will see is the flicker of hi lights, because in the great majority of cases when a generating unit or transmission facility fails the service is continued instantaneously by other facilities on the affected system and through the mutual help provided by strong interconnections.

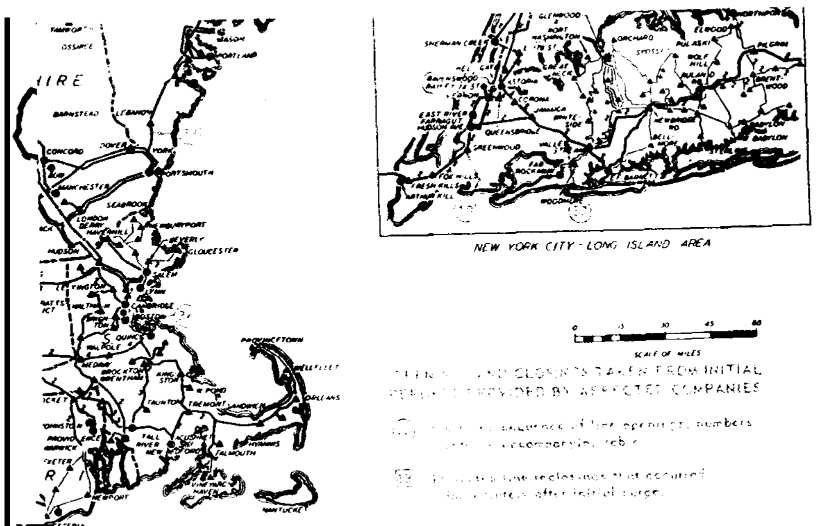
The same power network that blacked out on November 9 has supplied uninterrupted service on numerous other occasions when there were major disturbances. For example, the instantaneous transfer of power from Canada has replaced power lost through the breakdown of a generating unit in New York City, and New York City in turn has prevented outages upstate. Even today, New York City, which temporarily lost 1,500,000 kilowatts of generating capacity as a result of the disturbance of November 9, is being protected from a power shortage by the grid which collapsed that night.

EXHIBIT I-L

Condensed Summary of Sequence of Events

(For detailed description of each item see Appendix A)

Event Number	Time Hour/min/sec	Events
1-5	5:16:11	The first of the S-230 kv lines (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 lines and other paralleling networks to Syracuse and back to Ontario via 230 kv lines to Massena on the St. Lawrence.
6	5:16:14.3	The 230 kv line connecting PASNY and Ontario at Massena opened by over current relay action.
7	5:16:14.5	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.
9	5:16:14.5	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 lines tripped open.
10	5:16:14.6	Consolidated Edison Co. separated from PJM system at its Greenwood Substation in Brooklyn by relay action caused by excessive power flow.
8, 11, 12, 13, 14, 16, 17	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.
23, 24	5:16:15.8	After a number of rapid openings and closings, the two 230 kv lines extending from Massena 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 generators of the Massena plant of PASNY.
26	5:16:——	Two 115 kv intersystem ties in New England tripped open.
27, 28, 29	5:17:15.1	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.
31, 32	5:17:30 to 5:18:30	The two 230 kv ties between Ontario and PASNY at Niagara opened by under frequency relay action.
30, 35	5:17 to 5:21	CONVEX manually opened its ties to the rest of New England.



ELECTRIC POWER FACILITIES
IN NOVEMBER 9, 1965 BLACKOUT AREA

****

NORTHEASTERN UNITED STATES
AND ONTARIO, CANADA

Exhibit I-L

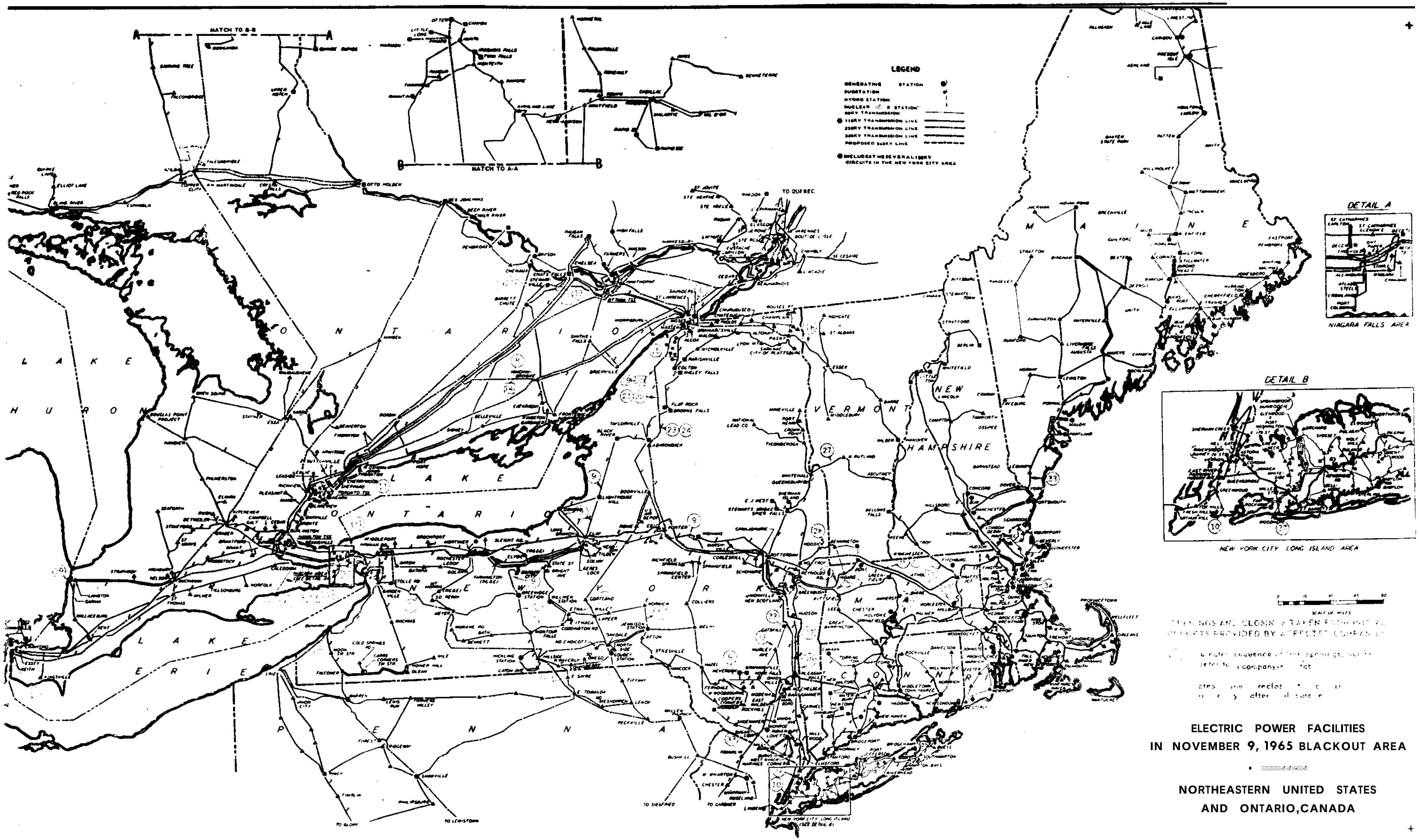


Exhibit I-l

[redacted]

8,

Chapter II

PROTECTING AGAINST THE LIKELIHOOD OF A RECURRENCE

When a failure occurs on any part d a power system it is incumbent on management to analyze it carefully to determine whether it could happen again. The blackout d November 9 has also raised the question of possible recurrence in the minds of the American people.

The Canadian authorities have already taken action to prevent a recurrence of the relay operation which triggered the November 9–10 blackout but the risk of a precise repetition of the power failure is not the main point. The basic questions are whether other previously unanticipated malfunctions or disturbances could create a recurrence of a similar cascading failure in the CANUSE area, and what economically feasible measures may be adopted to prevent widespread service outages in the future.

Each service outage teaches us lessons which should lead to more reliable service in the future. What we have learned from this experience does not indicate the likelihood that any failure within a fully coordinated power pool will cascade into a massive system outage. The key words are "fully coordinated." Nevertheless, we believe it necessary to reexamine the design and operations of power systems generally. In greatest need of reexamination in the light of the recent experience are those interconnected areas which are not yet fully coordinated either in their planning or operation and which may include systems whose own transmission networks are internally weak

By "fully coordinated" or "integrated" we mean that the interconnected system, whether of a single company or a pool of many companies, is designed, planned and operated as a unit, so that each part will fully reflect the duty which might be imposed upon it as a part of the system. The economic corollary is that the system will be operated for maximum economy consistent with the standard of reliable service.

It is necessary to distinguish sharply between failure of equipment and failure of service. The risk of failure of equipment is inherent in any mechanical device, and initially the risk may be increased by the very pioneering on the frontiers of science and technology upon which the long-term advancement of the industry and its consumers is dependent. There may be risk in increasing the size of generating units, in escalation of transmission voltages beyond current levels of practice, and in fact, in every new and experimental way of doing a better job. If the industry's prime objective were to avoid any risk of equipment failure, pioneering in improved equipment would stop and the American consumer would be the loser in terms both of service and costs.

In a well designed power system, however, the risks of equipment failure should not constitute a jeopardy to continuity of service. Every major power system has designed into it numerous factors d safety. There are large numbers of accidental breakdowns of major items of equipment for which account is taken in system design and of which the public is rarely aware.

To illustrate the distinction between equipment and service outages, we refer to some major equipment outages of which the public was totally unaware. The American Electric Power (AEP) system, for example, has had outages of generation ranging from 300,000 to 660,000 kw which have occurred with a loss in frequency of only about one-fortieth of a cycle (0.025 to 0.026 cycles). In the converse situation, when large loads ranging from 450,000 to 1,125,000 kw went suddenly off the line, with the aid of interconnections, the AEP system was able to sustain the shock of excess generation with a rise in frequency of only about 0.04 cycles. None of these instances involved any adverse effect upon service. As a result of the series of tornadoes on April 11, 1965, in Indiana and Ohio the AEP system lost twenty-one 138-kw and seven 345-kw lines. This disaster separated the AEP system but loads were rerouted and there was no loss of load or generation beyond the storm area.

The Florida Power Corporation on January 28. 1965 lost 480,000 kw of generation, an amount equal to about half of its total load, but with the help of interconnected systems there was only a slight and brief drop in frequency and with the exception of one industrial customer which was buying power on an interruptible basis then was no disruption in service.

An incident involving a massive equipment outage occurred on the Tennessee Valley Authority (TVA) system on January 19, 1964 when high winds blew some sheet metal into the 161-kv substation at the Paradise Steam plant in Kentucky causing a short circuit and separating the plant from the system. The plant was generating a total of 1250 mw, as compared with the 1500 mw flow reversal at Niagara on November 9. The system frequency declined by only 0.05 cycles. Loading on the interconnections with neighboring systems increased immediately from a zero level to 1175 mw. Within four and one-half minutes generation on TVA's own system picked up the total generation lost at Paradise. There was no interruption of service other than for a small amount of industrial load supplied directly from the Paradise switchyard.

Service continuity despite equipment outages, other than for the local areas dependent on the equipment, should be regarded as routine where the systems are designed to handle all the contingencies to which they may be subjected. This is not to say that service outages do not occur. In fact, the outage of November 9 was not a wholly unique experience either for the Northeast or for other parts of the nation even though, in general, continuity of electric power service has improved over the years. On August 17, 1959, and again on June 13, 1961, major portions of New York City were blacked out for several hours because of mechanical failures within the bulk supply elements of the power system. There have been several major outages during the current calendar year. On April 11 and 12, a series of tornadoes left many areas in the Midwest without power, although as we have mentioned the service outage did not cascade beyond the area of initial disturbance.

These outages were major in terms of the generating equipment and loads involved, but their effects did not attract major public notice because they were isolated within or near the area of direct damage by the protective devices in use. Every power system experiences occasional outages of these types, and of varying degrees of intensity.

One recent outage, which took place on January 28, 1965, has many points in common with the November 9-10 blackout. It covered most of Iowa and parts of five other states in the Midwest, affecting a larger area but considerably fewer customers (approximately 2 million) than the Northeast outage. Service was restored within 2½ hours. The Midwest problem was triggered by a loose connection in a protective relay circuit at the Corps of Engineers' Fort Randall power plant, in South Dakota, which opened and as a result the Fort Randall generating station bus was isolated, dropping six generators (240-m" of generation) off the line. This loss of generating capacity threw an abnormal load on other sources of supply, and caused the same general type of frequency variations and flow reversals that occurred in the Northeast. A report based on information from the Bureau of Reclamation, the marketing agency for Federal power in the Missouri River Basin, on the outage in the Midwest in January is attached as Appendix C. The areas affected by the January and November blackouts, and the duration of the outages, are shown on Exhibit II-A.

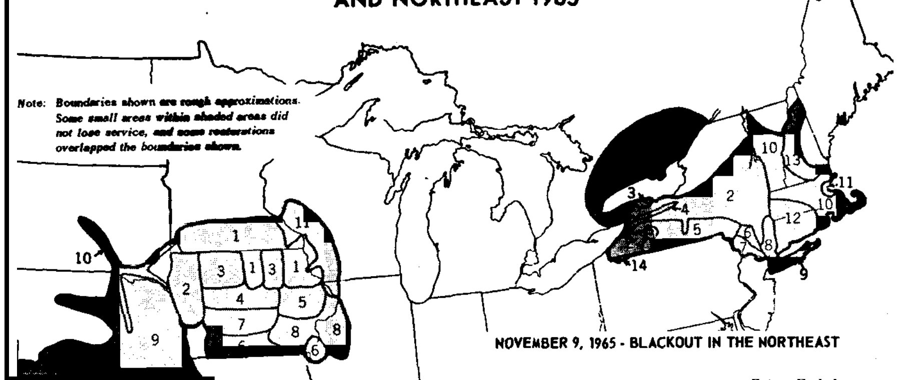
The measures to minimize the recurrence of the spread of any outage can be divided into two categories. First, there are the measures to strengthen the grid so as to minimize the possibility of any outage; and, second, there are the measures to prevent the spread of major unanticipated disturbances which the grid was not designed to handle. We shall fint examine the possibilities for strengthening the systems in the CANUSE area and then discuss whether measures can be taken so that any future outages may reasonably be limited to a small portion of that area.

Measures to Strengthen the Grid

As we have stated there is a vast difference among the power grids of this nation. Any interconnected group of companies is sometimes loosely referred to as a pool, but some are designed with such strength as to be virtually invulnerable to widespread outages, unless perhaps from an act of war or similar catastrophe, while others are linked only loosely. The power companies in the northeastern United States were interconnected on November 9, but it is apparent that the systems were not operating as a true power pool, that is, a fully integrated network.

In the CANUSE area the CONVEX group operating in Connecticut and western Massachu-

AREAS AFFECTED BY CASCADING ELECTRIC POWER FAILURES IN THE MIDWEST AND NORTHEAST 1965



NOVEMBER 9, 1965 - BLACKOUT IN THE NORTHEAST

JANUARY 28. 1965 - BLACKOUT IN THE MIDWEST

Systems	Outage Periods
1. Interstate Power Co.	14 min. to 2 hrs. 14 min.
2. Northwest Iowa Power Coop.	32 min.
3. Corn Belt Power Coop.	4 min. to 2 hrr.
4. Iowa Public Service Co.	S0 min. to 2 hrs. 30 min
5. Eastern Iowa Light & Power Co.	43 min. to 1 hr. 45 min.
6. Iowa Southern Utilities	S min to 1 hr. 58 min.
7. Iowa Electric Light k Porn	52 min. to 2 hrs.
8. Iowa-Illinois Gas & Electric	30 min. to 93 min.
9. Nebraska Public Power System	7 min. to 2 hrs. 30 min
10. USER	3 min to 1 hr 26 min
11. Dairyland Power Cooperative	0 to 1 hr. max.

NOVEMBER 9, 1965 - BLACKOUT IN THE NORTHEAST

Systems	Outage Periods
1. Hydro Elec. Pn. Comm. Ont.	1 hr. 31 min. to 3 hrs. 14 min
2. Niagara Mohawk Power Corp.	Momentary to 5 hrs. 14 min.
3. Rochester Gas & Elec. Co.	2 hrs. 1 min. to 6 hrs. 26 min.
4. Power Authority State of N.Y.	Momentary to 54 min.
5. New York State Elec. & Gas	1 hr. 14 min. to 6 hrs. 4 min.
6. Central Hudson Gas & Elec.	2 hrs. 8 min. to 4 hrs. 38 min.
7. Orange & Rockland Utilities	1 min. to 3 hrs. 52 min.
8. Consolidated Edison to.	8 hrs. 33 min. to 13 hrs. 32 min.
9. Long Island Lighting Co.	Momentary to 7 hrs. 30 min.
10. New Eng'd Power	Momentary to 4 hrs. 22 min.
11. Boston Edison Co.	2 hn. 53 min. to 7 hrs. 39 min.
12. Convex	13 min. to 5 hr. 58 min.
13. Public Service Co. of N.H.	Momentary
1i. Pennsylvania Elec. 6.	Momentary to 15 min.

EXHIBIT II-A

setts comes the closest to being an integrated pool. The other utilities in the CANUSE area, for the most part, operate their system as grids of their own with interties to adjoining systems for the principal purpose of exchanging surplus or firm power on a scheduled basis.

Interties of this type historically have been the forerunner of a more fully integrated power network. During the period of transition, however, serious consideration must be given to the internal strength of the adjoining systems and the magnitude of the interties. Weak ties may protect the adjoining system by separating quickly from interconnected groups as in the case of Maine but they diminish the ability of the adjoining systems to support each other in case of trouble. When the decision is made to install a strong backbone type of tie, adjoining systems in effect have combined for purposes of bulk power supply and separation is then not normally contemplated. A prerequisite to such an interconnection is that each system should be able internally to handle the consequences of a large disturbance. Its own internal transmission network must be reasonably related to the capacity of its interties.

It is possible that the very mixture of strong and weak interties within the CANUSE area and with others, such as the PJM pool, may have contributed to the inability of the affected companies to ride out the initial occurrence and hang together. From the liited analysis to date it would appear that stronger interties in some cases, such as with PJM, together with internally stronger matching systems of the individual companies and operating groups, could have substantially lessened the impact area of the initial disturbance. A final judgment as to whether this is the case must await the computer studies now under way. These same studies should

794-080 O-65-5

also prove extremely helpful in determining to what extent and in what manner further integration should follow.

The situation faced by the utilities operating in the CANUSE area is not unlike that in some other areas of the country. With the physical interconnection of adjoining companies, there arises an important responsibility of the management of these companies to assure that there is some group which can coordinate administratively the planning of the systems involved. There must be a recognition by the CANUSE group of the interdependence of each upon the actions of the other. For example, a relay setting by one not in accordance with coordinated plans can prove to be disastrous, as this incident demonstrates.

In some areas of the country, it has been possible to set up permanent, unified organizations to which the responsibility for planning and operating the pool is delegated. In other areas, informal committees have been entrusted with the responsibility of coordination and planning. In the CANUSE area it would seem advisable that the individual systems and pools should broaden the scope of their institutional arrangements and think in terms of a formal CANUSE planning and coordinating group.

Another factor of vital importance in avoiding trouble during an emergency is the type of spinning reserve available to pick up a large block of load quickly should it become necessary to do so. Based on the current state of the art, the industry should reevaluate the comparative usefulness of hydroelectric units, including pumped storage, and other fast-starting generators for use in emergencies and place a greater value on them as compared to the slower-starting types such as steam power plants, either conventional or nuclear. The type of reserve available may be as important as the amount, insofar as emergency needs are concerned. The distribution of the spinning reserve among the steam generating units on the system is also important because a large number of units can increase generation simultaneously and supply a greater amount of power mom quickly than a single unit with the same amount of reserve in total, where the load buildup is necessarily more gradual.

These and many other factors must be evaluated in our further search for measures to strengthen the power networks and minimize the occurrence of service outages.

Measures To Confine Future Outages

We must also explore what could have been done to minimize the spread of the outage of November 9-10. Such an analysis is certainly necessary if we are to develop the most effective measures to prevent a recurrence of the cascading feature of the blackout.

The importance of measures to confine the spread of any outage is made plain by the fact that in the lint four seconds after 5:16:11 p.m., the instant of the initial disturbance, service was interrupted to only portions of upstate New York, and Ontario. At this stage, the lights had not gone out in Albany or in New York City or in New England. The disturbance later caused the steam plants in upstate New York to shut off, but if the deficiency in generation in that area could have been supplied by the other companies in the CANUSE area or from other interconnections a blackout of wide proportions could have been averted.

