Prevention of Cascading Outages in Con Edison's Network

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Abstract— This paper describes the framework for prevention of cascading outages caused by thermal overloads. The approach presented in this paper is a fast, flexible and automated process for assessment of cascading outages and their prevention. It helps to prevent the cascading outages by optimizing the existing available controls in the transmission network. Optimal remedial actions are applied first after the occurrence of an initiating event, and then at each cascading Tier, until the cascading event is mitigated. The paper also presents the ranking of cascading outages that is based on a minimum amount of load curtailment which is needed to alleviate the steady-state stability violations caused by cascading events. The approach was implemented using the Con Edison's 50,000-bus planning case. The study results show that this approach is very effective in improving the reliability of Con Edison's network and preventing major blackouts, caused by the cascading outages. The analysis may also be included as part of NERC-compliance studies. Con Edison is planning to extend the assessment of cascading outages by incorporating transient stability analysis.

***Index Terms*— Preventing cascading outages, optimal mitigation measures, ranking cascades, reliability analysis.**

I. INTRODUCTION

A STEADY increase in the number of large blackouts has been observed over the past 40 years. The number of blackouts that result in a loss of over 1000 MW of demand doubles every 10 years, [1]. Many past blackouts were caused by the cascading failures, including the Northeast blackouts in 1965 and 2003, New York City blackout in 1977, and two WECC blackouts in 1996, [2, 3].

NERC defines the cascading outages as "the uncontrolled loss of any system facilities or load, whether because of thermal overload, voltage collapse, or loss of synchronism, except those occurring as a result of fault isolation", [4].

The cascading failure on August 14, 2003 had caused a wide-area blackout, that resulted in 63GW of load being interrupted (approximately 11% of the total load served in the Eastern Interconnection). That blackout had affected an estimated ten million people in Ontario, Canada, which is about one-third of the total population of Canada, and 40 million people in eight U.S. states, which constitutes approximately one-seventh of the population of the United States. The outage-related financial losses were estimated at 6 billion USD.

The U.S.-Canada Task Force responsible for investigating the causes of the August 14, 2003 blackout has reached a conclusion that some of the major reasons of that blackout were an inadequate operation of relays and inappropriate relay protection settings, [5]. The joint Task force had indicated in its *Recommendation 8: Improve System Protection to Slow or Limit the Spread of Future Cascading Outages*, that "the importance of automatic control and protection systems in preventing, slowing, or mitigating the impact of a large-scale outage cannot be stressed enough", [5].

The NERC Disturbance Reports indicate that approximately 75% of major disturbances reported by NERC from 1984 to 1988 involve protective relays or special protection schemes. As noted in those cases, post-disturbance misoperation of the protection system fails to prevent the spread of a major blackout, [6].

In an event of a major system blackout or a cascading outage, the protection systems and control actions should be able to prevent the spread of a blackout, the effective islanding should minimize its impact, and effective black start functionality should enable system restoration.

The August 14, 2003 Blackout Task Force in [5] indicates that "protection schemes need to consider the full range of possible extreme system condition, such as the low voltages and low and high frequencies experienced on August 14". The Task Force recommends that "improvements may be needed in under-frequency load shedding and its coordination with generator under- and over-frequency protection and controls".

The Blackout Task Force had concluded that the system operators could have likely been able to mitigate the extent and damage from the blackout if they had access to tools which would allow them to predict a cascading event and provide them with the information necessary to make timely, informed decisions, [5].

Analyses of this and other past blackouts in North and South America, as well as in Europe show that over 50% of those blackouts involved many cascading elements and were "slow" in progression. This means that the optimal measures which would prevent the spread of cascading events may be

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identified and implemented in order to alleviate or reduce the impact of cascading outages.

Analysis of the cascading outages also serves as a very important aspect of the planning studies, a fact that is recognized by NERC as part of the existing Transmission Planning Standards, [7] and a new planning standard TPL-001-1. This new standard provides for analysis of both the Planning Events and Extreme Events. Extreme Events are "events which are more severe and have a lower probability of occurrence than Planning Events". The requirement R3.4 of the new standard states that "those Extreme Events in Table 1 – Steady State Performance that are expected to produce more severe System Impacts shall be identified, evaluated for System performance, and the rationale for the Contingencies selected for evaluation shall be available as supporting information and shall include an explanation of why the remaining Contingencies would produce less severe System results. If the Extreme Events analysis concludes there are cascading outages caused by the occurrence of Extreme Events, an evaluation of implementing a change designed to reduce or mitigate the likelihood of such consequences shall be conducted." These studies will enable the utilities to analyze the future year power flow cases which include the transmission system expansion reinforcements in terms of their vulnerability to cascading outages. Those reinforcements may be ranked based on their vulnerability to cascading outages. Also, the trend in vulnerability to cascading outages in a utility's network over years may be determined as well. That will allow planning engineers to optimize the transmission system expansion process in order to help reduce the risk of a blackout and improve overall system reliability, [8].

Con Edison of New York Inc. (Con Edison) has been very active in the areas of predicting and preventing the cascading outages.

Con Edison has developed an advanced visualization system for real-time automated fault analysis. The next step would be to connect the visualization system with the cascading outages analyses, and demonstrate the results of these analyses in order to improve the awareness of Con Edison operators.

The paper describes Con Edison's current experience in identifying and predicting cascades, and the proposed framework for comprehensive analysis of the cascading outages.

This paper addresses the following issues related to assessment of the cascading outages:

- Determination of the contingencies which cause cascading outages (e.g., initiating events) and their spread and consequences,
- Identification of the optimal remedial actions needed to prevent cascades or mitigate their effect.

Con Edison's existing approach to the analysis of cascading outages enables the system planners to quantify a power system's ability to withstand cascading outages caused by the thermal overloads.

A comprehensive approach that Con Edison will start implementing in 2010 is also presented in the paper.

The computations described in this paper were performed using Physical an Operational Margins (POM) Suite of Applications. The programs "Physical and Operational Margins" (POM) [9, 10], "Potential Cascading Modes" (PCM) [11], and "Optimal Mitigation Measures" (OPM) [12] of POM Suite were utilized for the analyses.

POM is an extremely fast loadflow, AC contingency analysis, voltage stability, and transfer analysis application that solves a 50,000-bus case in approximately 0.1 s. This tool is intended to perform massive contingency analysis based on user selected lists, or automatically generated N-1 and N-2 contingency lists based on user defined model element selection.

POM is an AC analysis application, which uses the full Newton-Raphson method to solve a nonlinear power flow model. The normal conditions (N-0) model and each (N-k) contingency are applied while simultaneously monitoring multiple constraints: voltage stability, thermal overload, voltage deviation, and voltage limit violations. These constraints can be monitored over the entire network or any portion thereof.

POM capabilities include:

- Automatically perform contingency analysis (N-1, N-1-1, N-2, N-3 and higher) for large power system models;
- Simulate multiple power transfers while monitoring voltage, thermal, flowgate, voltage stability constraints during massive AC contingency analysis;
- Determine voltage stability margins;
- Visualize power system behavior.

OPM is a fast and powerful remedial actions program which is activated when POM finds a violation of at least one of the monitored constraints. Fully integrated into the POM application, OPM relieves thermal, voltage, and voltage stability violations identified by POM in approximately 10 seconds for one contingency for a 50,000-bus case.

The uniqueness of OPM is that it has the capability to automatically alleviate post-contingency violations during massive contingency analysis.

OPM also increases loadability and transfer capability. It determines the causes of voltage stability violations and recommends actions to increase voltage stability margins. OPM employs multiple measures to mitigate the constraint violations based on either automatically determined by the software or the user defined priorities.

The mitigation measures employed by OPM are: MW re-dispatch, Mvar re-dispatch, line switching in and out, emergency load curtailment, forced phase-shifter adjustment, forced capacitor and reactor switching, forced transformer tap change, capacitor placement, and user-defined operating procedures. Three separate sets of measures are available for N-0 (e.g., contingencies are not applied), N-1 and N-2 contingencies.

Fully integrated into the POM application, PCM is intended for predicting potential cascading modes. PCM capabilities include:

- Quickly identifying initiating events;
- Automatically identifying cascading chains;
- Ranking cascading outages;
- Visualizing cascading outages.

PCM offers three options to identify initiating events:

1. A list of N-1 and/or N-2 contingencies identified as a result of the "cluster" approach incorporated into PCM, [11].
2. A user-specified contingency list containing NERC Category B, C, and D contingencies.
3. Combination of the above mentioned lists (1) and (2).

PCM allows the user to identify potential cascading modes that initiate both within the utility's/ISO's footprint and outside of the footprint but spread into the utility's/ISO's footprint.