There was a period of some seven minutes to twelve minutes between the initial disturbance at 5:16 p.m. and the time when the service to the various portions of southern New York and New England finally collapsed. The operators at the various dispatching centers all knew after 5:16 pm on November 9 that the frequency on their systems was going down and that the load had reversed and was placing a large drain on their generating reserves. Unless automatic devices are provided to shed load within a power system, the time required for removing load (either manually or by communication with a switching center or by control devices to remotely operated switches) may be too long to prevent the continuing downward trend of system frequency and ultimate collapse of the thermal generating resources. Such shedding of loads might enable the entire interconnected system to recover frequency within a relatively few minutes and permit the rapid restoration of service thereby avoiding extended and widespread outages. The integrity of the total interconnection and the mutual assistance expected from interconnected operation would be realized. Whether in the long run such a procedure should be recommended in such a case as this can be better determined by the Commission after consultation with the study group and the affected companies taking into consideration the characteristics of their particular systems.

We believe that the service outage could possibly have been confined to the upstate New York area and Ontario but the mechanism for doing so required either automatic protective devices to sever interconnections or shed load, or the perfection of communications and information systems together with more precise guidelines that would provide the system operators on duty with a reliile basis upon which to make such decisions. Whether the reliance should be on automation or informed judgment based on precise criteria is a matter for further expert analysis. It is quite clear, however, that in the present state of interconnections in the CANUSE area more specific procedures must be implemented.

On November 13 the Commission surveyed each of the utilities involved in the interruption, asking in substance the steps the utilities were taking to facilitate restoration of service, their views as to system modifications to avoid recurrence of outages, their views as to the need for improved system and intersystem control equipment and a statement as to the facilities which were under construction and measures initiated and in implementation prior to the occurrence of thii incident. Responses were requested by November 17. The responses show that many steps have already been taken or am under way to alleviate risk of extended outages. The text of the questions [1] and the highlights of the responses are set forth below and a mote detailed summary of each of the responses is attached as Appendix E.

The Commission has not appraised the sufficiency or the insufficiency of the responses to the several questions, but is reporting this information as an indication of the measure of recognition by the utilities in the affected area of the need for improvements in system planning and operation.

Most systems which suffered major outage+ plan new measures to expedite restoration of electric service in the event of another widespread loss of power. Most significant are measures to maintain standby auxiliary power sources for the vital task of steam-electric plant restoration in case of another outage. Measures proposed include installation of emergency diesel engine generators and quick-starting gas turbine generators. One utility will use D.C. motor drives with ample storage battery capacity to assure in any emergency a supply of direct current for auxiliaries of one of its steam plants. Another company plans emergency standby power for its microwave communication equipment which failed during the November 9 disturbance because of loss of power.

Three of the power systems located in the blacked-out area and one of the fringe area systems questioned say that their present procedures for restoration of service were found adequate the evening of November 9. No new procedures have been or will be instituted, at least until results are in from studies of the disturbance now under way.

Most of the companies surveyed did not believe modification in the design or operation of systems or in their interconnections with other systems was called for until completion of studies now underway. Thus, the CONVEX group of New England utilities believes its system and interconnections are sound. No basic change in design philosophy will be made pending complete analysis of the recent power failure and other studies currently under way. This was essentially the answer received from most of the other systems.

One utility recommended that the Commission take the lead, with industry assistance, in developing guides for continuity of service to large metropolitan areas and loads of similar importance.

Boston Edison Company is studying the feasibility of isolating certain generators, their boilers, and auxiliaries fmm direct connection to system busses by automatic removal in the event of major system

[1] The questions put to the utilities were: "(1) What steps are you taking now to facilitate restoration in the event of a recurrence of outage? How many of these steps have been taken and what will be their effect?

"(2) What modifications (A) in the design or operation of your system (B) your interconnections with adjoining systems and (C) in the internal design or interconnections of other systems do you consider necessary or desirable to avoid a recurrence of widespread outage?

"(3) What an your views as to the need for improved system and intersystem control equipment, including communications, to prevent a recurrence of widespread outage?

"(4) What facilities and measures were initiated and under construction or implementation prior to the occurrence of this incident?

"Also please list all computer and board studies and internal memoranda and studies made by your organization or by interconnected groups of which your organization is a member relating to system stability and system planning. Please describe in sufficient detail so that the Commission can determine the nature of the reports and make a judgement as to which might be useful for review. Also please furnish a copy of any standing instructions for guidance of your load dispatchers in severing your ties with other systems under disturbed inter-system conditions."

disturbance. The prime purpose is to have an ample source of power available to restart other units following a complete system or area breakdown.

Although many utilities think their system and intersystem controls are adequate and functioned properly November 9, others am reevaluating operation of their control equipment. For example, one utility is seeking a method to provide faster automatic response of boilers and turbo-generators and improved methods of load shedding.

Some systems suffered communication difficulties during the November 9 trouble and are now providing standby power supply for their communications systems. The Pennsylvania-New Jersey-Maryland Interconnection gmup is providing additional communication channels between members.

Facilities under construction and measures initiated prior to the incident of November 9, which might have helped if completed, include a 500 kv transmission line to connect the Pennsylvania-New Jersey-Maryland interconnected 500 kv grid with Consolidated Edison Company of New York; PJM's digital computer and data transmission system; a new 170 mw thermal generating unit at the Lovett plant of Orange and Rockland Utilities, Inc.; a new 230 mw steam-electric unit at Danskammer Station of Central Hudson Gas & Electric Corporation; a 33-mile 230/115 kv line from Jennison generating station to Oakdale substation and an oscillograph at Oakdale sub both owned by New York State Electric & Gas Corporation; an analog load-frequency controller and a digital computer to be installed at the System Power Supervisory Control Center of Niagara Mohawk Power Corporation; two new 360 mw units at Northport Power Station of Long Island Eighting Company; the Cornwall 2000 mw pumped storage plant, a system operation dispatch computer, and an extra-high-voltage D.C. interconnection with the Quebec Hydro-Electric Commission, all of Consolidated Edison Company; a 345-k" transmission line from Barbour Hill, Connecticut, to Ludlow, Massachusetts, by CONVEX; and a number of emergency peaking and standby generators.

All systems either on their own or with outside engineering assistance are examining in detail various aspects of their system design and operation to pinpoint any improvements that may be needed. All systems will be participating in the computer studies sponsored by the Federal Power Commission and to be performed by two of the large quip ment manufacturers.

Conclusion

Them can be no absolute assurance that outages of the November 9 magnitude will not recur. On the other hand, there is no apparent reason why operating equipment and techniques cannot be improved to the point where the likelihood of recurrence would be so remote that it would not constitute a major worry to either the industry or the public. We believe the many steps already taken by the utilities on their own initiative together with implementation of our recommendation for immediate and long-term measures, which are set forth at a later point in the report, can achieve that goal.

Chapter III

THE PROBLEMS OF RESTORING SERVICE

At 5:28 p.m. on November 9, substantially the entire northeastern comer of the United States was without electricity. At the same moment the utilities began the tremendous task of restoring power to their lines, but some energized circuits which were lost in a fraction of a second would take hours to return to service. Generating stations throughout the area were now dead. In most cases even the auxiliary equipment needed to fire the boilers and provide the steam to drive the turbines and restore system generation was dependent on the system power supply which had failed. Before some circuits could be energized, power from outside sources was needed to start auxiliary equipment.

In thii chapter of the report we shall describe what is involved in the restoration of power to a "dead" system, and examine the factors which affect the speed with which restoration can be accomplished.

The General Problem

The speed of restoration varies with the nature and character of the system's sources of generation and transmission facilities, the availability of external sources of power, the nature and character of the disturbance causing the initial loss, the availability of trained personnel, and the nature and characteristics of the system load. For example, restoration of service to overhead transmission facilities can be accomplished more rapidly than restoration of service to the more complicated underground transmission networks. Utilities having available an emergency source of power for energizing their lines had an advantage in restoring service. Systems having available hydroelectric generation sources were able to restore service mom rapidly than those dependent solely upon thermal generation. These facts are illustrated in the discussion which follows, highlighting the varying experiences of the affected utilities in restoring service on the evening of November 9 and the morning of November 10.

When a utility's transmission system has lost its power, the first step in restoration is the isolation of the affected system fmm all other segments of the interconnected grid. This requires examination of the circuit breakers, switches, and relays in the affected area to determine which have tripped out and, if possible, the causative factor. In evaluating the problems faced by the utilities in restoring power it is important to keep in mind that during the r&oration period on the evening of November 9 and the morning of November 10 the cause of the power failure was unknown. Thus, each utility confronted the possibility that a causative factor may have existed within its system and the need, at a cost in time, to examine its facilities for possible contributing causes.

Having isolated the system, it was necessary, preparatory to the restoration of power, to see that the circuit breakers, switches, and relays were in proper condition. As power became available, it was essential that the load be picked up in a careful, sectionalized, synchronized process. As each section was brought up to load, it was necessary to synchronize its frequency with that of the energized remainder of the system. It was then possible to tie the section in with the remainder of the network without disturbing the maintenance of the network's synchronism. The same procedure was required for each of the individual segments or sections of a system, throughout each system within the interconnected network.

Relative Difficulty in Generation Startup

The prerequisite for the restoration of service in any section of a system is the availability of generation within the section or from external sources. When a generating station loses its load the automatic control equipment shuts it down. The boilers, generators, and the auxiliary equipment must then be inspected, all needed repairs made and the controls adjusted before the startup procedure can be initiated.

The complexity of the startup procedure depends upon the nature of the generation equipment All units require some outside power to start. Some diesel units and gas turbines, like the motor in the family car, have an electric starting mechanism. Like the car, the amount of starting power may be so small it can be supplied by batteries. Gas turbines, diesel generaton and hydroelectric facilities require relatively simple startup procedures, with little lead time necessary. Many diesels use a compressed air system for starting. The power required to start hydroelectric units is also modest.

Hydmelectric stations which have been shut down for only a few hours can usually be started without the requirement for auxiliary power other than that normally available as emergency power from station batteries for lights and control circuits. If shutdown is for an extended period, auxiliary power will be needed for operation of governor oil pumps, lubricating oil pumps and compressors.

In contrast, thermal electric generating equipment startup procedures are complicated, and the complexity increases with the size of the unit. These units consume approximately 5 percent of their electrical generation output in running their essential auxiliary equipment. Power is needed to operate the boiler feedwater pumps, combustion air fans, cooling water pumps, the fuel pumps for oil-fired equipment, the pulverizing equipment for coal-fired units, as well as the various other associated auxiliary equipment. As the water turns to steam, and steam pressure reaches operating level, the steam is used to start the turbines spinning. Large turbines must be warmed up gradually before being placed in service.

Few of the utilities made provision for auxiliary sources of power in the planning of their huge generating stations. The possibility that their own entire system would go dead at the same time that they lost their interconnections was not considered a sufficiently credible incident to warrant installing such additional equipment. Thus, when the system power was lost the generating stations were without a means of startup until power fmm a source external to the station was restored. Control panels were dead, aggravating the delay because of the time required for visual inspection of the equipment; and the generating stations were unable to provide the control centers with information helpful to decisions at that point.

Restomtion of Service in Upstate New York

Rochester Gas and Electric Corporation (Rochester), having service responsibility in the vicinity of Rochester, New York, is located on the western end of the area of disturbance. Rochester lost its load at about 5: 19 p.m., after separating from the interconnected systems (through Niagara Mohawk) and then from the systems to its south. Fmm the viewpoint of the problems of restoration, it was comparatively well-situated. Rochester's tie lines with PASNY remained energized throughout the disturbance. Thus it had a supply of power immediately available to it once the circumstances on its own system permitted it to receive such power. In addition it had hydroelectric generation sources on its own system which were brought on the line rapidly to contribute to the power needs of the necessary auxiliary equipment essential in the starting up of the system's thermal units. Once the thermal units were brought up to load they were adequate to carry Rochester's system requirements.

One complication for Rochester was the problem of closing the tie line from Rochester to Clay, New York, on the PASNY system, the energizing of which was essential to the restoration of service on the 345-kv system from west to east. When efforts to restore this tie to service did not succeed, PASNY was required to patrol the line to verify its integrity.

It has since been established that the breakers on the Clay-Rochester line would not close because repeated efforts to reactivate the breaker had dissipated the reserve air pressure in the pneumatically operated circuit breaker mechanism at the remote controlled switching station at Clay, New York. In turn, this was aggravated by the fact that the supply of essential electrical service to the Clay substation for station service purposes had opened, denying power supply to the compressors used to build up the air pressure on the breaker's pneumatic system storage tank.

Rochester provides customer service through a radial feeder circuit system, in contrast to the network system common to heavily developed metropolitan areas such as New York City and Boston. The Rochester system was able to give first priority to restoration of service to those customers providing services essential to the health, safety, and welfare

of the general public. By selective switching of circuit breakers it was able to energize its first hospital circuit at 7 : 45 p.m. Thereafter service to the other hospitals and to the water pumping stations in the area was restored promptly. As generation became available, the remaining circuits were closed to allow power to flow to the general customers as well. By 10:30 p.m., 80 percent of the entire system was restored.

The experience of New York State Electric and Gas similarly reflected the relative ease of restoration of service in a system with an internal transmission network of overhead lines, and with hydroelectric power available on its own system as well as access to power from external sources. For example, the company was able to teat its overhead transmission circuits simply by restoring Power to the circuits to determine if they would hold. The test proved successful and verified that the system lines were still intact, thus eliminating the need for a time-consuming visual inspection of the circuit breakers, relays, and switches at key stations and control units, and for patrolling the transmission lines.

New York State Electric and Gas was able to keep some of its generators in operation, primarily because its 230-kv tie to PASNY remained in service throughout the entire disturbance with the exception of a 15-second loss at the very outset. However, in order to preserve power at the generating stations for service to the boiler's auxiliary equipment, even the local load served by the generating stations which remained in operation was dropped. There was little delay in restoration, however, and the lint unit, the No. 1 unit at the Jennison Station, a 73-mw plant serving the Bainbridge and Sydney area, was back on the line by 5:38 p.m. By 7 : 20 p.m. these communities were back to normal.

The experience of this company also illustrates the problems arising from efforts to add load to a section of a system which is still in an unsettled condition. For example, at its Goudey Station in Binghamton, New York, the No. 8 unit with a net capability of 81 mw was in operation at 5: 16 p.m. when its 78 mw load was lost. By 5:38 an effort was made to start the unit by using the steam stored in its boilers and by 6 : 30 p.m., full voltage had been obtained and the full load was returned to the unit. Shortly thereafter, at 6:55 p.m., following frequency swings and large variations in load ranging from about 30 megawatts to 125 megawatts over a P-minute period, the No. 8 unit tripped off the line again. At 7:05 p.m. it was restored to the line, with a load of about 60 mw when the "thrust bearing low clearance" alarm sounded. Loading was tben immediily reduced but the unit tripped off the line again, due to low thrust bearing clearance at 7:28 p.m., with restoration to service occurring at 8 p.m. This abrupt shut down caused minor damage to the thrust bearing, necessitating restriction of the load to 20 megawatts from 8 p.m. to 10:30 p.m., at which time the thrust bearing adjustments were completed, and by 11: 30 p.m. the full load had been restored to the unit.

The efforts of New York State Electric and Gas to maintain its generation through this period caused minor damage to the electrical motors on the auxiliary equipment at several of its other stations. This minor damage further delayed the restoration process at the affected generating stations. New York State Electric and Gas finally accomplished total restoration to service in its areas of responsibility at approximately 11: 14 p.m.

Restomtion of Service in New England Areas

The experience of the CONVEX system illustrates the procedures in restoring service on an integrated system using hydroelectric stations and gas turbines for peaking purposes. The CONVEX system is made up of the Connecticut Light and Power Company, Hartford Electric Company, United Illuminating Company, and Western Massachusetts Electric Company, and interconnects western Massachusetts and substantially all of Connecticut in a single power grid. Its entire generation and transmission complex is controlled from central dispatching centers at North Bloomfield, and at Southington, Connecticut, without regard to division of ownership of the facilities among participating companies.

Between 5: 19 and 5: 30 p.m. the generators at Bridgeport, Middletown, Devon, and Norwalk, Connecticut, and West Springfield and Mt. Tom, Massachusetts, lost their loads, primarily due to loss of an adequate Power supply to their auxiliary equipment.

The lost generators had a combined net capacity of 1588 megawatts, out of the pool's combined generating capacity of 2685 megawatts. The remaining stations, including the 10,000 kilowatt gas turbine generating units at Hartford Electric Light's South Meadow station in Hartford, Connecticut, stayed on the line and carried local loads.

By 5:30 the CONVEX pool was isolated from the CANUSE network and initiated restoration procedures. Between 5 : 30 and 8 p.m. the transmission system was used to restore station power for operation of the auxiliary equipment essential to the starting up of the thermal generators, and for restoration of interconnections within the CONVEX pool. By 9 p.m. critical lines feeding hospitals and other essential community services had been restored; and by 10:30 p.m. full customer service was available. This was not the end, because a few minutes later, at 10:35 p.m., the tie lines between Agawam, Massachusetts, and North Bloom&Id, Connecticut, went out due to an insulator failure and the tie line loops were burned open. By 11 :00 p.m., however, the CONVEX system was intact and normal conditions were restored by midnight.

The New England Power Company's (NEPCO) experience illustrates the range of restoration time experienced by the utilities. Its Webster Street steam generating facility in Worcester, Massachusetts, a 50 mw unit went dead at 5: 18 p.m. At 6 p.m. power for station lights and auxiliary equipment was restored with the benefit of power received from the Harriman hydro generating station at Whittingham, Vermont. By 6:03 p.m. energy was restored to St. Vincent's Hospital, and by 6 : 37 p.m. the No. 8 generator, which had been on the line at the time of the system failure, was back in service. At 6:45 p.m. the underground network was energized and by 7 : 33 p.m. the No. 8 generator had assumed its full load.

NEPCO's Brayton Point Plant, its largest, with a net main generating capacity of 482 mw, was on its Nos. 1 and 2 generators when it lost its load at 5:17 p.m. Station service was restored at 6:25 p.m. and the startup procedure for unit No. 2 (241 mw) was initiated at 6:35 p.m., but not until 12:25 a.m. on November 10 was the unit No. 2 generator placed on the line. By 2: 00 a.m. it was carrying a 125 mw load.

The Boston Edison Company (Boston), having electric utility responsibility in the Boston metropolitan area, had a load of 1375 megawatts when its system collapsed at approximately 5:21 pm. The entire Boston metropolitan area was without service, with the exception of the Metropolitan Transit Authority which has its own generation equipment and continued operation during the outage.

At 6: 30 p.m. a 1250 kva generating unit, powered by residual steam, was started at Boston's Edgar Station in Weymouth, Massachusetts, in an effort to provide station power for the auxiliary equip ment essential to the startup of the principal generating equipment at the station. In the interim, however, the necessary power for station purposes became available from NEPCO at Edgar and at Boston's L Street generating station. At the same time, Boston's Mystic generating station in Everett, Massachusetts, obtained auxiliary power from the U.S. Naval Shipyard in Charleston. Between 7 :40 p.m. and 9 : 20 p.m. generation was restored at these stations and thereafter until 2:22 a.m. additional units were brought into service.

Service to the downtown Boston area is provided through a network system fed by underground cables similar to that employed by Consolidated Edison in New York City. The system is, however, considerably smaller, in size, miles of cable, and loads, than that of New York City. In Boston, as in New York, the use of the network system pmcluded priority in restoration of service to essential municipal services, such as traffic control systems and hospitals.

The CANUSE power failure illustrates the importance of relay settings on key transmission and generation facilities; an experience of Boston Edison illustrates the importance of relay settings on distribution systems. In the Somerville primary network, an attempt was made to start the entire network by simultaneous closing of associated line breakers. The network, which was capable of carrying the normal operating load of the area, could not withstand the increased demand resulting from the sudden restoration of power to cold machinery and appliances. The cold load inrush currents caused the feeder relays to trip out the associated circuit breakers. It was necessary to sectionalize the network and restart loads within the capability of the feeder relays. The false start necessarily delayed the restoration process in the affected areas.

Restoration of Service in New York City

Consolidated Edison faced the most elaborate restoration task of the utilities. Its principal operating areas are served by a network of 59 miles of 345 kv and 305 miles of 138 kv underground transmission cables. This is the largest underground transmission system in the world, both in terms of net miles of cable as well as in terms of the capacity of the cables.

Consolidated Edison also maintains a 25-cycle network used to provide service to the railroads and to the Metropolitan Transit Authority, and a small DC transmission system for service to the Metropolitan Transit Authority. In addition, Consolidated Edison provides to some of the railroads and subways direct 60-cycle service which the customers convert to 25-cycle service or rectify to the DC service required for the operation of their systems. Except for these small systems, Con Ed's distribution system is divided into 42 networks which am electrically isolated and can be energized independently.

Each network area in Consolidated Edison's system (other than those in the outlying sections) serves a geographical area with a load ranging from 25 to almost 400 megawatts and is supplied from a single substation which in turn is served by the transmission network from two or more directions. These are in addition to numerous small substations which serve the outlying part of Consolidated Edison's service area. A substation may serve two or more areas. The size of a network area is limited by ability of the system to pick up its maximum load in one start. In the restoration process the networks are restored one at a time commensurate with the amount of power available at each substation.

The network grid system is the common method of providing electrical service in highly urbanized areas such as New York City or Boston. As the blackout illustrates, however, in a total system failure the utility is confronted with complex problems of sectionalizing in seeking to reestablish power to the city, a problem compounded by the fact that each segment of the load which is to be added to the system generation sources is large in itself compared with the loads experienced by most utilities.

A disadvantage of the network grid system in a time of total system failure is the inability of the company to provide a priority of restoration of service to essential loads (such as hospitals, street lights, transportation, etc.) because they are supplied from a network and the network must be energized completely to pick up any part of its associated load.

Consolidated Edison's restoration process was executed in conformity with a plan originated in 1938, which has been kept updated and was available at every control center and startup Point. It was initiated from two principal points. At the southern end of the system, Power from the company's Arthur Kill Plant on Staten Island was available throughout the period of the disturbance through the Greenwood substation in Brooklyn. To the north, as Power became available through the Central Hudson Gas and Electric Corporation ties, restoration of service was being accomplished from the Pleasant Valley substation in Dutchess County, New York. The principal object of thii plan was to restore, as rapidly as possible, adequate auxiliary power to the principal generating stations and substations.

The speed with which this process could be accomplished was, however, severely limited by the so-called condenser effect which occurs on the underground transmission cables as they am energized. This condenser or capacitor effect causes a voltage rise on cables which have been energized without sufficient load on them, and can reach dangerous limits if orderly sequences of adding loads are not followed. Thus before power could be transmitted via these underground cables to the principal generation points and substations, even for the purposes of providing energizing station power, it was necessary to balance the loads on these cables by picking up the load serviced in the area traversed by the cables so as to limit the condenser effect.

To the south, as soon as Personnel could be assembled, the necessary switches and circuit breakers were inspected and reset, and by 6:50 p.m. electricity for station service purposes was restored to the Hudson Avenue generating station in Brooklyn. By 9: 17 p.m. the Hudson Avenue unit No. 4, an 80,000-kw unit, was restored to service. Thereafter as rapidly as possible the remaining seven units at the station were restored. By 11: 30 p.m. the Hudson Avenue station frequency converter was put on the line and service to the 25-cycle subway system was restored.

794-080 O-65-6

By 9:30 p.m. station service power also bad been restored to the Astoria, Hell Gate, and Sherman Creek generation stations in the Bronx and Upper Manhattan. After midnight station service power was restored to the 59th Street, Ravenswood, and Kent Avenue generating stations and by 1: 50 a.m. power for station service purposes had been restored to the last of Con Ed's generating stations.

With power available to auxiliary equipment, generation was restored at the Waterside Station by 10:36 p.m., and at the 59th Street station by 11: 34 p.m. Generation was thereafter restored at Ravenswood, Astoria, 74th Street, East River, and the Sherman Creek stations.

As the restoration process in the South was moving forward, Consolidated Edison crews were also moving Power from the North as it became available from the Central Hudson Gas and Electric Corporation tie. The Pleasantville tie had energy by 8:25 p.m. which was fed to Millwood and through Millwood, via the Dunwoodie substation to Sherman Creek and East 179th Street, where power also was made available for the Hell Gate generating station.

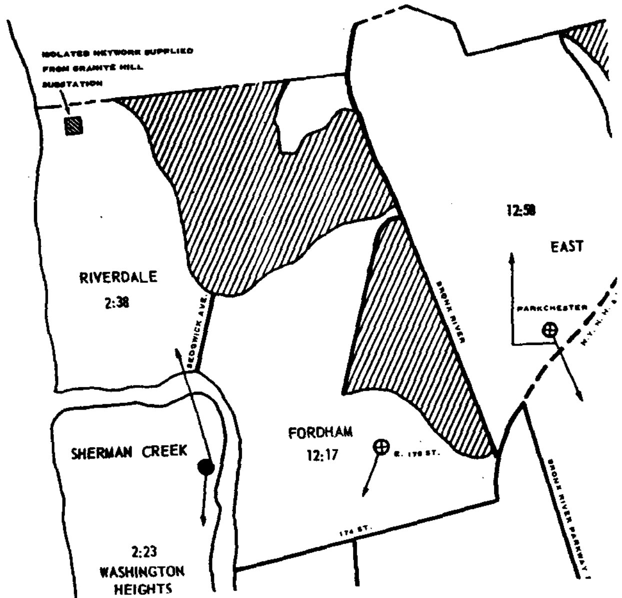
Simultaneously with the restoration of service to the generating stations, segments of the 345 kv and 138-kv lines were being energized for customer set-vice Exhibit III-A shows the geographic bound-aries of Consolidated Edison's various networks, and the times at which restoration of customer service in each area was accomplished. By 10:36 p.m., at the southern end of the Consolidated Edison system, customer services were being restored to the Borough Hall area of Brooklyn. From the North, by 1: 30 a.m., Buchanan, Millwood, and Pleasantville had been restored to service Thereafter, as rapidly as power became available the networks were energized, with the last network-the West Bronx area—being restored to power at 6:58 a.m.

In analyzing the difficulties experienced by the Consolidated Edison Company it is apparent that its present total reliance on steam generation was a restrictive factor in the speed with which it was able to restore service to its customers.

The lack of emergency power sources for the operation of generating station auxiliary equipment and substation control panels similarly adversely affected the speed with which restoration could be accomplished. Thus, for example, at the Farragut Station in Brooklyn (Exhibit III-B), it was necessary that each of the many circuit breakers and switches at this 5-acre installation be visually inspected by trained personnel to ascertain if the switches had tripped. Had the substation control panels been energized, a light on the control Panel would have readily identified those circuit breakers which had tripped, and the resetting could have been accomplished from the control panel, releasing manpower for use elsewhere and reducing the outage Period.

Exhibit III-E. Consolidated Edison's Farragut Substation, foreground, and Hudson Avenue Generating Station, background, were among the first facilities restored to service in New York City.

During the sudden shutdown Consolidated Edison lost 1,500,000 kw of generation because of damage to the bearings caused by the loss of power to the auxiliary equipment necessary to a safe shutdown of the generators. The Ravenswood Unit No. 3 burned out its main bearing because of a loss of oil pressure on the bearings when the auxiliary oil feed pump stopped at the time of the failure of the Power system. Damage to the journal is shown in Exhibit III-C. In addition, at other stations a large transformer as well as several motors and auxiliary equipment were damaged as a result of the shutdown. The loss of these key units extended the time required by Consodiated Edison to effect a restoration of service.



... breakers and
llation be visually in-
el to ascertain if the
the substation control
t on the control panel
those circuit breakers
resetting could have
control panel, releas-
ere and reducing the

ison's Farragut Sub- Avenue Generating he first facilities re-

Consolidated Edi-
n because of dam-
e loss of power to
y to a safe shut-
Ravenswood Unit
ring because of a
s when the a&l-
: time of the fail-
ge to the journal
ddition, at other
as several motors
naged as a result
ese key units ex-
nsodiated Edison

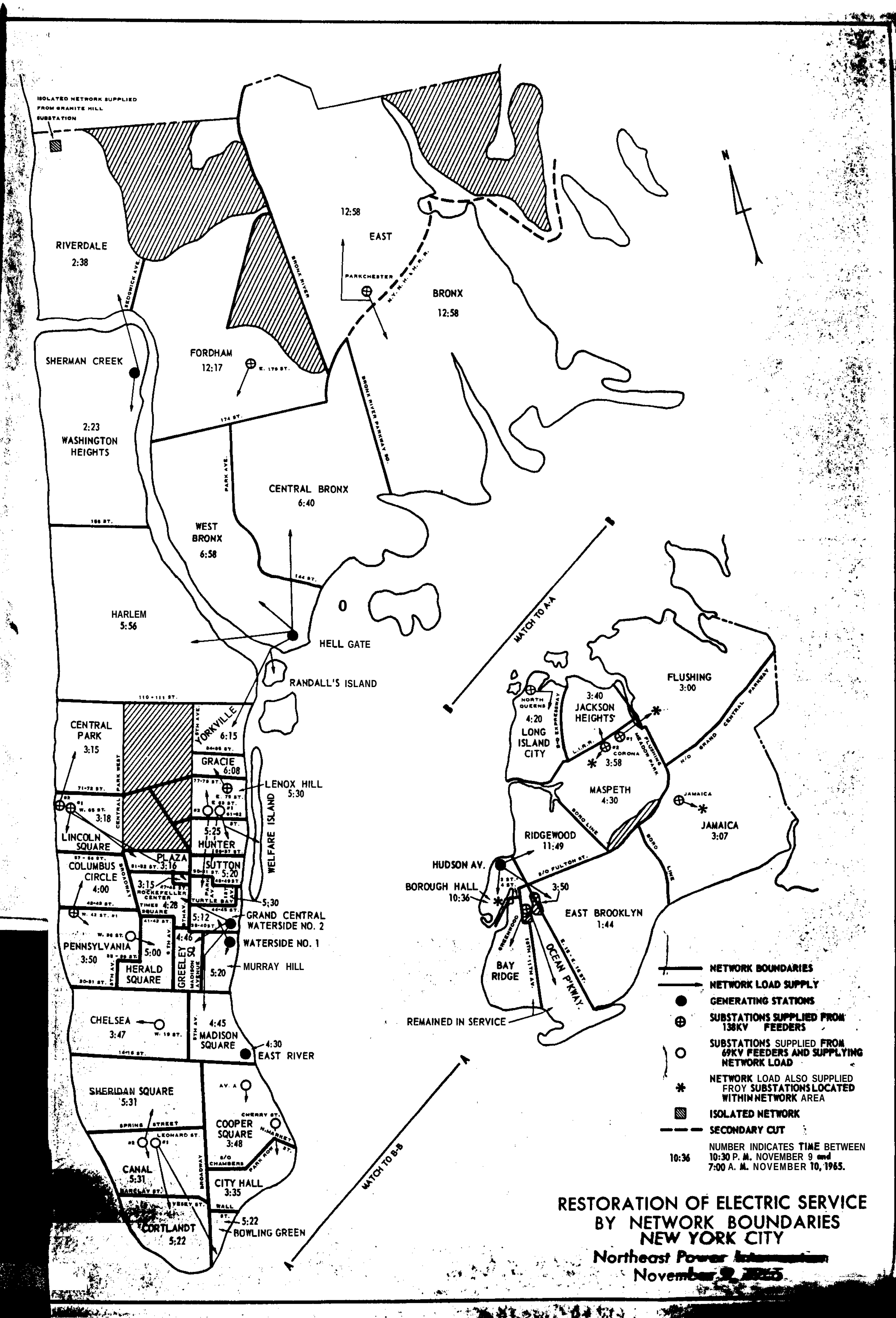


EXHIBIT III-A

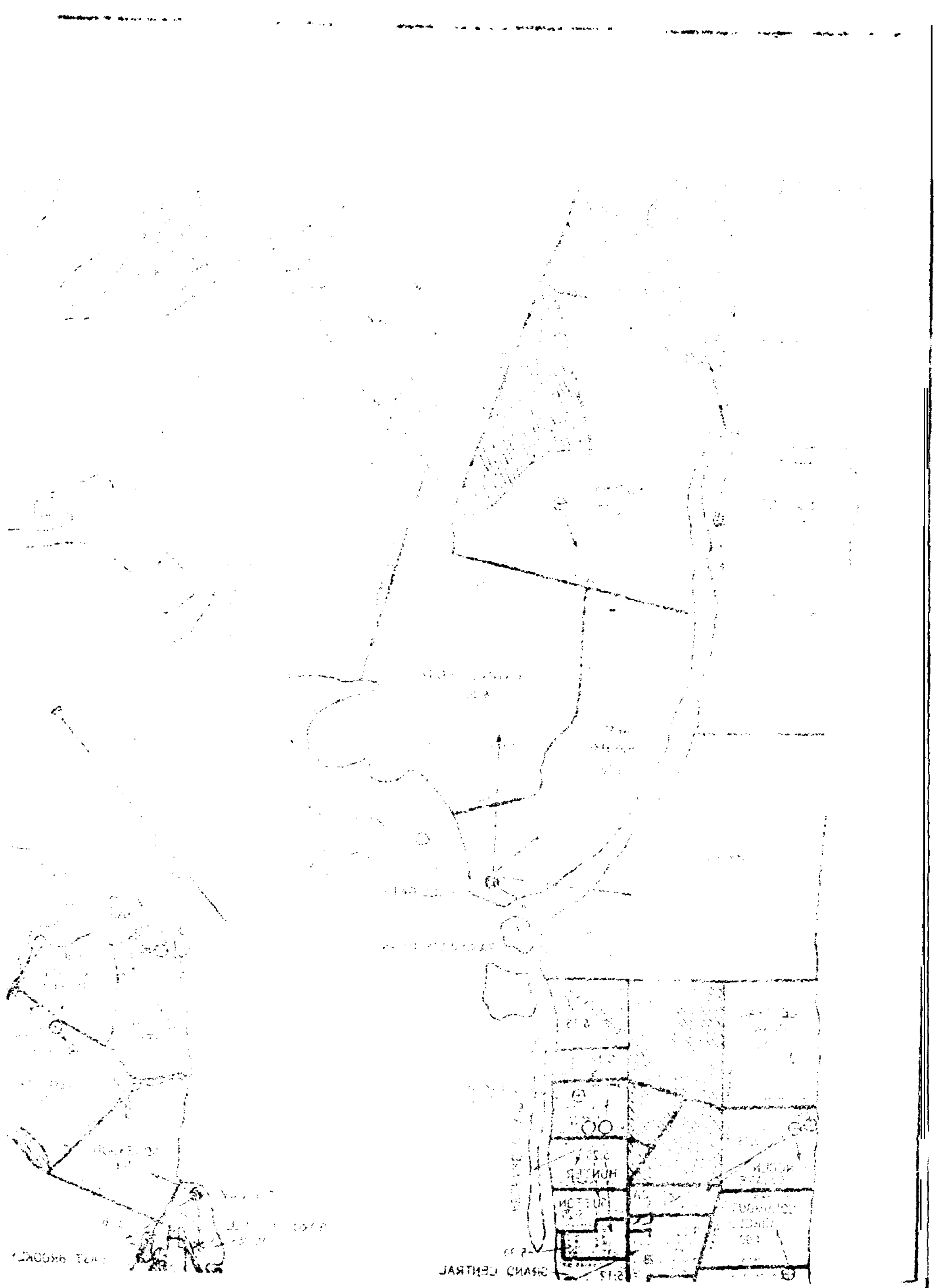


Exhibit III–C. When station service was lost at the Ravenswood plant of Consolidated Edison, oil pressure circulation to the bearings of the 1,000,000 Kilowatt Unit No. 3 was lost. The machine was taken off the line, but the bearings were damaged and the journal, shown above, was scored during the run-down period.

Nuclear Plants Not in Operation

Questions have arisen as to the performance of nuclear generating plants during the blackout. The affected areas have two atomic generating plants operable: the Indian Point Atomic Generating Plant of the Consolidated Edison Company at Indian Point, New York, and the Yankee Nuclear Power Station at Rowe, Massachusetts. On the night of November 9 neither of these was in service, and thus no experience was gained as to the effects of a shutdown from loss of load on a nuclear plant with the loss of auxiliary power. Also, there was no opportunity to examine the relative contributions which nuclear sources can provide to the restoration process.

One evaluation of the restoration process of Consolidated Edison, which could apply as well to that of other northeastern utilities, is found in the statement of the chief operating engineer of the Consolidated Edison system in the hearing conducted by the Commission:

> "Given the opportunity we could cut this (the time of restoration) in half, and maybe in half again, but I do not want the opportunity again." (Transcript page 250.)

Chapter IV

THE IMPACT OF THE POWER FAILURE ON THE PEOPLE IN THE AFFECTED AREA

The power failure which occurred on November 9 directly affected the lives of 30 million people who live in the blackout area It was the worst outage in the nation's history in terms of number of people involved, although other outages have involved broader areas or resulted in longer interruptions of service.

The President of the United States provided immediate assistance to State and local officials in the affected areas and instituted a full-scale investigation. That panic was averted during the blackout is a tribute to the courage, poise, resourcefulness and faith of the millions of Americans who were left in darkness. There was much successful improvisation by individuals and agencies. Among the reasons the situation did not develop into a disaster was the prompt and efficient action by the President and by local government bodies, the effective dissemination of news by the radio industry, and the willingness to assist on the part of many volunteers. The dangers were alleviated somewhat by mild temperatures and a bright moon. There was no widespread looting, and reports indicate that crime rates throughout the region fell below normal.

Transportation

The outage occurred at a peak hour for the subway system in New York and about 600 trains were in operation at the time. Mom than 600,000 people were stranded. Ten thousand people were still on the immobile subway trains at midnight, and seventeen hundred passengers were stranded for five hours on the Williamsburg Bridge above the East River. Before service could be restored at approximately 6:00 a.m., all 720 miles of track in the New York subway had to be patrolled. By 8:30 a.m., all trains were back in operation, but trains were still behind schedule well into the following day. Unlike New York City, the subway system in Boston continued to operate throughout the blackout because it has its own generating facilities which operate independently of the Boston Edison system. However, the Boston subway system is connected to the Boston Edison system and has received power from the latter system when its own generation has been shut down in the past.

Rail travel in the New York City area came to a virtual standstill. All railroads were out of service until 5 :00 a.m. except the Pennsylvania Railroad, served by Public Service Company of New Jersey, which did not experience a service outage. Throughout the region, railroad operations were hampered by the outage, since most railroads depend on commercial power to operate signal systems. The Pennsylvania Railroad experienced loss of power for switching, but after some delay was able to utilize locomotives to furnish this power. Some railroads suffered a complete stoppage of service. Others maintained some service, apparently by using auxiliary power or manual blocking techniques.

The blackout revealed a great need for more standby electric generation at airports. Air tragedy was averted in the first moments of the blackout only because of the bright, moonlit night and the continued operation of main control towers which were equipped with auxiliary power. In the New York City area it was necessary to cancel or divert to other airports approximately 250 flights. At LaGuardia Field, limited operation was restored after a 2-hour delay with emergency lighting on one runway powered by a water-pump generator. By using emergency communications from several aircraft on the ground, it was possible to land 240 aircraft before power was restored. A similar situation prevailed at the Boston Airport, where standby power permitted the control tower to maintain contact with the aircraft, but field lighting failed. Radar and navigation aids in the New York area remained out of service for about six hours. Control towers at Kennedy International and LaGuardia Airports were out of service for 11 hours and 35 minutes, and field lighting, navigational aids and radar were without power and inoperative until 5:30 a.m. The air route traffic control centers at

New York and Boston, which control traffic passing through the respective control areas rather than takeoffs and landings at a specific airport, switched to standby power and were in full operation. This permitted en mute traffic to move normally and aided in diverting flights to other airports.

Based on its experience during the outage, the Federal Aviation Agency reports that it is moving swiftly to equip its facilities with engine generators and is working with the operators of large hub airports to install auxiliary generators for backup on present principal runway lights.

Hospitals

Approximately 855 hospitals were without commercial power as a result of the failure. With the exception of the New York City area, virtually all hospitals had some form of standby power available. No patient deaths are known to have resulted from the outage. Three hospitals in Massachusetts and one in New York were reported to have standby power sources which were not operable during the emergency. In New York City out of approximately 150 hospitals less than half had adequate emergency power. At many hospitals without emergency power, police and fire officials were called upon to supply portable units to maintain essential facilities and to help in the movement of patients. At one hospital, workmen who were in the process of installing a standby generator were able to hook it up on a temporary basis to provide emergency power. Many utilities report that they were able to supply hospitals and other public services on a priority basis once some generation was available.

Communications

Radio service continued despite the blackout. According to FCC reports, 40 to 50 percent of the radio stations in the blackout area have auxiliary power for transmission. After a few minutes delay, many radio stations resumed broadcasting utilizing their emergency power and were able to maintain an almost continuous flow of much needed information to the public, who were able to receive through battery-operated and automobile radios.

Most television stations, the operations of which depend on commercial power, were out of operation for the full period of the blackout. The inability of most television stations to continue broadcasting was of little moment, however, as virtually all television receivers arc also dependent on commercial power. A few television stations in the Boston area, using emergency power sources, returned to the air after short periods since some of their receiving areas are outside the blackout area. In New York City, the hardest hit population center, television stations were unable to resume operations until about 7:00 am. Wednesday, while in some other parts of the blackout area television stations were back on the air early Tuesday evening. After a short delay, the national television networks were able to switch their broadcast operations from New York to other cities outside the blackout area and continued broadcasting.