II. Prevention of Cascading Outages: Con Edison's Past Experience

During the past two years Con Edison has concentrated their efforts on assessment and prevention of cascading outages. Con Edison has implemented, tested and validated the approach to prediction and prevention of cascades under the following three projects:"

1. "Cascading Outages", [11]
   This is a supplemental EPRI project with eight participants: American Electric Power, Con Edison, Entergy Services, Exelon Corp., FirstEnergy Corp., ISO New England, New York Power Authority, and Tri-State G&T.
   The main objective of this study is to identify contingencies that cause cascading effect due to thermal overloads and their spread, and further quantify the impact of cascading outages.
2. "Visualizing Cascading Outages and Their Impact"
   The main objective of this project is to identify the data that is necessary for the operators and planners in order to assess cascading outages and their impact.
3. "Prevention of Cascading Outages for Con Edison's System"
   The main objective of this project is to identify the optimal remedial actions to prevent/stop the spread of cascading outages for Con Edison's system.

Under all of these projects, cascading outages are analyzed from the steady-state approach. They deal with the assessment of cascades due to thermal overloads.

The methodology for identifying initiating events, spread of cascading outage and their consequences was tested under the project #1"Cascading Outages" and described in [11].

In the other two projects, ##2 and 3 above, this methodology was combined with optimal mitigation measures, in order to provide the planning and operations engineers with information on various alternatives to prevent the spread of the cascading outages.

III. Con Edison's Methodology for Prevention of Cascading Outages

A. Con Edison's Framework for Identifying Cascading Outages

A thermal violation occurs if the total power flow on a branch is at or above a thermal limit. For the purpose of this particular study, it was assumed that the overloaded branches would trip automatically and at highest priority due to flows that are in excess of the highest thermal limits. In this way, a sensitivity study could be performed to determine the impact of branch tripping on the initiation of potential cascading events.

During the course of the analysis, all of the overloaded branches are identified, but only those which are overloaded above the user-specified branch tripping threshold are automatically tripped for the purpose of simulating the operation of the protection schemes. A contingency which causes an overload above the branch tripping threshold is referred to as an initiating event, or Tier 0, and the overloaded branches form the following tier, Tier 1, etc., [11].

Therefore, the sequential contingency analysis is performed while monitoring the thermal overloads and steady-state stability violations, and tiers in the cascading chain are identified. Following an initiating event, the branches overloaded above the user-specified branch tripping threshold are consecutively tripped until one of the following events occurs:

1. System fails to solve due to voltage instability;
2. Loss of load exceeds a user-specified threshold value;
3. Islanding with imbalance of load and/or generation within an island
4. A thermal violation is alleviated or drops below the line tripping threshold value.

Thus, a cascading outage is a successive loss of the system elements which causes stability violation, large loss of load, or islanding,

The analysis of cascading outages which lead to events (1) - (3) listed above were the subject of the project "Cascading Outages" (see Section II), and described in [11].

B. Setting the Branch Tripping Threshold

The threshold for line tripping is a user-specified parameter, since there is currently no uniform NERC standard with regards to the branch tripping threshold. NERC recommends a minimum setting of 150% of the emergency rating to be used as the threshold, [13].

The line tripping threshold for tripping branches was set at 100% of Rate C, which is lower than that currently implemented at Con Edison. A more conservative line tripping threshold was used during the analysis so that the outages which are the most vulnerable to cascading are identified and mitigation measures to prevent them are determined. This scenario enables the Con Edison planning and operations engineers to take necessary remedial actions prior to any branches being tripped.

C. Con Edison's Scenario for Applying Remedial Actions during the Analyses of the Cascading Outages

The present study concentrates on identification of the optimal remedial actions to prevent the cascades.

The proposed approach applies the remedial actions after an initiating event and at each cascading tier in order to completely prevent or decrease the spread of cascading outages.

The following analysis scenario has been executed:

1. Identify initiating events (N-1 and/or N-2 contingencies) that cause overloads above the branch tripping threshold, see Section IV.A.
2. Determine the remedial actions in order to alleviate the overloads and apply these remedial actions in order to bring the flow on the overloaded branches below the branch tripping threshold.
3. If the remedial actions identified in item (2) bring the flow on the overloaded branches below the branch tripping threshold (e.g. are successful), the cascading stops.
4. If the remedial actions identified in item (2) decrease the overloads, but do not bring the flow on the overloaded branches below the branch tripping threshold, the overloaded lines are tripped, and the next Tier in cascading is formed.
   Since the overload is decreased as a result of using the remedial actions, the effect of this tripping is expected to be less than if the mitigation measures are not utilized.
5. Steps (2) - (4) are repeated at each cascading Tier.
6. In the event a cascading outage cannot be prevented, the remedial actions needed to mitigate the consequences of the blackout (e.g., steady-state stability violation) are identified.

The remedial actions and their priorities that were used during the study are shown in Table 1.