Telephone communications were maintained in most areas throughout the blackout period by the use of auxiliary standby power, but some areas in upstate New York and New England were without service for short periods. Local exchanges, long distance and overseas services functioned well considering the circumstances. However, delays in placing calls were experienced because of overloading of long distance and local lines, especially in New York City, due to the inability of some companies to meet such an abnormal peak load.

Telegraph service delays in some major service areas affected by the power failure varied from relatively short delays to as much as 14 hours. Public message and commercial private wire services were at a virtual standstill due to the power failure, which prevented the use of teleprinters and facsimile equipment regardless of the use of emergency power by the telegraph offices. In many of the smaller cities telegraph offices were already closed when the outage occurred and were not affected. In New York City, telegraph services were out until 7:40 the next morning. Most of the vital intergovernmental services, including overseas service, either remained in service or were restored quickly. However, available equipment was not sufficient to provide commercial service to several military facilities.

The FCC is conducting an investigation of the effect of the power failure upon the functioning of communication facilities. The broadcast stations in the area have been requested to supply the FCC with all facts which might be helpful in analyzing the impact of the power outage and in making plans for future incidents. The results of this inquiry should provide valuable information to assist in developing emergency communication plans and systems.

Public Services

Other essential public services and facilities were affected throughout the blackout area. Operations of water and sewage systems dependent on pumping operations were impaired throughout the area; however, apparently no real problems arose except in western Massachusetts, where four of ten water supply systems were unable to carry out pumping operations for periods varying from fifteen minutes to three hours, and in the Jamaica area of Queens, New York, where the water system was out of service until around midnight.

Massive traffic jams occurred in cities throughout the region due to the failure of traffic control signals. Lack of transportation and failure of gasoline pumps left many people stranded in downtown areas of New York City, where hotels were unable to provide accommodations on upper floors because of lack of elevator and water service. Police and fire departments were left without normal communication systems, although it was reported that many of these departments had emergency and mobile units at their disposal.

National Defense

The impact of the power failure on civilian and military defense appears to have been negligible. A check by the Department of Defense of major military installations, including Strategic Air Canmand (SAC) and North American Air Defense (NORAD), confirms that communications were intact. There were reports of difficulty on some lines, but there were adequate alternate routes to take care of such emergencies. All Defense Communirations Stations have auxiliary power systems. The Pentagon was able to put through without difficulty calls to SAC Headquarters at Omaha, NORAD Headquarters at Colorado Springs and to air bases and other installations all along the eastern seaboard. The Department of Defense is presently conducting a study to analyze in detail the effect of the outage on all defense activities in the affected area.

The National Warning System (NAWAS), remained operational during the entire period of the power failure. This system, which is operated by the Office of Civil Defense, consists of leased telephone lines, open 24 hours a day, 7 days a week, with the main control point at NORAD Headquarters in Colorado Springs. It reaches over 700 cities across the country. Through its 97 civil defense warning points in the northeastern states and through its circuit to the Canadian Federal Warning Center, the Office of Civil Defense rapidly determined the general extent of the power failure and received subsequent reports of restoration.

In addition to full communications from the Federal and regional levels to state and local governments, the states in turn were in communication with their local jurisdictions. Emergency organizations at the state and local levels were activated within 5 to 15 minutes after the power failure. Civil Defense employees and volunteers were used in many cities to assist fire and police organizations. In Massachusetts, the NAWAS system was used by the Civil Defense organization as its emergency communications network within the state.

In response to this emergency the Office of Civil Defense has begun a study of the impact of the blackout on local government and the general public and is attempting to ascertain the effectiveness of the emergency government services and the use of emergency communications systems, standby generators, and other emergency supplies. The use of commercial broadcasting stations by civil defense officials is also being studied. The Office of Civil Defense has directed the Disaster Research Center of The Ohio State University to send a task force into New York City to determine the impact of the power failure, particularly on the organizational response of fire and police departments and medical facilities. OCD is also accelerating its program to install alarms and loudspeaker equipment at its warning points and emergency operating centers. This equipment is activated by signals from the telephone lines. OCD recommends that all levels of government review their civil defense procedures to assure emergency communications to support essential government services and dissemination of information to the public.

The extensiveness of the Northeast outage posed the immediate possibility that more than an accidental power failure was involved. This activated the Office of Emergency Planning to assume a preliminary war stance, and it began to implement emergency plans and procedures. Its regional office in New England was put on an emergency status and continued to operate with standby power until commercial power service was restored. Liaison was established with appropriate civilian and military defense agencies and immediate attempts were made to determine the cause of the incident. Preliminary reports indicated a power system difficulty near Niagara Falls; however, it was impossible for OEP at that time to obtain the details. The Office of Emergency Planning is now reviewing reports of various Federal agencies on the effect of the blackout on those resources and areas of economic activity within their responsibility and is working with other Government agencies to assist the power industry to establish, in cooperation with Government, an effective reporting system so that the American people can be authoritatively and rapidly informed of the cause and extent of such failure.

The Department of Justice reports that Federal prison facilities utilized emergency lighting which permitted the maintenance of full security. At the Walpole Massachusetts State Penitentiary it was reported that 320 prisoners took advantage of the darkness to riot, causing $75,000 damage. Offices of the FBI which were affected by the outage were able to continue operations using standby power.

Commerce

Brokerage houses, banks and other financial institutions in New York, Boston, and other cities were handicapped by the blackout. The stock exchanges in New York City delayed the start of trading until about 11 :00 a.m. Wednesday, one hour after the normal 10 : 00 a.m. opening. Most New York commodity exchanges opened late, and one did not trade at all. Also affected by the lack of power were about 600 stock tickers in downtown New York City. As an aftermath of the blackout many banks, brokerage offices and other commercial and industrial firms throughout the affected area faced huge backlogs of work. This was due in part to the failure of an estimated 30 percent of the work force to return to work on November 10. Various sources have estimated the total economic loss attributable to the failure to be in the neighborhood of $100 million, much of which is not covered by insurance; however, statistics on the loss are not yet available, so it is impossible for us to comment on the validity of these estimates.

Conclusion

The impact of the blackout points to the need to develop measures to minimize the impact on the lives of our citizens if there should be a recurrence. Actions which we believe should be taken at this time are included in our recommendations at the end of this report. Additional recommendations may evolve from our further studies.

Chapter V

SCOPE OF FURTHER STUDIES

This nation of elect& energy users rightly demands further measures to perfect the reliability of electric service, including every reasonable precaution against recurrence of widespread outages. It is evident fmm the experiences of the Northeast power failure, and its social, economic and national defense implications, that the nation can spare no effort in devising measures which, while they cannot assure freedom from localized interruptions of loads, will limit to the minimum the extent of such interruptions and their frequency of occurrence. The Commission's investigation will continue until we are satisfied that we have taken every step within our authority which might contribute to the elimination of massive service interruptions from any foreseeable cause and rendered every possible service to you and the Congress in developing pmgrams for the future.

The Commission is establishing a panel of experts to coordinate the accumulation of necessary information and the definition of the study patterns to be pursued. These studies will require full cooperation on the part of the utility systems, equipment manufacturers, and government agencies.

The two largest manufacturers of electric utility equipment have offered to assist in two series of studies using their computer facilities. These would be of the character of system network analyzer studies in which generation, transmission, and loads of the CANUSE and PJM interconnected system groups will be electrically represented in miniature. Such studies will require the assembly of extensive data from the individual systems.

Since November 9 we have established and there is now functioning an industrywide advisory group for the study and development of criteria for industry guidance in making areawide intersystem stability studies. Such studies are an essential tool in the planning and analysis of adequate transmission networks. Full assurance of the integrity of our major interconnecting networks requires that they be examined and strengthened where necessary for extreme conditions of disturbance.

This gmup is also charged with developing criteria for systems operation which we hope will serve as a guide to the industry in improving present policies and procedures for operation under emergency conditions. The studies will include a realistic evaluation of the reliability and rate of response of spinning reserves.

The Commission has dispatched to the field investigating teams to study in depth the operations and communications of the affected systems for the purpose of suggesting corrective measures. The Commission has also elicited from each company involved its suggestions for improved operations. We shall pursue this aspect of the study and expect to be able to make many detailed recommendations as a result of these studies, and to witness great emphasis by the companies themselves in preparation for emergencies.

The Commission, as a continuing responsibility, has developed plans for regional advisory groups from the electric utility industry to aid in implementation of the widespread coordination patterns outlined in the National Power Survey. These committees can provide effective liaison between the Commission and the electric utility industry in a voluntary program for the examination and appraisal of planning and operating practices of the power systems in every region of the nation.

We believe that measures to reduce the likelihood of power outages and to lessen the impact of failures of power supply when they occur would be of value to our national defense, and we are coordinating our studies with the Office of Civil Defense, as well as other agencies of the Department of Defense, the Office of Emergency Planning, and the Defense Electric Power Administration (DEPA) of the Department of Interior.

794-080 o-61-7

Chapter VI

RECOMMENDATIONS

We make the recommendations set out below on the basis of our study to date. A panel of experts has also independently adopted a series of recommendations for interim and permanent actions to be taken by the affected utilities to avoid recurrence of major power failures, which support our own recommendations. A copy of the panel's recommendations is attached as Appendix F.

The Commission's recommendations are partial and tentative. We are proceeding to determine whether there are any additional changes in facilities or operational procedures in the affected area which are necessary to minimize the risk of a breakdown of service and to prevent the spread of a blackout beyond the areas of first impact. We also plan to recommend further actions to minimize the impact of power interruptions on essential services.

1. Measures have already been taken by Ontario Hydro to prevent the same relays from triggering another power failure. A number of the other affected utilities have also taken numerous precautions to avoid a recurrence of the series of events which resulted in the blackout. While we are unable to say that another blackout of similar magnitude is impossible, we regard the possibility of a recurrence as remote. The completion of the stability studies which have been initiated will offer a better basis for appraising the risks of a widespread blackout in the northeast and the measures required to avoid such a possibility. We recommend that all utilities, individually and collectively, reexamine the overall design and operation of their power systems.

2. The blackout, while it makes plain the need for full coordination between Ontario Hydro and the interconnected United States systems, also demonstrates the readiness of these systems to work together on electric energy problems. We recommend even closer working relationships between Canadian and U.S. operating organizations on the one hand and between Canadian and U.S. governmental authorities on the other. In this connection, the National Energy Board of Canada has been fully apprised of the various stages of the investigation and has continuously extended the utmost cooperation.

3. Isolated systems are not well adapted to modern needs either for purposes of economy or service. The power systems in the affected area are in a period of transition from isolated operation or light interconnections to strong linkages and close coordination. The system stability and freedom from outage hazard which is inherent in an integrated and coordinated power pool because of the ability of each participating system to draw on its neighbors for emergency support will be increased when the affected companies strengthen their internal transmission systems and the interties between systems. The stability of the system may also be strengthened by the proper location of generating capacity planned on a pool basis. These aspects must be considered together and constitute a parallel and closely coordinated development.

There are numerous additional high voltage transmission facilities which the systems in the affected area have already agreed to build or which are under consideration both to strengthen the internal ties among generating plants and load centers within the individual systems and to strengthen the links between adjoining systems. The computer studies to which we have referred should be of assistance in determining which of these projects should be built on an accelerated priority basis.

We recommend an acceleration of the present trend toward stronger transmission networks within each system and stronger interconnections between systems in order to achieve more reliable service at the lowest possible cost.

4. The systems in the CANUSE area should plan their future growth and operate their systems on a fully coordinated basis if they are to achieve maxi-

mum reliability of service. Achievement of this goal requires close coordination of system planning and operation, which would be easier to achieve if the companies established one or more unified planning and operating groups which made this task their primary responsibility. We recommend the delegation to such planning and operating groups of sufficient responsibility to assure the performance of those functions which require close intersystem coordination.

5. The stability studies carried out by the systems in the CANUSE area-that is, the studies of how the systems would function under emergency conditions-did not postulate an emergency of the proportions which occurred. Additional stability studies are urgently required based upon the more stringent assumptions as to credible incidents which have now been shown to be necessary, and such studies are under way.

6. The power failure demonstrated the importance of close and frequent checks of relay settings controlling major facilities. The companies concerned should make such a check immediately and establish procedures for frequent reviews in the light of changing circumstances.

7. In the light of the consequences of the blackout we recommend a review of the question of reserve margins both in transmission and generating capacity. We hope to make specific recommendations on this subject as the result of the studies we are carrying out. Ample reserve margins constitute an important measure of insurance against peace-time outage hazards and would have even greater value under some assumptions as to defense needs.

8. Where there is a conflict between economic and service reliability factors in power system design the need for security of service should be given heavy weighting.

9. Our preliminary investigation makes clear that the type and distribution of generating reserves available may be as important as the amount, insofar as emergency use is concerned. The utilities in the CANUSE area must make a more sophisticated evaluation of the time factor involved in the utilization of spinning reserves in order to determine the responsiveness of the components of the total spinning reserves to emergency demands. Hydroelectric generation (including pumped storage), and other generation with quick starting and load pickup characteristics, are better capable of absorbing sudden increases in load than steam power stations which have slower rates of production increases. We recommend that the factor of quick responsiveness in the event of emergency should be given due consideration in the evaluation of alternative generating projects.

10. We recommend an industrywide as well as a utility-by-utility study of the adequacy of automatic equipment, communication facilities, recording facilities, and operating procedures in the dispatching and control centers and in power plants during emergency conditions.

11. It is possible that internal load shedding within the various systems involved could have prevented the complete collapse of the CANUSE network. Load shedding should be considered by the utilities along with other measures as part of their emergency operating procedures.

12. We are not in position to pass judgment on the need for improvement in emergency startup training for plant crews, although we pay tribute to their dedication and indefatigability. We recommend a thorough review of training procedures for emergencies.

13. The November 9 outage revealed the need by the utility systems for additional auxiliary power equipment to cope with systemwide outages. In some cases communication systems were dependent upon power supply from the power system itself. The same is true for automatic recording equipment and for the power required for startup of some of the steam plants. Other auxiliary facilities which were essential in restoring service were dependent upon system power supply. We recommend that the services required to limit the scope of a failure, to preserve a record of what occurred, and to enable startup of power plants in minimum time be provided with auxiliary power sources.

14. Civilian services which are deemed so essential that they cannot tolerate any interruption-that is, for which 99.9+ percent availability is not adequate--should arrange an auxiliary power supply. These include hospitals, airports, tunnels, draw-bridges, railroad and subway stations, some bus terminals, and basic communications services.

15. In most cases the cost of a full auxiliary power supply may be beyond its value, but in many situations it is feasible to provide a degree of protection to the public while system power supply is cut off. Thus, with respect to the Independent Subway in New York, where an alternative power supply for

train operation may be impracticable, and Possibly for the other New York City subways, at a minimum a subway evacuation scheme should be developed which would make the risk of interruption tolerable. This would require auxiliary liiting facilities for stations and tunnels.

16. Elevators are a special problem. In some cases it may be feasible to install auxiliary power supply adequate to move at least one elevator at a time to evacuate passengers. As a minimum, elevators should be provided with mechanical cranks or levers so that they can be moved manually in the event of stalling between floors in a power outage.

17. Communication facilities powered from auxiliary sources should be developed so that in the event of a power failure the public may be informed promptly as to the circumstances and appropriate governmental authorities notified.

18. One of the consequences of the power failure was that motorists were unable to buy gasoline because gasoline pumps were dependent upon the system power supply. We recommend to the petroleum industry that it devise a means to solve this problem in order to avoid risk of a transportation breakdown in the event d power failure.

19. When the Federal Power Act was passed in 1935 no specific provision was made for jurisdiction over reliability of service for bulk power supply from interstate grids, tbe focus of the Act being rather on accounting and rate regulation. Presumably the reason was that service reliability was regarded as a problem for the states. Insofar as service by distribution systems is concerned thii is still valid, but the enormous development of interstate power networks in the last thirty years requires a reevaluation of the governmental responsibility for continuity of the service supplied by them, since it is impossible for a single state effectively to regulate the service from an intentate pool or grid. The question of the need for additional legislation is under active consideration.

ACKNOWLEDGMENTS

This study and report was undertaken in response to the President's memorandum of November 9, to Joseph C. Swidler, Chairman of the Federal Power Commission, directing him to launch a thorough study of the cause of the power failure which took place that day in the northeastern United States and the steps which should be taken to prevent a recurrence. The study was carried out by the full Commission, consisting of Chairman Swidler, Vice Chairman David S. Black, and Commissioners Lawrence J. O'Connor, Jr., Charles R. Ross, and Carl E. Bagge.

F. Stewart Brown, Chief of the Federal Power Commission's Bureau of Power, served as Staff Director of the investigation. S. David Freeman, Assistant to the Chairman, participated in all stages of the study and in the preparation of the report.

The Commission acknowledges with gratitude the assistance it has received from the electric systems affected by the outage, from United States and Canadian agencies, from electric power experts from all parts of the United States and Canada, and from state agencies. These men have worked under great pressure of time to help the Commission in planning and carrying out its study and the analyses made thus far. We are especially indebted to the many dedicated members of our staff who have worked without regard to self.

Those from outside the agency who have made especially important contributions to the work are listed below. Messrs. Almon, Nagel and Hauspurg have devoted all their time to this matter since November 10.

ADVISORY PANEL

C. P. Almon, Jr. : Tennessee Valley Authority.
Charles Concordia: General Electric Company.
E. B. Crutchfield: Virginia Electric and Power Company.
Joseph K. Dillard : Westinghouse Electric Corporation.
Morgan Dubrow: Department of the Interior,
W. S. Kleinbach: Pennsylvania-New Jersey-Maryland Interconnection.
L. F. Lischer: Commonwealth Edison Company.
G. H. McDaniel: American Electric Power Company, Inc.
T. J. Nagel: American Electric Power Company, Inc.
G. 0. Wessenauer: Tennessee Valley Authority.

Special Consultants From the Electric Power Industry

R. L. Bolger: Commonwealth Edison Company.
A. Hauspurg: American Electric Power Company.
Harvey D. Hunkins: U.S. Bureau of Reclamation.
R. J. Mather: Bonneville Power Administration.
M. Stephen Merritt: Tennessee Valley Authority.
Eugene L. White: Bonneville Power Administration.

Persons Assisting the Commission on Field Surveys

Reed Canady: Southern California Edison Company.
E. B. Crutchfield: Virginia Electric & Power Company.
K. E. Hapgood: Tennessee Valley Authority.
J. P. Jolliffe: Bonneville Power Administration.
Carl Kist: Los Angeles Department of Water & Power.
F. W. Lachicotte, Jr.: U.S. Bureau of Reclamation.
A. J. Mary: Gulf States Utilities Company.
J. L. McKinley: Public Service Company of Colorado.
Melvin E. Mezek: California Public Utilities Commission.
E. F. Timme: Northwest Power Pool Coordinating Group.

Representatives of Associated Agencies and Offices

Canada

National Energy Board of Canada

I. N. McKinnon, Chairman.
Lee Briggs, Member.
K. G. Richardson.
E. A. Moore.

United States

Robert Barlow: Office of Science and Technology.

A. c. Lewis: Office of Emergency Planning.

John W. McConnell: Office of Civil Defense.

R. R. Reed: Office of Civil Defense.

Emmet Riordan: Office of Emergency Planning.

Barefoot Sanders: Department of Justice.

Many representatives of electric power utilities in the affected areas were helpful to the Commission in supplying information on the events which took place. Without effort at completeness, we wish particularly to acknowledge the contributions of the following:

W. P. Allen: New York State Electric and Gas Corporation.

Robert Brandt : New England Power Company.

E. C. Brown: Hartford Electric Light Company.

W. S. Chapin: Power Authority, State of New York.

Francis E. Drake, Jr.: Rochester Gas & Electric Corporation.

T. C. Duncan: Consolidated Edison Company.

James A. Fitzpatrick: Power Authority, State of New York.

H. C. Forbes: Consolidated Edison Company.

F. H. Freer: Niagara Mohawk Power Corporation.

E. L. Gochnauer: Power Authority, State of New York.

J. R. Gummersall: Long Island Lighting Company.

A. J. Harris: Hydro-Electric Power Commission of Ontario.

K. W. Hasbrouck: New York State Electric & Gas Corporation.

Vincent J. Hayes: Connecticut Light & Power Company.

R. H. Hillery: Hydro-Electric Power Commission of Ontario.

W. S. Kleinbach: Pennsylvania-New Jersey-Maryland Interconnection.

R. A. Lamley: Consumers Power Company.

W. A. Lyons: New York State Electric & Gas Corporation.

J. E. McCormack: Consolidated Edison Company.

W. G. Meese: Detroit Edison Company.

H. H. Mochon: Connecticut Valley Electric Exchange.

Thomas F. Moore, Jr.: Power Authority, State of New York.

Edward J. Nelson: Rochester Gas & Electric Corporation.

F. J. Schneider: Niagara Mohawk Power Corporation.

L. F. Sillin, Jr.: Central Hudson Gas & Electric Corporation.

Harry G. Slater: Niagara Mohawk Power Corporation.

H. A. Smith: Hydra-Electric Power Commission of Ontario.

E. V. Stalcup: Power Authority, State of New York.

R. A. Thompson: Hydro-Electric Power Commission of Ontario.

W. D. Wilder: Niagara Mohawk Power Corporation.

APPENDIX A

SUMMARY OF EVENTS

Prior to, During, and Immediately After the Power Interruption November 9 and 10, 1965

Introduction-The System Opemting Conditions Prior to the Disturbance

Baaed on the information submitted by all of the power system representatives in the New York, New England, Michigan, and PJM systems there were no abnormal conditions just prior to the disturbance at 5: 16 p.m., E.S.T. The power use in Michigan was 5,400 megawatts approximately. The Ontario Hydro-Electric system 6,488 megawatts, the Pennsylvania-New Jersey interconnection 13,600 megawatts, the New York-New England system 18,200 megawatts. Thii was a total of approximately 43,600 megawatts. The combined generating capacity for the total area was approximately 49,000 megawatts. The total available generation in New York and New England was about 22,000 megawatts. The following shows the loading for the major hydroelectric stations at this time. PASNY-Niagara 2,274 megawatts; PASNY-Massena 700 megawatts; Saunders-Hydro of Ontario 700 megawatts; Beck-Hydro of Ontario 1,281 megawatts.

The net scheduled deliveries to Canada on the two ties at Beck with the United States and the one tie at Saunders called for 300 megawatts delivered to Canada. The actual flows were 470 megawatts to Canada at Beck and 190 megawatts to Massena at Saunders, a net actual flow of 288 megawatts. The power flow from New York to New England was 140 megawatts. The power flow to the Southeast New York pool was 400 megawatts. The net flow to all of the PJM interconnections was 68 megawatts to PJM. The flow on the combined 230 and 115 kv lines from PASNY-Niagara was approximately 1,170 megawatts from Niagara. The loading of the two 345 kv lines from PASNY-Niagara to Rochester was approximately 845 megawatts. The schedule between Michigan and Hydro of Ontario was zero. The Rochester Gas and Electric system generation was 300 megawatts and their load was 500 megawatts.

The frequency on CANUSE and the total interconnected system just prior to 5 : 16 p.m. was 59.98 cycles. It had dropped gradually to this value in a period of about fifteen minutes. This is a typical frequency variation on the interconnected system during this time of day, indicating that the generator output is not being increased as fast as the power use is increasing. In this inter-connection, load control between various substations of the interconnections is accomplished by what is commonly called control areas. This means that metering at all of the interconnecting lines with the adjoining utilities outside of the control area is telemetered to a central location where it is used to compare the scheduled transfers to or from the control area to generating stations within the control area so that the generating station can inc- or decrease its output to maintain schedule on the surrounding ties. The control areas in New York, New England, and Canada are shown on Exhibit 1-E.

Sequence of Events in the System Split Up at the Beginning of the Disturbance of November 9, 1965 (Based on Data Available November 20, 1965)

Sequence	*Time*	*Oscillographic* Data
(1)	5:16:11 p.m.	230 kv. Line Q 29BD opened at Beck hydroelectric plant of the Hydro-electric Power Commission of Ontario (HEPCO) by relay action, following a tap change (Pos 10–7) of load control (phase angle) at St. Lawrence plant in the tie with PASNY. Loss of this line caused other Ontario Hydro lines to open at:
(2)	$52 cycles	230 kv. line Q23BW opened by CEB backup relay due to overload as seen by the relays.
(3)	+ 106 cycles	230 kv. line Q25BW opened by CEB backup relay due to overload as seen by the relays.
(4)	+121 cycles	230 kv. line Q24BD opened by GCX relay due to overload as seen by the relays.

Oscillographic Data

Sequence	*Time*	
	5:16:11 p.m.	
(5)	+161 cycles	230 kv. line Q30AW opened by GCX relay due to overload as seen by the relays. These operations separated the Beck plant of HEPCO from all its lines except Q26A a 230 kv. radial line and the 230 kv. ties with PASNY and Niagara Mohawk. Beck generation was fed to Niagara Mohawk and PASNY and thru the 345 kv. lines and other paralleling networks to Syracuse thence to St. Lawrence via 230 kv. lines.
	5:16:11 p.m.	
(6)	+197½ cycles	230 kv line L33P St. Lawrence-Moses tie between Ontario Hydro and PASNY tripped at Moses by Directional Overcurrent relay on excess load. This left an excess of generation of approximately 1346 mw in the PASNY-Niagara Mohawk area.
(7)	+212 cycles	About this time the following lines opened due to instability: a. Meyer-Hillside 230 kv line between Niagara-Mohawk and NYSE&G. (It reclosed automatically). b. Stolle-Meyer (NYSE&G) 230 kv line. (It reclosed automatically). c. E. Towanda (PJM)—Hillside (NYSE&G) 230 kv line d. N. Waverly (NYSE&G)—E. Sayre (PJM) 115 kv line. e. Goudey (NYSE&G)—Lennox (PJM) 115 kv line. f. Erie-Dunkirk 230 kv (at Dunkirk only) Directional overcurrent relays Zone 2 separating PJM from Niagara Mohawk. g. Warren area lines opened separating the Niagara Mohawk system and the Warren area load from PJM
(8)	+212½ cycles	230 kv line H23C Cherrywood-Hinchinbrooke of HEPCO tripped at both ends.
(9)	+213½ cycles	About this time the following group of lines operated: a. The 345 kv Rochester-Clay No. 2 line tripped by Instantaneous Distance relay at both ends as a result of instability. b. The 345 kv Rochester-Clay No. 1 line tripped by Directional Distance relays at both ends as a result of instability. c. All of the 115 kv circuits of Niagara Mohawk and of NYSE&G in parallel with the 345 kv lines and bridged between the Rochester-Clay opening points tripped. Many of these reclosed successfully (after the Moses-Adirondack-Porter 230 kv lines opened and remained open.) Others were closed manually. Mortimer 115 kv bus tie opened. The initiation of the shutdown of the Rochester Gas and Electric system was probably at this time and the system was down in about three minutes (5:19 p.m.).
(10)	+214½ cycles	At approximately this time Consolidated Edison Co. separated at Greenwood Substation in Brooklyn by Directional Distance relays on excessive power flow. Some Brooklyn load from Greenwood, the Staten Island load, and the Arthur Kill generating plant of Consolidated Edison remained connected with the PJM system.
(11)	+ 215 cycles	HEPCO 230 kv line H24C tripped at Cherrywood.
(12)	+218 cycles	HEPCO 230 kv line C26C tripped at Chats Falls.
(13)	+226 cycles	HEPCO 230 kv line C27P tripped at Chats Falls.
(14)	+227½ cycles	HEPCO 230 kv line H23C reclosed at Hinchinbrooke

Oscillographic Data

Sequence	*Time*	
	5:16:11 p.m.	
(15)	+240½ cycles	Adirondack No. 2,230 kv line tripped at Moses by Instantaneous Directional Distance relays.
	+241½ cycles	Adirondack No. 1,230 kv line tripped at Moses by Instantaneous Directional Distance relays. This tripped two transformers and five generators at Moses-St. Lawrence plant (a programmed operation).
(16)	+241 cycles	HEPCO 230 kv line C26C reclosed.
(17)	+ 242 cycles	HEPCO 230 kv line C27P reclosed.
(18)	+ 247½ cycles	Plattsburgh-Essex line (PASNY-Vermont 115 kv) tripped by Instantaneous Directional Distance relay caused by instability. Automatic reclosing unsuccessful.
(19)	+255½ cycles	Adirondack No. 2, 230 kv line reclosed automatically at Moses (St. Lawrence).
(20)	+256½ cycles	Adirondack No. 1, 230 kv line rcclosed automatically at Moses (St. Lawrence).
	+ 267 cycles	One unit at Moses-Niagara on Feeder #1 trips (pump storage unit 27 mw).
(21)	+288½ cycles	Adirondack No. 2, 230 kv line tripped at Moses (St. Lawrence) by Instanstaneous Directional Distance relays due to instability.
(22)	+289½ cycles	Adirondack No. 1, 230 kv lime tripped at Moses (St. Lawrence) by Instantaneous Directional Distance relays due to instability.
(23)	+290½ cycles	Adirondack No. 2, 230 kv line tripped at Adirondack due to instability.
(24)	+29 1½ cycles	Adirondack No. 1 tripped at Adirondack due to instability.

Lag Chart Data

Time	Time Correlation Included in Item Description
5:16 p.m.	HEPCO system split in three major sections due to trouble as noted above. Major losses of load and generation resulted. Similar trouble occurred at 6:54 and 7:24 p.m. All load restored at 8:30 p.m.
(25) 5:16 p.m.	Detroit Edison Co. separated from HEPCO on the Waterman-Keith 230 kv line. This tie was closed back at 5:33 p.m. The other Detroit-HEPCO tie remained in service.
(26) 5:16 p.m.	Two 115 kv tie lines between NEPCo and Boston Edison Co. and one 115 kv tie lime between NEPCo and Western Massachusetts Electric Co. opened.
(27) 5:17 p.m.	Whitehall-Rutland 115 kv lime (Niagara Mohawk to Velco) tripped on instability (approximate cycle +247½).
(28) 5:17 p.m.	Hoosick-Bennington 115 kv line (Niagara Mohawk to Velco) tripped on instability (approximate cycle 247%).
(29) 5:17 p.m.	The Rotterdam-Pratts Junction 230 kv line connecting Niagara Mohawk and NEES tripped at Pratts Junction and reclosed automatically then opened at the Rotterdam terminal (approximately 247½ cycles).
(30) 5:17 p.m.	Convex started opening manually the New England ties (East Springfield-Palmer, Doreen-East Greenbush, Montague-Yankee, and Montague-Millbury).
5:17:03 to 5:18:01 p.m	Ten units at Beck off before 5:17:30 automatically. (Low Governor Oil Pressure from trying to follow power swings). In same period PASNY lost five Pump-generating units due to over speed. (No other PASNY-Niagara units were shut down.)

Log Chart Data

Time	
(31) 5:17:30 p.m.	PA-27 Beck-PASNY 230 kv line tripped by Under Frequency r&y.
(32) 5:18:30 p.m.	BP-76 Beck-Packard 230 kv line tripped by Under Frequency and Power Directional relays.
(33) 5:18 to 5:23:30 p.m.	Before the end of this period there were numerous 230,115, and 69 kv lines openings and reclosures and some loss of generation in the NEES. [In this period at 5:20 p.m. Orange & Rockland system separated from Consolidated Edison Co. and other systems. The Central Hudson system had shut down by 5:23 p.m. *Note:* At 5:23 p.m. the charts at Pleasant Valley indicated no power flow on the Niagara Mohawk lines. No data available as to exact time but Central Maine probably separated from the other systems about 5:18 p.m.]
(34) 5:21 p.m.	Boston Edison stated that their system went black.
(35) 5:21 p.m.	Convex completed opening of ties manually to NEES. NEES System reported most of their system went dead at this time.
(36) 5:23:30 p.m.	Greenbush 115 kv lines to NEES opened separating NEES from the ties to west.
(37) 5:24 p.m.	Long Island Lighting Co. separated manually from Consolidated Edison Co. at Long Island Lighting Co. terminal.
(38) 5:28 p.m.	Consolidated Edison reported that all 345 kv and the 115 kv ties to Niagara Mohawk were opened by supervisor control at Pleasant Valley. By thii time the Consolidated Edison System was blacked out. The load had gone down gradually in a period of one to two minutes as shown by the charts. The CONVEX system was now isolated and there were five separate load and generation centers left supplying a total of about 500 mw.
(39) 7:25 p.m.	Detroit Edison Co. separated automatically from HEPCO on both the Waterman-Keith and Marysville-Sarnia ties. They were closed back respectively at 7:41 and 7:46 p.m. Delivery to Canada was 100 mw after closing. Normal operation restored at 10:30 p.m.

Power System Restoration
November 9 and 10, 1965

345 *Kv Transmission* Connections

6:43 p.m.-Clay-Edit 1 & 2 345 Kv tripped by phase No. 3, zone No. 1 and transfer trip relays.
7:25 p.m.—Clay-Edic tie restored. Bank at Clay energized from Fdic.
6:59 p.m.—Porter-Edic 345 Kv line restored to service.
6:28 p.m.-Adirondack-Porter 230 Kv lines 11 & 12 opened,
6:40 p.m.-Adirondack-Porter 230 Kv line 11 & 12 closed.
6:53 p.m.-F&-New Scotland 345 Kv opened manually,
7:44 p.m.—Edic-New Scotland 345 Kv closed.
6:59 p.m.—Edic 345/230 Kv hank back to service.
5:50 p.m.--Clay reports 345 Kv breakers on Rochester lines closed, had remained in after reclosure at 5:16:14.
9:59 p.m.-New Scotland-Pleasant Valley 345 kv line 92 was energized from New Scotland.

November 10, 1965

12:06 a.m.-Rochester-Clay #1, 345 Kv tie restored after being tied for 7 minutes, 10:54 to 11:01 p.m.
12:37 a.m.-Rochester-Clay #2, 345 Kv tie restored after being tied for a few minutes at 11:09 p.m.

Nom.-Switching at the Clay Terminals of the 345 Kv lines hampered by low air pressure, low voltage prevented operation of air compressors of breakers.

power System Restoration
November 9 and 10, 1965

St. Lawrence Am PASNY & Niagara Mohawk

5:18 p.m.-Several attempts were made to restore load from the 115 and 230 Kv sources at Moses-St.
to Lawrence plant.
6:54 p.m. Ties were made with VELCO out of Plattsburg and with NYSE&G at Saranac several timed but were opened due to low voltage and power swings when attempts were made to close the 230 Kv connection.
5:18 p.m.—Moses to Adirondack to Porter connections attempted unsuccessfully a number of times; line
to tripping at Moses automatically tripped generators.
6:46 p.m.
7:35 p.m.-230 Kv lines energized to Porter without load.
7:48 p.m.—Moses-Saunders 230 Kv tie line L33P was opened manually.
8:05 p.m.-Began picking up load at Porter up to 700 Mw.
8:14 p.m.—PASNY closed at Saranac tying with NYSE&G successfully and picked up load.
5:33 p.m.-Essex lii energized from Plattsburg.
7:15 p.m.-VELCO closed at Essex sub picking up a small amount of load.
7:17 p.m.-VELCO picking up State of Vermont load to 75 Mw.
7:24 p.m.-System surge high and low frequency at Moses but load held.
7:48 p.m.—Moses-Saunders 230 Kv tie line L33P opened at HEPC request to stabilize system.

November 10, 1965

1:07 a.m.-Moses-Saunders 230 Kv tie line closed with Phase Shifter in service, load 60 Mw to south.

115 and 230 *Kv Lines Niagara* Area

5:53 p.m.-The 230 Kv Beck-Packard tie line BP-76 was closed paralleling the HEPC system with PASNY
to and Niagara Mohawk systems.
5:59 p.m.
6:02 p.m.-The 230 Kv Beck-Packard tie line BP-76 was again closed paralleling HEPC with PASNY and Niagara Mohawk.
6:17 p.m.-The 230 Kv Beck-Moses tie line PA-27 was closed connecting these plant busses of HEPC & PASNY.
6:26 p.m.-The 230 Kv Moses (St. Lawrence)-Saunders line L33P was closed establishing tie HEPC to PASNY at these stations.
5:50 p.m.-Niagara Mohawk made substantial progress in restoration of normal connections of its 115
to Kv internal tie lines involved in the 5:16 split up. This partially undone by disturbance at
6:54 p.m. 6:54.
6:54 p.m.—The Beck-Packard 230 Kv line BP-76 tripped at Beck by Power Directional relays. Beck was generating 1350 Mw.
6:54 p.m.-The Beck-Moses 230 Kv line PA-27 tripped at Beck by Under Frequency relays.
7:16 p.m.-Niagara Mohawk restored connections of its 115 Kv internal system tie lines and to NYSE&G
to 115 Kv connection in the Long Branch, Mortimer, and Geres Lock Areas.
8:40 p.m.
7:28 p.m.-Erie Station of Penn. Elect. Co. closed on the Dunkirk 230 Kv tine restoring parallel operation between CANUSE & PJM Systems.
7:43 p.m.—Warren Station, of Penn. Elect. Co. closed on the Falconer line tying between Niagara Mohawk & PJM.
10:09 p.m.—Greenbush-Pleasant Valley 115 kv line energized to Pleasant Valley 115 kv busses. Power was also made available to the Pleasant Valley 115 kv bus from Niagara Mohawk Unionville Pleasant Valley line.

New York State Electric & Gas Corporation

5:16 p.m.-The Stolle Rd-Meyer and Meyer-Hillside 230 Kv reclosed automatically after initial tripping. (Line opened 5:16:11 + 212)

7:51 p.m.-Closed the Hillside-Towanda 230 Kv line tying Penn. Elect. Co. with NYSE&G. (Line opened 5:16:11 + 212)

The 115 Kv tie lines internal to NYSE&G system which were not restored automatically after the system split and, those 115 Kv lines tying with other systems were closed manually.

5:41 p.m.-E. Norwich closed on the Jennison line.
5:45 p.m.—Etna closed on Lapeer.
Unknown-Courtland closed by Niagara Mohawk on Jennison line.
6:10 p.m.—Greenidge closed on Border City line.
6:17 p.m.-Greenidge closed on Montour Falls lie.
6:20 p.m.—Coddington closed on Montour Falls line.
8:39 p.m.-Border City closed on Geres Lock line.
10:05 p.m.-East Sayer closed on N. Waverly line, restoring tie with Penn. Elect. Co.
11:14 p.m.-West Woodbourn dosed restoring tie with Central Hudson.

Rochester Gas 6 Electric Corp.

November 9, 1965

6:28 p.m.-A feeder was established from hydro station #5 to auxiliary buses at Beebee Station.
7:16 p.m.-Power to Russell Station.
7:17 p.m.--Some hospital service was restored.
9:22 p.m.-The City of Rochester pumping station was energized.
10:30 p.m.-Eighty percent of the system load was restored.
11:44 p.m.-Complete restoration was effected.

Long Island Lighting Company

November 9, 1965

5:45 p.m.—Glenwood Station back on the line.
6:10 p.m.-Barrett Station back on the line. Bus voltage normal.
7:00 p.m.-By this time all 126 major substations were normal.
7:09 p.m.-Seven Mw of load had been picked up.
11:00 p.m.-Eighty percent of system load picked up.

November 10, 1965

1:00 a.m.-By thii time the remainder of the load had been picked up.
138 kv tie to Con Edison was closed.

Orange & Rockland Utilities

November 9, 1965

5:28 p.m.-Closed 115 kv Interconnection to Central Hudson for them to start up the Danskammer Station.
7:05 p.m.-Closed 115 kv tie to New Jersey Power & Light Co.
7:50 p.m.-Closed 115 kv tie to Con. Ed. to give station service Power for Indian Point Plant and other use.

Central Hudson Gas and Electric Corp.

November 9, 1965 (Corp's. log times adjusted by + 1 min.)

5:45 p.m.—Central Hudson started to open all buses of main stations and substation.
6:28 p.m.-Received power from Orange and Rockland for starting Danskammer Steam Station service (via Sugarloaf 115 kv line.)
7:04 p.m.—Central Hudson Gas & Electric Corporation phased with New Jersey Power & Light Co. at Sugarloaf.
7:27 p.m.4 kv service made available to Poughkeepsie.
7:42 p.m.-Offered power to New York State Electric & Gas Corp.
9:59 p.m.-The #92 345 kv was energized at New Scotland (Niagara Mohawk) to Pleasant Valley. (Consolidated Ediin closed in on #92 circuit at Pleasant Valley at 2:20 a.m., 11-10-65.
10:00 p.m.-Records indicate a majority of the customers had been restored.
10:09 p.m.-115 kv lines 8, 12 and 14 were closed at Pleasant Valley and service now available for Consolidated Edison from Niagara Mohawk.
10:22 p.m.-Central Hudson 115 kv interconnection with Niagara Mohawk was close-d at Catskill Substation.

P.J.M. Interconnection

6:57 p.m.—Gaudy-Lenox 115 kv line closed.
7:25 p.m.-Dunkirk-Erie South 230 kv line closed.
7:43 p.m.-Warren-Falconer 115 kv line closed.
7:51 p.m.-East Towanda-Hillside 230 kv line energized closed to Hillside.
10:05 p.m.-North Waverly, East Towanda-E. Sayre 115 kv line closed.

New England Electric System

November 9, 1965

5:31 p.m.-Harriman Station back on energizing 115 kv line #131 to Adams. By 5:47 p.m. system was energized down to Millburg and Pratts Junction.
6:06 p.m.-l 15 kv lines energized to Providence.
6:08 p.m.-Energized line #138 to Boston Edison Co's. Edgar Station.
6:21 p.m.-Milbum 115 kv line energized to Palmer and thence to West Springfield. West Springfield not ready to use.
6:24 p.m.-Woonsocket energized line #147. Thii circuit ties to Montaup Electric Co. and Brayton Point. Montaup phased in and tied the two systems together.
6:33 p.m.—69 kv limes to Pratts Junction were energized to Pratts Junction. This picked up the entire high tension system. Started picking up load. Both PS of NH and Montaup had surplus and could help NEES. "It was after 9:00 p.m. before NEES tied to New York and CONVEX. By 9:30 or 10:00 p.m. we were ready to tie with anyone."

Connecticut Valley Power Exchange

November 9, 1965

5:30 p.m. to 8:10 p.m.- System lines being switched.
5:30 p.m. to 10:25 p.m.-Customers being picked up.
9:40 p.m.— CONVEX paralleled with New England.
10:35 p.m.— Ties between CONVEX and Massachusetts opened due to line trouble. An insulator failed and a line jumper burned open.
10:55 p.m.— Phased with Massachusetts. Some load was curtailed.
11:29 p.m.— Last CONVEX-New England tie closed.

November 10, 1965

5:00 a.m.— Closed 345 kv to Consolidated Edison Pleasant Valley substation.

Power System Restoration
November 9 and 10, 1965

Boston Edison Company

November 9, 1965

6:40 p.m.-Starting 1A bus from Navy generator.
7:00 p.m.-Starting station service at station 75.
7:58 p.m.-First critical load reestablished.
9:20 p.m.-Synchronized with New Bedford system.

November 10, 1965

12:16 a.m.-Interconnection with New England Electric System reestablished.
12:28 a.m.-Circuits from station 2.50 were closed. This station had been alive from Massachusetts Electric Company.
12:50 a.m.-This is the last item indicated for the rutoration of service.

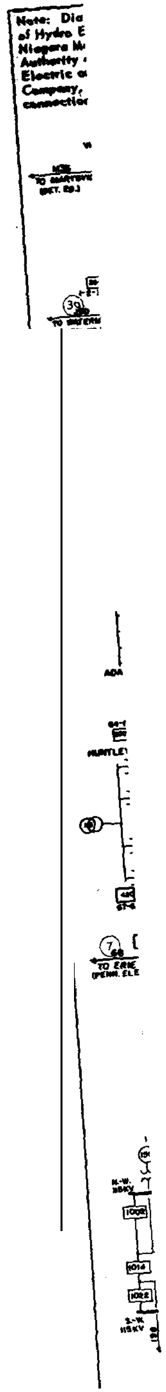
Consolidated Edison Company

November 9, 1965

6:52 p.m.-Greenwood switch 138 kv 6S was closed energizing circuit 23073 to Hudson Ave.
7:17 p.m.-Greenwood 138kv bus tie switch BT was closed.
8:30 p.m.-Greenwood 138 kv switch 8S was closed energizing circuit 31231 to Vernon.
Note these steps made power available from the Fresh Kii bus for use in restoring the network. Throughout the interruption period the Fresh Kills station lines remained tied to the large network of PJM and connecting companies.
8:25 p.m.-Pleasant Valley 138 kv switch R-62 was closed energizing a part of the Consolidated Edison system.
9:05 p.m.-Pleasant Valley 138 kv switch R-61 was closed energizing circuits to another part of the Consolidated Edison system.

November 10, 1965

2:27 a.m.-Pleasant Valley 345 kv switch RNS4 was closed. Thii tied the New Scotland Line 92 to the south Pleasant Valley bus.
2:46 a.m.-Pleasant Valley 138 kv circuit 93932. This completed a tie between the 345 kv system, a part of the Consolidated Edison 138 kv system and the 115 kv lines of Niagara Mohawk at Pleasant Valley.
4:02 a.m.-Pleasant Valley 345 kv switch RM2 was closed tieing the Southington circuit to the north bus and New Scotland Circuit 91.
4:04 a.m.-Pleasant Valley 345 kv switch RNS2 was closed tieing circuit 81 to the Southington line. This restored the major external interconnections.



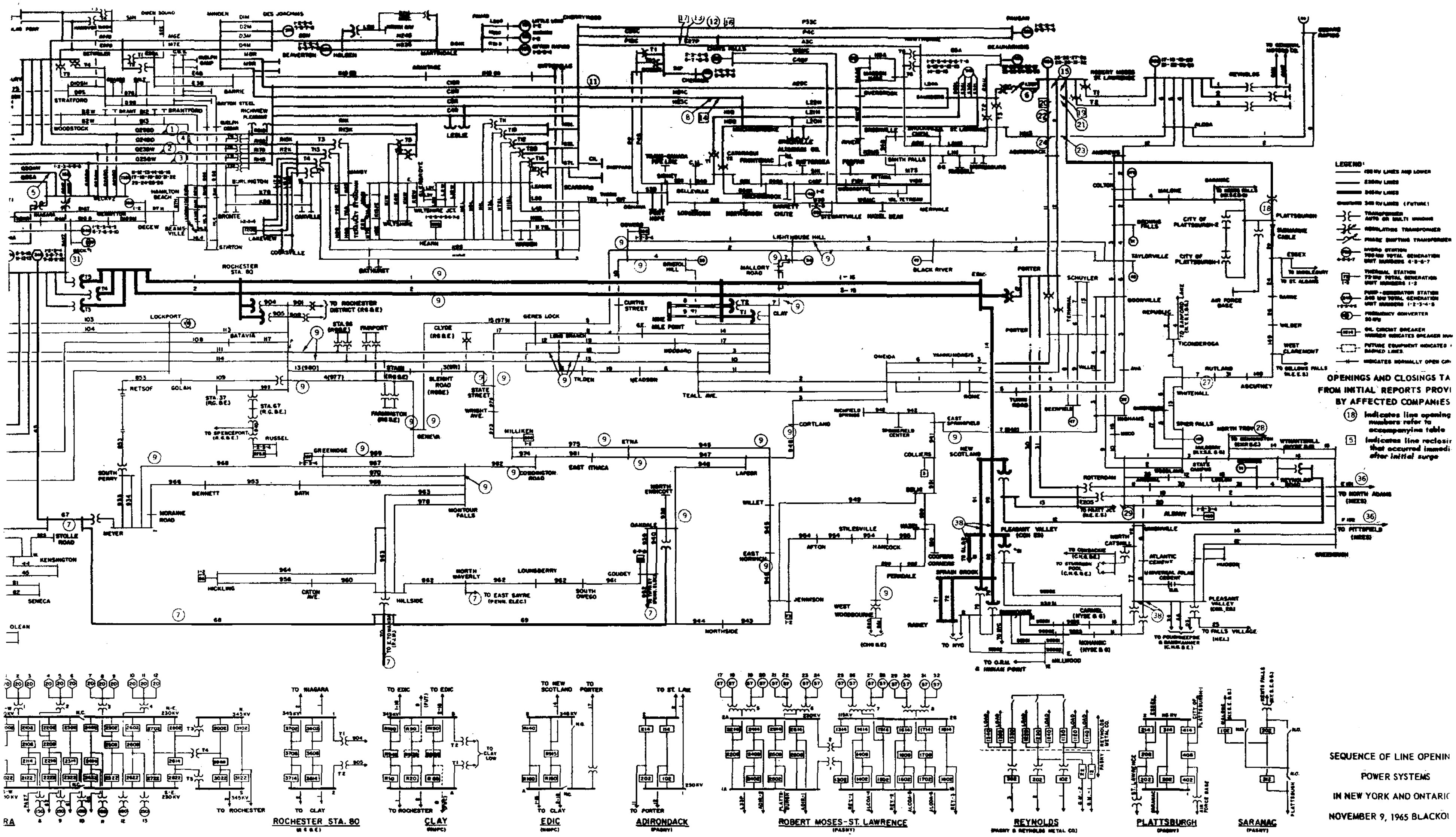

OPENINGS AND CLOSINGS TA
FROM INITIAL REPORTS PROVI
BY AFFECTED COMPANIES
SEQUENCE OF LINE OPENIN
POWER SYSTEMS
IN NEW YORK AND ONTARIC
NOVEMBER 9, 1965 BLACKOU
ROCHESTER STA. 80
CLAY
EDIC
ADIRONDACK
ROBERT MOSES-ST. LAWRENCE
REYNOLDS
PLATTSBURGH
SARANAC

Exhibit A-I

Electric Utility Planning Studies

Emphasizing Transient Stability Analyses of Transmission Network

The production, distribution, and sale of electric power is different from the activities of other businesses in the sense that a sale is consummated immediately upon placing an order (closing a switch) without prior warning of the customer's requirement. Because of this need for instantaneous power supply, the fact that the demand for electricity is experiencing continuous growth and the fact that long lead times are required to construct power supply facilities (*e.g.*, transmission lines 2–3 years; thermal generation 3–4 years; hydro generation 4–5 years), long range planning studies are necessary.

The procedure used in planning power systems starts with a projection of future load demands based on a careful examination of customer use patterns and trends together with an evaluation of the probable future level of general economic activity. With this as a basis, the power system is simulated from a mathematical model on a digital computer. The electrical performance of the system is then tested for various levels of future power demands. These tests are intended to reveal any possible inadequacies in facilities and in the ability of the system to function reliably with equipment out of service. The digital computer automatically performs most of these tests and reports deficiencies in system design. The planner then added such additional tests as typified by more severe but credible incidents, to meet the design criteria.

After an examination of possible system inadequacies, the planner from his first-hand knowledge of the physical facilities modifies the transmission and generation characteristics of the computer model and retests the system's performance. After testing several alternative programs of facility reinforcement, together with tests on the longer range needs of the system, he examines the economics of the alternative program and decides on a preliminary plan adequate to meet load requirements. This plan is then further tested to examine the system's response under transient conditions, caused by short circuits, the switching in and out of service of various facilities and the sudden interruption of load or generation. These studies require a different type of mathematical representation and are much more complex than the steady state representation used in the previous studies. The preliminary system design is established before the transient tests are undertaken since it is desirable to minimize the number of highly complex cases to be studied for transient performance. The transient tests are analyzed for potential system weaknesses and restudied if further modifications are required. The completion of these studies results in a series of planned system modifications required to meet the long range load projections. These plans are continually modified as load developments or operating experience dictate.

The planning of interconnections between companies is handled in much the same manner except that more complex network representations, embracing the systems of all participating companies, are required in order properly to coordinate the planning of the principal internal facilities of each company with the interconnection facilities between the companies.

Transient Stability Studies

The simulation of electric power system performance following sudden short-circuits, transmission line openings, loss of generation or loss of load, is very complex. At present, there is no completely adequate mathematical representation or digital computer program which will start with a disturbance and show the exact performance of the system until a new steady state condition evolves. Fortunately, the system will exhibit its weaknesses either during the first second of the disturbance or after a new steady state condition is established and therefore only these two time periods are usually studied. The sequence of time periods from the instant a disturbance occurs to when the power system reaches a new level of steady-state equilibrium may be classified as follows:

A. 0–1 second—Transient performance before voltage regulators and governors at generating plants can respond.

B. 1 second to 5 minutes—Performance with regulators, governors and changing boiler conditions but before system load control equipment can respond.

C. 5 minutes and longer—Performance under the action of the system load control equipment.

For the period covering the first second of time, mathematical representations are available to simulate the generator, transmission line, transformer, and load characteristics. The effect of any disturbance on the electrical system, whether it is caused by a short circuit or by switching out a line, generator, transformer or load, is to upset the energy balance in the system since the turbine outputs will not match the generator outputs. This unbalance in energy creates forces which accelerate the generators and change their phase angles. If the transmission system remaining after the disturbance has the capability to absorb the energy transfers, the system will restore to a new stable condition after a number of oscillations. On the other hand, if the energy unbalance exceeds the transmission system capability, the acceleration continues and the generators will be driven out of synchronism. When the system approaches 180° out-of-phase, a null voltage point will occur in the transmission system at its electrical center. This null point appears like a short circuit to the protective relays and they will operate to trip the line section which contains the electrical center.

Computer Simulation

A computer simulation of transient stability proceeds from an initial balanced load flow to an instant after the disturbance when the new electrical flows are calculated. These conditions are compared with the initial conditions and the accelerating forces calculated. The amount of angular movement of the generators is calculated as the result of these forces acting over a very short interval of time such as 0.02 second. The representation is then modified by these angular movements and new power flow conditions are calculated along with the new accelerating forces. Again, new angular positions of generators are calculated over the next time interval. This process is repeated for 40 to 60 of these time intervals.

The results of these calculations may be described as "swing curves" which reproduce on a detailed graph the angular movement of each generator as a function of time. The planner examines these graphs and from them can determine if the system is stable or unstable. Exhibit B–1 shows a typical graph which results in a stable condition because all the generators stay together in angular position. Exhibit B–2 shows a graph of an unstable condition because one of the generators is clearly moving away from the main group.

Selection of Disturbances

While the calculations for determining system stability are, in general, complex, the most critical part of the study lies in the assumptions used in the representation of the system and in the selection of the disturbances to be investigated. Present day digital computer programs available from the General Electric and Westinghouse Companies can represent only about 120 generators and about 500 system buses. An extensive system study requires many more elements for full representation and therefore equivalents which simplify and combine portions of the system are often used. Careful judgment must be exercised in establishing these equivalents so as not to destroy the accuracy of the study.

The selection of the disturbance is even more critical and again experience and judgment is necessary so as to select the initial loading and type of disturbance which will be a reasonable balance between the most severe credible incident and the margin needed to maintain system stability. Usually the planner will try to make the test conditions severe enough to cause instability so that he will know the consequences of the instability and also the amount of stability margin to be designed into the system.

System Modification

From the transient stability studies the planner can then determine if the system needs further modification. Some of the modifications might be:

(1) Additional or strengthened transmission lines.
(2) Revision of plans for the future location of generation.
(3) Changes in future generator or transformer design characteristics.
(4) Changes in switching facilities.
(5) Modifications of loading schedules on generation.
(6) Changes in relaying equipment and settings.
(7) Procedures for dropping of generation or for shedding of load in times of emergency.

The planner selects from among these system design and operating procedures the method he needs to provide the necessary stability margins and then establishes the final method for operating the system.

Exhibit B1

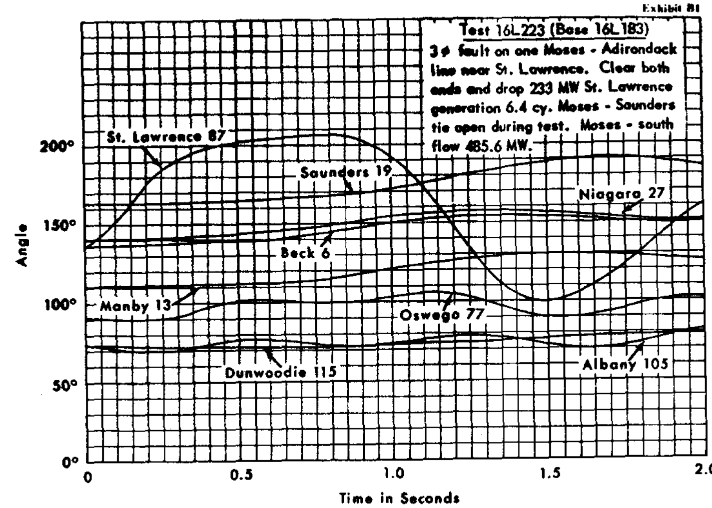
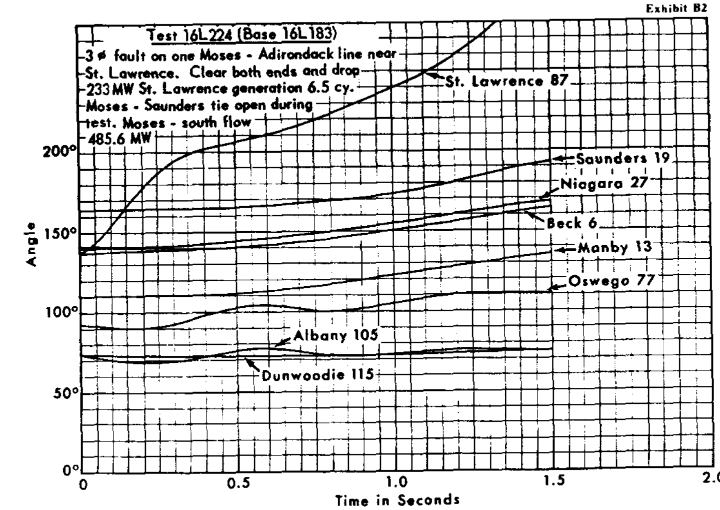


Exhibit B2



APPENDIX C

SUMMARY OF EVENTS

The Missouri Basin Area Power Interruption of January 28, 1965

The Missouri Basin Area Power Interruption of January 28, 1965

At 1:20 p.m. CST, the 230-kv bus at Ft. Randall power plant was lost due to false operation of the differential relays. The false operation resulted from accidental separation of a relay connection during maintenance.

The area affected by this power operation is shown on Exhibit II-A, page 25. The extent of outage is shown on Exhibit C-l.

This resulted in a severe shock to the interconnected transmission system by dropping approximately 90 megawatts of generation, opening five 230-kv lines and interrupting the important 230 to 115-kv supply transformer to the 115-kv system. In addition to the loss of generation approximately 170-mw of power being transmitted thmugh this bus into Nebraska and Iowa was interrupted.

The remaining alternate transmission paths through eastern South Dakota and southern Minnesota did not have sufficient capacity to transmit the surplus generation from the Dakota system to Nebraska and Iowa. These tie lines subsequently opened as power surges operated protective relays.

The Dakota-Central Minnesota power system speeded up and became unstable with the Nebraska-Iowa system thus preventing successful reclosure of any of 230-kv lines entering and leaving the Ft. Randall bus.

The utilities in Southern Minnesota, Iowa and Nebraska were not able to cover the lost input quickly enough from spinning reserve and remaining interconnections to Illinois, Missouri and Kansas or by reducing loads to avoid a major depression in system frequency and subsequent shutdown. Ties to other utilities outside of Iowa and Nebraska were also opened by protective relays.

Individual system dispatchers and power-plant operators did not have sufficient information to evaluate the severity of the disturbance as it occurred. Communication channels were overloaded preventing effective communication between operators. In several outlying power systems that might have been saved by disconnecting when the frequency fell past 58 cycles, operating instructions were too general to permit effective action. Attempts to drop load manually were too late and insufficient to halt the frequency drop on the main system.

Although the Ft. Randall bus was restored within about three minutes several utilities required from 45 minutes to 2 hours to restore all service because of the time required to restart steam generators. The outages could have been less had the operators disconnected in time to return the units to speed-no-load operation and not lost station service.

To avoid another total loss of the Ft. Randall bus, sectionalizing circuit breakers are being installed that will limit the number of transmission lines that would be lost for a bus fault. The arrangement of electrical connections to the differential relays was changed and maintenance procedures have been unproved. New transmission lines planned or under construction will provide new parallel paths from Dakota and Minnesota into Nebraska, and Iowa and from these States to other adjoining areas.

To limit the spread of the disturbance communication channels have been improved and procedures have been established for dropping load utilizing automatic equipment sensitive to frequency drop. Emergency operating instructions under conditions of low frequency have been revised and periodic review procedures established to assure continued alertness of operators.

EXHIBIT C-I

Summary of Extent of Outage Due to Power Interruption at Fort Randall Power Plant, January 28, 1965. States Affected: Iowa, Nebraska, South Dakota, Minnesota, Wisconsin, Illinois

Reporting Utility	*Extent of Outage*	*Length of Time Out*
Iowa Public Service.	Entire system went dead within 10 minutes. Major cities out: Sioux City, Waterloo, Charles City and Hampton areas.	Varied fmm 50 minutes to 2 hours and 30 minutes.
Iowa Southern Utilities.	Major cities out: Centerville, Chariton, Corydon, Leon, Mount Ayr, Creston, Osceola, Newton, Grinnell, Siquomey, Washington, Ottumwa, Oskaloosa.	Varied from 5 minutes to 1 hour and 58 minutes.

EXHIBIT C-1—Continued

Reporting Utility	*Extent of Outage*	*Length of Time Out*
Northwest Iowa Power Cooperative.	Total System (No generation-Supplied by USBR).	32 minutes.
Corn Belt Power Cooperative.	Both plants down. No. 4 unit at Humboldt plant picked up some load after 4 minutes.	4 minutes to 2 hours.
Eastern Iowa Light & Power Cooperative.	45 percent of load. Lost no generation (22mw).	43 minutes to 1 hour and 45 minutes.
Iowa-Illinois Gas & Electric.	Major cities out: Quad Cities, Iowa City and Fort Dodge. Ties opened: Illinois Power Co., Union Electric Co., Iowa Electric Light & Power, Eastern Iowa Light & Power Cooperative, Muscatine Municipal, and Iowa Southern Utilities.	30 to 93 minutes.
Iowa Electric Light & Power.	Ties opened: Iowa Public Service, Interstate Power Co., USBR, Iowa Southern Utilities, Iowa-Illinois G. & E. Cedar Rapids load salvaged and Boone City and part of Marshalltown.	52 minutes to 2 hours.
Interstate Power Co.	Major cities out: Albert Lea, Clinton, Lansing, Hayward, Winnebago.	14 minutes to 2 hours and 14 minutes.
Cedar Falls, Iowa	Tie opened with Iowa Public Service. No loss of load.	
Omaha Public Power District.	All 69-kv and 161-kv circuits opened. North and South Omaha plant down. Tie with Kansas opened.	42 minutes to 2 hours and 20 minutes.
Nebraska Public Power System.	Lost following generating plants: Canaday, Sheldon, Kramer, North Platte, Jeffrey, Johnson No. 1 and 2, and Columbus. NPPS-OPPD tie opened (manually).	7 minutes to 2½ hours.
Otter Tail Power Co.	No loss of generation or load.	
Northern States Power Co., Rural Cooperative power Association, and Minnesota Power & Light Co.	NSP interconnected system, RCPA, Minnesota Power & Light Co., and part of USBR isolated from Interconnected System Groups. Isolation of NSP Minnesota and Wisconsin systems. Isolation of NSP (Wisconsin) fmm Wisconsin Public Service Corp. NSP and Dairyland Power cooperative ties opened. NSP Wisconsin was out of service except for Cedar Falls-Menomonie Area (remained tied to Minnesota). LaCrosse area separated from Wisconsin System. French Island plant isolated from load. Winona Division became isolated fmm NSP Wisconsin, but remained tied to Dairyland. Sioux Falls area became isolated with only Lawrence plant carrying load.	19 minutes to 1 hour and 35 minutes.
Dairyland Power Cooperative.	Operated isolated. Ties with Northern States Power Co. and Interstate Power Co. opened. Lost about one-half of load due to overloading of boilers.	hour maximum

EXHIBIT C-1—Continued

Reporting Utility	*Extent of Outage*	*Length of Time Out*
USBR, Watertown Operations Office.	Fort Randall Power Plant, Bureau Southern S.D. system, and Nebraska and Iowa portion of Interconnected Systems Group. All 230-kv lines at Fort Randall opened.	3 minutes to 1 hour and 26 minutes.

Report of January 28, 1965, System Disturbance on the Missouri Basin Interconnected System

Thii summary of events is based on information compiled by the Bureau of Reclamation on February 25, 1965.

1. *Date and time of disturbance*

January 28, 1965, Thursday, 1:20 p.m., CST.

2. *Area involved*

Fort Randall Powerplant, Bureau southern South Dakota system, and Nebraska and Iowa portions of the Interconnected Systems Group.

3. *System conditions*

a. System connections were normal.

b. Approximate line loadings at time of disturbance:

At Fort Randall	
Columbus 230-kv line	+50 mw
Sioux Falls-Sioux City 230-kv line	+ 100 mw
Sioux City 230-kv line	+80 mw
Fort Thompson No. 1,230-k" line	-85 mw
Fort Thompson No. 2, 230-kv line	-85 mw
O'Neill 115-kv line	+24 mw
Mount Vernon 115-k" line	+44 mw
Gavins Point 115-kv line	+17 mw
Mission 115-kv line	+1 mw
At Gavins Point	
Belden 115-kv line	+17 mw
Neligh 115-kv line	+7 mw
Sioux Falls 115-kv line	+20 mw
At Sioux Falls	
Fort Randall-Sioux City 230-kv line	-34 mw
Brookings 115-kv line	—16 mw
Gavins Point 115-k" line	-2 mw
Northern States Power Company's Lawrence 115-k" line	+36 mw
At Sioux City	
Sioux Falls-Fort Randall 230-k" line	-45 mw
Fort Randall 230-kv line	-77 mw
Iowa Public Service Company 161-k" line	-19 mw
Spencer 161-kv line	+36 mw
Denison-Creston 161-kv line	+61 mw
161/69&v transformer KY3A	+40 mw

c. Powerplant loadings:

Fort Peck	175 mw	-25 mvar
Garrison	345 mw	-80 mvar
Oahe	215mw	-95 mvar

3. *System conditions*—Continued

c. Powerplant loadings—Continued

Big Bend	65 mw	—1 mvar
Fort Randall	90 mw	-110 mvar
Gavins Point	30 mw	- 6 mvar

d. Scheduled deliveries to interconnected systems:

Northern States Power Company	56
Rural Cooperative Power Association	14
Omaha Public Power District	- 5
Nebraska Public Power System	138
Iowa Public Service Company	0
Corn Belt Power Cooperative	24
Iowa Electric Light and Power Company	31
Iowa Southern Utilities Company	3
	261

4. *Weather conditions*

Fair; subzero temperatures over system.

5. *Cause of disturbance*

False operation of 230-kv bus differential relays at Fort Randall Powerplant. This de-energized Fort Randall 230-kv bus, disconnecting 6, 40 mw generators and open-ending 5 major 230-kv transmission lines.

The following statement as to the cause of the false relay operation was provided by the Corps of Engineers' Omaha Division office. (Fort Randall Powerplant was built by and is operated and maintained by the U.S. Army Corps of Engineers.)

"The Fort Randall 230-kv bus differential relay action was caused by an open circuit in the bus protection scheme. Checkout of relay changes in connection with the Fort Randall-Winner 115-kv line circuit involved manual tracing of wires located in the same wireways as the 230-kv bus diierential circuits. Movement of the wires in this wireway resulted in moving a wire in the bus differential circuit which caused looseness in lugs attached to a terminal strip by a screw. The movement resulted in an open circuit or a high resistance connection at this terminal resulting in a false bus differential relay operation."

6. *Events of disturbance*

1:19 p.m.-Fort Randall 230-kv Breakers 1182, 1282, 1382, 1982, 2182, 2282, 2382, 2482, and 2682, and 115-kv Breaker 1962 relayed by 87B,ØA, 87BX. This opened the Fort Randall terminal of the Fort Randall-Fort Thompson Nos. 1 and 2, Fort Randall-Sioux Falls-Sioux City, Fort Randall-Sioux City, and Fort Randall-Columbus 230-kv lines, de-energizing the 230/115-kv autotransformer and separated Fort Randall Units, Nos. 3, 4, 5, 6, 7, and 8 from the system. These units were loaded to 90 mw prior to the trouble. The Fort Randall 115-kv bus remained intact with Units Nos. 1 and 2 condensing.

1:19+ p.m.-Oahe generation increased 90 mw at dispatcher's request in attempt to correct area requirement.

1:20 p.m.-Philip 1462 relayed to lock out due to overload.

Huron 1362 relayed *to* lock out due to overload.

Brookings 262 relayed to lock out due to overload.

NSP Co. W-23 at Wausau related to lock out due to overload, separating NSP Co. and northern system USBR from ISG.

It appears that at this time Iowa and OPPD ties with ISG opened, separating Iowa, Nebraska, and southern USBR systems from ISG.

6. *Events of disturbance*—Continued

1:22 p.m.-Fort Randall 87BX hand reset relay reset and Fort Randall began picking up to full generation on Units Nos. 1 and 2 which are connected to the 115-kv bus.

Fort Randall 1962 closed, energizing 230/115-kv autotransformer.

Fort Randall 1982 closed, energizing 230-kv main bus.

Corn Belt Power Cooperative separated from USBR at Wisdom.

1:23 p.m.-Fort Randall 1182 closed, restoring Units Nos. 3 and 4 to 115-kv system via autotransformer. Units Nos. 1 and 2 up to full generation.

1:26 p.m.-Fort Randall 2182 closed to connect Fort Thompson No. 1, 230-kv lime to Fort Randall bus, relayed immediately due to out of phase condition.

Fort Thompson 1782 relayed due to closing at Fort Randall out of synchronism. It reclosed automatically.

Fort Randall frequency was less than 59 cycles. Oahe frequency was about 60.05 cycles.

1:27 p.m.-NSP Co.'s Lawrence 798 opened manually, separating NSP Co. from USBR Sioux Falls 115-kv line.

Fort Randall 1382 closed, restoring Units Nos. 7 and 8 to 230-kv bus.

Fort Randall 2682 closed, paralleling with Fort Randall-Sioux City No. 2, 230-kv line and Iowa system. Closing of this breaker caused another 230-kv bus differential relay action.

Fort Randall 1182, 1382, 1982, 2682, and 1962 relayed by 87B,ØA,87BX, separating Fort Randall from Sioux City No. 2 line, and 230/115-kv autotransformer; also Units Nos. 3, 4, 7, and 8 from 230-kv bus.

1:28 p.m.-Nebraska Public Power System's Neligh-Ablion, Norfolk-Columbus and Oakland-Beemer 115-kv lines relayed, separating majority of NPPS system from USBR system.

1:29 p.m.-I.E.L. & P. Co. opened Guthrie 9020, separating from Denison-Anita Tap-Creston 161-kv line.

Creston 1242 opened by supervisory control by Southwestern Federated Power Cooperative, separating SWF Power Coop. from Denison-Anita Tap-Creston 161-kv Iii. SWF Power Coop.-ISU Co. ties relayed due to overload, separating SWF Power Coop. from ISG.

1:29 + p.m.-Apparently the progressive automatic and manual breaker openings in the Iowa and Nebraska systems, with loss of generators and general system collapse, resulted in very low 115-kv voltages in the Fort Randall-Gavins Point area in consequence of which Gavins Point ACB 124 relayed due to overload, separating Unit No. 1 from 115-kv system.

1:29+p.m.—Gavins Point 762 relayed to lock out due to out-of-step condition, separating Gavins Point from Sioux Falls 115-kv line. (For winter operation at Gavins Point, only one generator is normally connected to the bus.) Voltage on the isolated Fort Randall-Gavins Point system was now in the 50–90-kv range.

Fort Randall 87BX hand reset relay reset.

Fort Randall 1962 closed, energizing 230/115-kv autotransformer.

Fort Randall 1982 closed, energizing 230-kv bus from autotransformer.

1:32 p.m.-Brookings 262, Sioux Falls 115-kv line, closed by supervisory control through dead line check relays, relayed immediately to lock out due to overload as all Sioux Falls and Sioux City Substation breakers were still closed.

Watertown 1362 (Brookings line) relayed due to overload and closed automatically.

1:33 p.m.-Fort Randall 1182 closed, paralleling Units Nos. 3 and 4 to 115-kv system through autotransformer.

1:35 p.m.-SWF Power Coop. picked up approximately 5 mw of their load with diesel generation.

Fort Randall 2382 closed out of parallel on Fort Thompson No. 2, 230-kv line and remained closed.

Fort Thompson 1582 and 1586 on Fort Randall No. 2 line, relayed due to out of phase closing at Fort Randall and failed to reclose automatically. (These breakers developed air leaks and it was necessary to open associated Disconnects 1581 and 1585 to isolate breakers from system before breakers lost all of air supply.)

1:35 p.m.-Continued

Relaying of Fort Thompson 1582 and 1586 opened Big Bend No. 1 line since its other breaker in the 1½ breaker scheme was out of service for maintenance at Fort Thompson.

Fort Randall 2182 closed manually and it relayed immediately due to out of phase condition, and remained open.

Fort Thompson 1782 (Fort Randall No. 1 line) relayed due to Fort Randall closing 2182 out of synchronism and failed to reclose successfully.

1:36 p.m.-Big Bend 224 opened manually, separating Unit No. 2 from Fort Thompson No. 1 line, which was open at Fort Thompson Substation.

1:38 p.m.-Fort Randall 2182 closed, energizing Fort Thompson No. 1, 230-kv line.

Fort Randall 1282 closed, restoring Units Nos. 5 and 6 to service.

1:43 p.m.-Fort Randall 2682 closed, energizing Sioux City 230-kv line and Sioux City Substation. This caused another false 230-kv bus differential relay action at Fort Randall.

Fort Randall 1182, 1282, 1982, 2182, 2382, 2682, and 1962 relayed by 187B, ØA, 87BX, deenergizing Fort Thompson Nos. 1 and 2, 230-kv lines, Sioux City 230-kv line, 230/115-kv autotransformer, and separating Units Nos. 3, 4, 5, and 6 from system.

1:44 p.m.—Gavins Point 362 closed, Unit No. 3 on system.

Gavins Point 762 (Sioux Falls line) closed, relayed immediately due to overload.

Sioux Falls 262 (Brookings line) opened by supervisory control

Fort Randall 87BX hand reset relay reset.

Fort Randall 1962 closed, energizing 230/115-kv transformer.

Fort Randall 1982 closed, energizing 230-kv main bus.

1:45 p.m.-Fort Randall 1182 closed, restoring Units Nos. 3 and 4 to service.

Sioux Falls 562 (Gavins Point line) opened by supervisory control, preparatory to energizing Sioux Falls Substation from north.

Sioux Falls 662 (to 230-kv Fort Randall-Sioux City line) opened by supervisory control, separating Sioux Falls Substation from Fort Randall-Sioux City line. All Sioux City PCB's were still closed at this time, but station was dead.

1:46 p.m.-Fort Thompson 1782 closed, energizing Fort Randall No. 1, 230-kv lime.

1:47 p.m.—Brookings 262 closed by supervisory control, energizing Sioux Falls 115-k" line and Flandreau Substation.

Sioux Falls 262 closed by supervisory control, energizing Sioux Falls Substation and restoring service to East River Electric Power Cooperative and L and 0 Power Cooperative.

Fort Randall 2382 closed, energizing Fort Thompson-Fort Randall No. 2, 230-kv line.

1:48 p.m.-Sioux City 482, 1262, 1362, 1462, and 1662 opened manually, preparatory to restoring service selectively from the north.

Sioux Falls 562 (Gavins Point line) closed by supervisory control, relayed immediately, due to frequency difference.

Gavins Point 362 relayed due to overload, separating Unit No. 3 from system. Local frequency fell below 55 cycles in Fort Randall-Gavins Point-northern Nebraska isolated area.

Fort Randall 2182 (Fort Thompson No. 1 line) closed, relayed immediately due to out of phase condition.

Fort Thompson 1782 relayed due to out of phase closure of Fort Randall 2182 and closed automatically.

1:49 p.m.-Fort Randall generation increased on Units Nos. 3 and 4, restoring frequency to 60 cycles.

Fort Randall synchronized and closed 2182 (Fort Thompson No. 1 line).

1:51 p.m.—Gavins Point 762 closed, energizing Sioux Falls 115-kv line and Yankton and Beresford Substations.

1:53 p.m.-Fort Randall 2482 closed, energizing Sioux Falls-Sioux City 230-kv line.

Note: Faulty bus differential relay wiring involved Fort Randall 2482 and 2682 current transformer circuits.

Fort Randall 1182, 1982, 2182, 2382, 2482, and I962 relayed by 87B, ØA, 87BX, separating from Fort Thompson No. 1 line, Sioux Falls-Sioux City 230-kv line and 230/115-kv autotransformer and separating Units Nos. 3 and 4 from the bus.

1:53+ p.m.-Fort Randall 87BX hand reset relay reset, closed 1962 and 1982.

1:54 p.m.-Fort Randall closed 1182, putting Nos. 3 and 4 generators on bus.

1:55 p.m.-Fort Randall 2182 closed, energizing Fort Thompson-Fort Randall No. 1,230-k" line.

Sioux Falls 562 closed automatically, restoring Gavins Point-Sioux Falls 115-h line to service.

NSP Co.-Sioux Falls-Lawrence 798 closed, restoring NSP Co.-USBR 115-kv line to normal.

1:56 p.m.-Fort Randall 1282 closed, restoring Units Nos. 5 and 6 to 230-kv bus.

1:57 p.m.—Gavins Point 362 closed, restoring Unit No. 3 to the system.

2:00 p.m.-Sioux Falls 662 closed by supervisory control, energizing Fort Randall-Sioux City 230-kv line and Sioux City Substation.

2:01 p.m.-Sioux City 1362 closed, energizing Sioux City 161/69-kv transformer, 69-kv bus and N1PCO's 69-kv system.

2:02 p.m.-Fort Randall 1382 closed, Units Nos. 7 and 8 on bus.

Fort Randall 2282 closed, energizing Fort Randall-Columbus 230-kv line. NPPS advised to take power as required.

Sioux City 1262 closed, energizing Sioux City-Spencer 161-kv line and Spencer Substation.

2:04 p.m.--Sioux City 1462 closed, energizing Sioux City-Denison-Creston 161-kv lii and Denison and Creston Substations.

Spencer 1142, 1242, 1442, and 1542 relayed due to overvoltage.

2:07 p.m.-Fort Randall 230-kv, 87B relays removed from service.

2:08 p.m.-Fort Randall 2482 closed, restoring Fort Randall-Sioux Falls-Sioux City 230-kv line to normal.

Philip 1462 closed by supervisory control, restoring Philip-Mission 115-k" line to normal.

2:10 p.m.--Sioux City 1662 closed, restoring Sioux City-Iowa Public Service Company 161-kv line to normal.

2:11 p.m.-Fort Thompson 1582 closed, energizing Fort Thompson-Fort Randall No. 2, 230-kv line.

Fort Thompson 1586 closed, energizing Fort Thompson-Big Bend No. 1, 230-k" line.

2:12 p.m.-Spencer 1242 closed by supervisory control, energizing Spencer 69-kv bus.

Spencer 1442 closed, restoring service to L and 0 Power Coop.'s 69-kv delivery.

2:13 p.m.—Fort Randall 2382 closed, restoring Fort Thompson-Fort Randall No. 2, 230-kv line to normal.

Spencer 1542 closed, restoring Spencer-NIPCO 69-kv system to normal.

2:14 p.m.—Creston 1242 closed by supervisory control, restoring service to SWF Power Coop.

2:15 p.m.-IPS Co. paralleled with USBR, and IPS Co. was limited to only enough power to supply Neal Powerplant station service for startup.

2:19 p.m.-Big Bend 124 closed, restoring Unit No. 1 to system.

2:25 p.m.-Sioux City 482 closed, energizing Fort Randall-Sioux City 230-kv line.

2:25+ p.m.-Spencer 1242, 1442, and 1542 relayed due to overvoltage (80-k").

2:28 p.m.-NSP Co.'s Wisota 8 closed, reconnecting NSP Co. and USBR systems to ISG.

2:29 p.m.-Spencer 1242 closed by supervisory control, energizing Spencer 69-kv bus. Spencer 1542 closed by supervisory control, restoring Spencer-NIPCO 69-kv service to normal.

2:30 p.m.—Spencer 1442 closed by supervisory control, Spencer 1242, 1442, and 1542 relayed immediately due to overvoltage.

6. *Events of disturbance*—Continued

2:30+ p.m.-Spencer 1242 closed by supervisory control, energizing 69-kv bus.

2:30+ p.m.—Spencer 1542 closed, restoring Spencer-NIPCO 69-kv line to normal.

Spencer 1242 and 1542 relayed immediately due to overvoltage.

2:33 p.m.-Fort Randall 2682 closed, restoring Fort Randall-Sioux City 230-kv line to normal.

2:34 p.m.-Not&d IPS Co. and OPPD dispatchers USBR system was normal and they could receive interchange to help restore their systems to normal.

2:39 p.m.-OPPD-IPS Co.'s 161-kv lii restored to normal,

2:41 p.m.—Spencer 1242 closed by supervisory control, energizing Spencer 69-kv bus.

2:46 p.m.-Spencer 1142 closed by supervisory control, restoring Spencer-Corn Belt Power Coop. 69-kv line to normal.

L and 0 Power Coop. and NIPCO breakers were left open at Spencer Substation to investigate cause of repeated breaker operations. Their load was served from other delivery points.

7. Remarks

All records for this disturbance report have not been completely checked, although it is felt this report is substantially correct. It should be considered as preliminary, possibly subject to minor revisions later.

Certain action has been taken subsequent to the disturbance in an effort to improve operational reliability. Some maintenance procedures have been tightened so as to preclude tripping of sensitive "in service" relays for work on or near them. Where one set of differential relays trips an entire powerplant high voltage switchyard, the contacts of a relay operated by polarizing current have been introduced in series in the trip circuit so that false tripping of the differential relays cannot take place. This is a temporary expedient pending splitting of the powerplant buses into sectional differential relay zones as a permanent expedient.

APPENDIX D

Operation Guide No. 9

North American Power Systems Interconnection Committee

Action in Emergencies

North American Power Systems Inkrconnection Committee

OPERATING GUIDE NO. 9
Action in Emergency

Approved: Fourth NAPSIC Meeting, Niagara Falls, Ontario, July 21, 1964

In a large interconnected system consisting of several pools and many systems, a temporary shortage of generating capacity in one system or even in an entire interconnected area is an ever-present operating possibility. Should such an emergency develop that is or may become of sufficient magnitude to affect operation throughout a significant portion of the interconnected system, a uniform understanding and approach is essential.

Since it is a basic principle that each control area shall plan to provide sufficient generating capacity to carry its expected load at 60 cps with provision for adequate ready reserve and regulating margin, if the internal resources are temporarily inadequate, arrangements should be made in advance with neighboring interconnected systems or pools to provide the necessary assistance. Thii assistance should be scheduled sufficiently in advance to permit the assisting systems or pools to provide the needed generating capability. In the event of a deficiency of generation in one system or pool which is offset by prearranged power supply fmm another system or pool, it is possible that certain interconnecting ties will be heavily loaded. Should an outage or unexpectedly heavy load occur, these interconnecting lines may become overloaded or may even fail to hold. This possibility must be recognized when making commitments for prearranged power supply. If due to an unforeseen emergency any transmission facility becomes seriously overloaded and cannot be relieved by adjusting generation, or by other means, appropriate relief measures shall be applied immediately by the deficient system to bring loading to within established emergency liiits.

When a system disturbance occurs, a prime consideration is to maintain parallel operation throughout the interconnected system if at all possible. Thii will permit rendering maximum assistance to the system in trouble and may prevent cascading of trouble to other parts of the interconnection and assist in restoration of normal operation.

Operating Guide No. 9

It is recommended that in such emergencies the following action shall be taken.

A. *Power Shortage in a System or Pool*

1. If a tie with other parts of the interconnection is seriously overloaded and cannot be relieved by adjusting generation in a systan or pool, relief measures shall be applied immediately by the deficient system to bring the tie loading to within the established emergency liiits.
2. The deficient system or pool shall be prepad to take action as in (1) above if requested to relieve serious overloads on a remote tie which is caused by the continuing deficiency.
3. In a large interconnected system, the possibility of critically low frequency in an emergency is remote. However, if a group of systems or pools becomes separated fmm the interconnected system, the possibility of critically low frequency does exist. If a power shortage in a system or pool is causing low frequency of a magnitude to impair or jeopardize the operation of other systems or pools, relief measures shall be applied by the deficient system to restore frequency to permit resynchronizing at any point of separation.

B. *Power Shortage in an Adjacent or Remote System or Pool*

1. Automatic tie-line bias frequency control should remain operative as long as practicable.
2. *If* automatic tie-line bii frequency control has become inoperative due to low frequency, manual control shall not be used to increase generation beyond the point necessary to restore automatic control unless mutual agreement is obtained with adjacent systems or pools.
3. If an overload persists on a tie *toward a* neighboring system or pool:
   a. The a&ted system or pool shall notify the neighboring system or pool of the magnitude of the overload and request immediate relief.
   b. If intolerable overload continues and equipment is endangered, the affected system Or pool may open the overloaded tics.

APPENDIX E

SUMMARY OF UTILITY RESPONSES

TO

FPC QUESTIONS OF NOVEMBER 13, 1965

NO. 1 What steps are you taking now to facilitate restoration in the event of a recurrence of outage? How many of these step have been taken and what will be their effect?	NO. 2 What modifications (A) in the design or operation of your system, (B) your interconnections with adjoinmg systems, and (C) in the internal design or interconnections of other systems do you consider necessary or desirable to avoid a recurrence of widespread outage?	*Utility*
(a) Order placed for 15-mva source of auxiliary power to assist in restoration of generating station equipment. (b) At Station 4, L St. plant, stoker-fired boilers arc being operated 24 hours per day. These have DC drives with ample storage battery standby supply. This will expedite emergency restoration of service. (c) Relay settings of feeders in the Somerville network are being reviewed. (d) Study being made of possible changes in frequency changer set which would expedite its return to service. (Set provides tie with Massachusetts Bay Transit Authority system.)	(a) At Station 200, Mystic plant, and at Station 75, Edgar plant, studying possibility of isolating certain generators, their boilers, and auxiliaries from direct connection to system buses by automatic removal in event of a major system disturbance. The prime purpose is to have an ample source of power available to restart other units following a complete area or system shutdown.	Boston Edison Co.
(a) Hydro station was delayed in startup due to loss of station service. Permanent connection will be made to auxiliary generating equipment located at station. (b) Communication affected at dispatch center due to loss of power to microwave equipment. Steps taken to provide auxiliary power. (See (a) and (b), Question 4.)	(a) Believe studies underway will indicate means of avoiding future recurrence of widespread outage.	New England Electric System.
(a) Reviewing communications. (b) Reviewing plant operating procedure under system disturbance conditions. (c) Reviewing district operating procedure under emergency condition.	(a) Outage did not result from system design or operation. (b) Studies underway with other utilities to see if modifications will be considered necessary.	New York State Electric & Gas Corp.

Utility	NO. 3 What are your views as to the need for improved system and intersystem control equipment, including communications, to prevent a recurrence of widespread outage?	NO. 4 What facilities and measures were initiated and under construction or implementation prior to the occurrence of this incident?
Boston Edison co.	(a) Believe present ties with neighboring utilities are adequate. (b) Studying methods of effecting faster separation of New York to New England ties under extreme conditions since New England area is well integrated and could recover by itself after prompt separation from New York. (c) Not yet in position to offer suggestions concerning impmved system and intersystem control.	Prior to Nov. 9, 1965, had not undertaken any measures "or constructed any facilities which would have altered the effect of the disturbance.
New England Electric System.	(a) Equipment operated as it was designed to function. (b) Problems with power supply for microwave and for ringing telephones. Steps have bee" taken to remedy this.	(a) Install IO-mw auxiliary generator at Brayton Point to allow start-up without outside power. Equipment 0" order. (b) Modification of 10-mw diesel at Gloucester for dead load startup. Equipment 0" order.
New York State Electric & Gas Corp.	(a) Need improved communications both within system and between systems. (b) Study should consider microwave between cities or stations and radio for other areas.	(a) A 33-mile 220/115-kv line is under construction between Oakdale substation and Jennison plant. Completion Jan. 15, 1966. Line will be extended ultimately to PJM. A" oscillograph will be installed in the Oakdale substation.

NO. 1	NO. 2	Utility
(d) Considering further auxiliary generating system for plant service.		New York State Electric & Gas Corp.-continued
(a) IC generators have been purchased for emergency operation of motors of turbogenerator emergency oil pumps, etc. (10 units). (b) Requirements for emergency power for other units being studied. (c) Plan to expand use of shunt reactors for cable charging current compensation. Studies underway to determine what additional shunt reactors would be useful in improving voltage conditions during system startup. (d) Correction of high-voltage conditions by use of additional shunt reactors will expedite restoration of station auxiliary light and power, transit facilities, and distribution load. (e) Study is underway to determine if a large unit-type turbogenerator, whose auxiliaries now operate from a transformer on its own generator, could recover from low frequency and continue to supply its own auxiliaries when load is automatically disconnected. If study indicates success, the unit would be immediately available to restore service and there would be no disadvantage in automatically disconnecting the Unit from the system. (f) Studies underway to speed restoration of transit service. Cost expected to be $10 million.	(a) Studies sponsored by FPC and those of Stone & Webster and the utilities will determine whether tie reinforcements or any other change or additions are necessary.	Consolidated Edison Co.

Utility	NO. 3	NO. 4
New York State Electric & Gas Corp.—Continued		(b) Emergency generator for communications has been planned at Auburn. (c) Are continually expanding dial tie-line network telephone facilities. (d) Additional relaying and automatic reclosing equipment at major substations is planned.
Consolidated Edison Co	(a) Studying means to provide faster automatic response of boilers and turbogenerators. (b) Studies underway on methods of load shedding.	(a) Constructing a 345-kv tie with Public Service Electric & Gas Co. from Arthur Kill plant to Farragut substation (Hudson Ave. plant). This will remove restriction on amount of power which can be taken from PSE. & G. when Arthur Kill No. 2 is in service. Tie scheduled for service in spring 1967. This will permit full utilization of a 300-mw circuit now existing between the companies. (b) A review is underway of facilities to start up Consolidated Edison from a complete shutdown without use of foreign ties. (c) December 1965 the Ashtabula, Ohio, to Erie, Pa., 230-kv line will be in. This will improve stability on the whole interconnection. (d) A study is underway to determine the advantages of a PSE. & G. tie reinforcement between Branchburg and Linden to increase emergcncy supply to Consolidated Edison by way of Staten Island. (e) New 500-kv tie, PJM Branchburg, N.J., to Consolidated Edison 345-kv system at Millwood, N.Y.—completion, 1968. (f) Cornwall 2,000-mw pumped storage expected to be in service 1969-70. (g) System operation dispatch computet to bc in service in 1966. (h) Study nearing completion for additional generating capacity for 1969. (i) Study nearing completion on DC tie with Quebec hydro.

NO. 1	NO. 2	*Utility*
Taking steps to provide auxiliary power to generating stations and to eliminate introduction of thermal stresses in steam turbine shafts. Adding 3 quick-starting gas turbines in early spring 1966. Four 15-mw gas turbines ordered *Nov.* 12, 1965, for delivery in September 1966.	(a) As detailed under (1), we are providing auxiliary generating quip ment at each major plant to enable plants to start from a shutdown condition. (b) No changes in transmission and interconnection with Consolidated Edison believed advisable until analysis of *Nov.* 9, 1965, outages and board studies are completed.	Long Island Lighting Co.
We have installed an emergency radio in the control room of our Danskammer Station which will operate on the assigned frequency of our mobile radio system. This radio will insure communication between our System Operators' Office and the Danskamma Station control *room*. A telephone line directly connecting the System Operators' Office has been leased in order to provide direct communication without dialing with the Danskammer Station control room. An application is being made to FCC for assignment of two additional radio frequencies, one of these frequencies would be reserved for communications between generating station and the System Operators' Office.	We believe it is premature for us, not having complete information available and the assistance of competent technical industry experts, to endeavor to reach conclusions or make recommendations of changes in *in*ternal designs of interconnections of other systems.	Central Hudson Gas & Electric Corp.
Experience in restoration of service has not to date suggested new steps in restoration of service and no new procedures are presently planned.	The precise cause or causes of the service disruption *are* still a matter *of* inquiry and no definitive conclusions have been reached. May be abk to adjust control equipment and add blocking relays which will be of use in *such* a system disturbance.	Niagara Mohawk Power Corp.

Utility	NO. 3	NO. 4
Long Island Lighting Co	(a) Believe specific recommendations for improvements to system and intersystem control equipment must await outcome of the board study. (b) Communications both internally and with Consolidated Edison functioned excellently during Nov. 9, 1965, disturbance.	(a) A program of installing peaking units on an "area protection" basis was started several years ago. Two such 15-mw gas turbines started automatically, carried local load, and provided startup power for larger units during Nov. 9, 1965, disturbance. (b) Continuing with this program, three 20-mw gas turbines are on order and scheduled for service in February 1966. (c) A 300-mw submarine interconnection with Connecticut Light & Power Co. planned for service in 1968. (d) Two 360-mw units scheduled for Northport plant to go in service in 1967 and 1968, respectively.
Central Hudson Gas & Electric Corp.	We recommend that the Federal Power Commission take the leadership, with the assistance of the industry, in developing policy guides for operation of interconnected systems, pools, and regions that recognize the higher priority need for continuity of service to large metropolitan areas, seats of government, defense installations, general public safety, etc.	Completion of the fourth generating unit at Danskammer Station with a generating capability of 230 mw is scheduled for completion by May 1, 1967. Land at two separate sites along the Hudson River was acquired several years ago for power generating purposes.
Niagara Mohawk Power Corp.	Niagara Mohawk will study intensively all details of its system, controls, and operation in an attempt to find what equipment, if any, can be installed to better control any massive surge of power into its system and the disruptive effects of such a surge. There were no communications failures which seriously impeded service restoration.	No new facilities or measures were initiated or under construction prior to the service disruption. We have ordered an analog load-frequency controller and a digital computer for use in economic operation of our system and its interconnected neighbors. We expect to have this equipment in service during 1966. Other new facilities include our 500-mw, nuclear-generating plant and related transmission lines scheduled for service in 1968.

NO. 1	NO. 2	Utility
Providing alternate sources for startup power to stations tied directly to transmission system. Gas turbines have been ordered for some stations and procedure3 set up for using nearby hydm units or steam stations which survived breakdown. This could shorten restoration by an hour. New gas turbines will also supply peaking capacity. Studies have been initiated of communications, adequacy of instrumentation, performance of telemetering, location and adequacy of phasing equipment, steady state and transient stability of system and its interconnections, and operating instructions. Negative sequence relays which tripped West Springfield units have been removed from service.	Believe the design of our system and its interconnection has been basically sound. No basic modifications of design philosophy are contemplated until outage has been studied and analyzed. Studies to minimize the transfer of disturbances between systems may justify some type of "out-of-step" tripping at strategic points.	CONVEX [1]
Present procedures considered adequate. No change proposed prior to completion of studies now in progress.	Pending completion of studies: (a) None. (b) None. (c) No suggestions at thin time.	Power Authority of the State of New York.
Same steps would be taken as were taken Nov. 9, 1965.	(a) Company engineers are making a thorough examination of company's interconnection facilities. (b) Ebasco Services, Inc., have been retained to conduct independent examination of R.G. & E.'s interconnections with adjoining systems. Ebasco engineers are now on job in Rochester. (c) R.G. & E. has joined with other New York State utilities in engaging Stone & Webster Corp. for making an exhaustive analysis of the Northeast U.S. interruption of Nov. 9, 1965. (d) R.G. & E. is participating with g-company group in conducting an independent computer study of the N.E. Power Pool in conjunction with the FPC.	Rochester Gas & Electric Corp.

[1] Includes: The Connecticut Light & Power Co.
The Hartford Electric Light Co.
The United Illuminating Co.
Western Massachusetts Electric Co.

Utility	No. 3	NO. 4
CONVEX	Control equipment and communication must keep step with the size and complexities of the interconnected systems. In general this has been accomplished. New studies or those underway may pinpoint areas of improvement.	New 345-kv transmission line from Barbour Hill, Conn., to Ludlow, Mass., now nearly complete, will increase tie capacity and reduce restoration time. A digital alarm device between the dispatching centers has been authorized and is on order. This will facilitate the transmission of information in time of emergency. Comprehensive communication system has been authorized. It will include microwave, carrier, and leased lines to provide three independent channels of voice communication. It will be coordinated with the installation late next year of the digital dispatch control. Expect to make application for Northfield pumped storage project which will improve ability of system to respond to sudden changes.
Power Authority of the State of New York.	Review of all automatic control equipment and expanded availability of emergency standby service.	None.
Rochester Gas and Electric Corp.	All system and intersystem control equipment on R.G. & E. system performed properly during Nov. 9, 1965, emergency. There were no communications interruptions nor did communications delay restoration of service.	Not applicable.

NO. 1	NO. 2	Utility
Standard operating instructions are followed at all times. Power transfers over our tielines are closely observed at all times to determine changes in flow from those scheduled so that appropriate compensating measures can be taken. The importance of these instructions has been reviewed with our dispatchers since the disturbance to assist them in preparedness for future periods of system disturbance.	None.	central Maine Power Co.
No major problems were encountered in restoring service to our customers.	Preliminary evaluation of available data does not indicate that any significant changes will be necessary on our system. However, minor improvements in equipment and procedures may well prove desirable.	Orange & Rockland Utilities, Inc.
Restoration procedures following complete shutdown an being reviewed by member companies.	The design of generation and transmission systems of the members of PJM is being continually reviewed. This results in system design having the necessary safeguards to minimize the probability of a widespread outage. Studies include the examination of existing and planned interconnection ties to adjacent pools. We believe it necessary to reexamine operating conditions and consider it desirable to improve monitoring and metering of system conditions and make improvements in the communication of pertinent information to operating personnel.	PJM

Utility	NO. 3	NO. 4
Central Maine Power co.	Present control and communications equipment is adequate and reliable. However, we intend to study the adequacy of the signal equipment and the auxiliary power source for the indicators on this equipment on our communication circuit.	None.
Orange & Rockland Utilities, Inc.	Intersystem control equipment at our points of interconnection with other systems and intersystem communications functioned properly. Only comprehensive study by all companies concerned can determine whether any changes should be instituted in existing equipment or practices.	Restoration of service was limited by the loss of firm capacity over our interconnection to Consolidated Edison Co. of New York. Our reliance on Consolidated Edison as a source of firm supply will cease when the new 170-mw generating unit is placed in service at the Lovett plant in the spring of 1966.
PJM ’	PJM is installing a digital computer and data transmission system. This installation will involve additional communication channels and will permit system operators to more closely monitor major transmission lines and assure that safe operating limits are not exceeded.	A 500-kv transmission system is under construction which will distribute the output of the Keystone Generating Station, also under construction, to member systems. Thii 500-kv system will also be extended to interconnect with Allegheny Power System and with Consolidated Edison Co, of New York. A 345-kv interconnection with Cleveland Electric Illuminating Co. will be placed in service by the end of 1965. Other generating plant and transmission line additions arc under construction by PJM members.

[1] Pennsylvania-New Jersey-Maryland Interconnection includes:
- Atlantic City Electric Co.
- Baltimore Gas & Electric Co.
- Delaware Power & Light Co.
- Jersey Central Power & Light Co.
- Luzerne Electric & Gas Division, United Gas Improvement Co.
- Metropolitan Edison Cu.
- New Jersey Power & Light Co.
- Pennsylvania Electric co.
- Pennsylvania Power & Light Co.
- Philadelphia Electric Co.
- Potomac Electric Power CO.
- Public Service Electric & Gas Co.

APPENDIX F

Recommendations of the
FEDERAL POWER COMMISSION ADVISORY PANEL—
NORTHEAST POWER INTERRUPTION

Recommendations for Actions To Be Taken by Affected Companies To Avoid Recurrence of Major Power Failures

I. *Interim Measures*

1. Immediately review standing instructions to operating personnel of each system supplying very large metropolitan areas relative to separation of the system from the interconnected network if system frequency drops to a predetermined value which indicates danger of loss of power supply due to trouble external to the system. Consider also the installation of automatic devices which may be available for tripping major transmission ties, non-critical load and generation, if necessary, to maintain adequate power supply to critical load areas.
2. Immediately undertake coordinated studies to review the adequacy of system and intersystem design and operating practices under unusually severe system disturbances comparable to the incident recently experienced.
3. Review means for assuring communications at all times between major system control centers.
4. Assess the adequacy of practices regarding the assignment of spinning reserve capacity on each system and the coördination of spinning reserve capacity among systems.
5. Investigate the feasibility of interruption of substantial blocks of non-critical load to provide effective emergency capacity when necessary.
6. Review present practices of scheduling power between systems and power pools so as to assure essential protection to critical load areas.
7. Review present relay applications.
8. Review standing procedures for restoring tia between systems so as to obtain maximum assistance for various contingencies.
9. Reexamine methods and facilities to obtain power supply for the rapid start-up of power plants shut-down by an emergency.
10. Determine steps which may be taken to prevent damage to generating units as they undergo emergency shut-down and to improve the start-up time of such units.
11. Reexamine the size of network segments and the adequacy of equipment, procedures and automatic devices to assure rapid restoration of underground urban network loads.

II. *Permanent Measures*

1. Accelerate construction of those facilities (transmission, generation, control and communication) now planned which will contribute significantly to reliability of service.
2. Reexamine the need for additional transmission, interconnection and related facilities which would enhance reliability of service within and among the affected systems and between the affected systems and outside utilities.

Approved by the Advisory Panel:

C. P. ALMON, Jr.
CHARLES CONCORDIA.
E. B. CRUTCHFIELD.
JOSEPH K. DILLARD.
MORGAN DUBROW.
W. S. KLEINBACH.
L. F. LISCHER.
G. H. MCDANIEL.
T. J. NAGEL.
G. O. WESSENAUER.

NOVEMBER 16, 1965.

U.S. GOVERNMENT PRINTING OFFICE : 1965 O—794-080