Table 1. Remedial Actions and Their Priorities

Remedial Actions	Priority
Transformer Tap Change	1
Transformer Phase-Shifter Adjustment	2
Capacitor and Reactor Switching	3
MVAr Dispatch	4
MW Dispatch	5

Transformer Tap Change measure adjusts transformer tap ratio.

Transformer Phase-Shifter Adjustment measure shifts phase-shifter transformer phase.

Capacitor and Reactor Switching measure adjusts switched shunt admittance.

MVAR Dispatch measure changes scheduled voltage setpoints of generators and continuous shunts.

MW Dispatch measure provides for the redispatch of generator real powers within the specified real power limits.

A priority code is assigned by the user to each mitigation measure representing the order in which the measures are being applied, with "1" being the highest priority.

Mitigation measures are applied from the highest to the lowest priority. If using a mitigation measure with the highest priority completely alleviates the violation(s), then the mitigation process is completed, and OPM proceeds to the next initiating event. If using a mitigation measure with the highest priority does not completely alleviate violations, the mitigation measure with the next priority is applied. The process continues until either (a) violations are completely alleviated, or (b) all mitigation measures are exhausted.

During the study, if the use of preferable priorities is found to be ineffective, the priorities should be changed such that the most effective remedial actions that prevent possible cascading modes at the Con Edison's network are identified .

If the use of remedial actions listed in Table 1 does not prevent cascading, an additional set of runs should be performed with Load Curtailment measure utilized.

The study concentrated on optimizing the existing resources in the system in order to prevent cascading and improve reliability of the Con Edison's transmission network, and didn't involve development and prioritization of future transmission expansion projects.

IV. Study Results

A. Identifying and Grouping Initiating Events that Lead to Cascading Outages

A 2007 Summer Peak NYISO load flow case with approximately 50,000 buses was used during the study.

A partial NYISO contingency list, consisting of 250 single and complex contingencies, including stuck breakers, tower outages, etc. was used as an "N-1" contingency list. All "N-1" contingencies from the list were further combined by POM into "N-2" contingencies. Over 31,000 combinations were obtained. These "N-2" contingencies formed the list of initiating events and were processed through the cascading outages analysis.

Thermal overloads on all elements 13 kV and above in three of NY ISO control areas were monitored.

In this research scenario, even while using a lower than currently accepted branch tripping threshold, only 38 "N-2" contingencies, which is 0.13% of all contingencies, resulted in cascading outages that lead to steady-state stability violation.

All cascading outages identified as result of this analysis caused steady-state stability violations in three or less Tiers:

- 17 Initiating Events - in one Tier
- 11 Initiating Events - in two Tiers
- 10 Initiating Events - in three Tiers

The initiating events, branches that participate in cascading Tiers, and any loss of load and generation were reported. Records associated with processing of one initiating event are shown in Fig. 1.

A	B	C	D	E	F	G	H	I	J	K	L	M
Initiating Event	Violations						Loss of					
	Overall Results		Overload				Load			Gener.		
N-1 / N-2	Violated Facility	Actual	%	Limit	Overload	Total	Bus #	MVA	Total	Bus #	MVA	Total
36+110	Branch XXX	520.8	104.8%	497	23.8	23.8		0	0		0	0

O	P	Q	R	S	T	U	V	W	X	Y	Z	AA
Tier 1	Violations						Loss of					
Action	Overall Results		Overload				Load			Gener.		
	Violated Facility	Actual	%	Limit	Overload	Total	Bus #	MVA	Total	Bus #	MVA	Total
RemoveTran	Branch XXX	582	117.1%	497	85.0	185.1		0	0		0	0
	Branch XXX	597.1	120.1%	497	100.1							

AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO
Tier 2	Violations						Loss of					
Action	Overall Results		Overload				Load			Gener.		
	Violated Facility	Actual	%	Limit	Overload	Total	Bus #	MVA	Total	Bus #	MVA	Total
RemoveBran	Branch XXX	435.1	115.1%	378	57.1	136.2		0	0		0	0
RemoveTran	Branch XXX	436.5	115.5%	378	58.5							
	Branch XXX	411.6	102.6%	401	10.6							
	Branch XXX	411	102.5%	401	10.0							

AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC
Tier 3	Violations						Loss of					
Action	Overall Results		Overload				Load			Gener.		
	Violated Facility	Actual	%	Limit	Overload	Total	Bus #	MVA	Total	Bus #	MVA	Total
RemoveTran	No Overloads							0	0	XXX	2	2
RemoveTran	Loss of Load/Generatio											
RemoveTran												

Fig. 1. Reporting of the Initiating Event and Cascading Tiers

Then, these 38 cascading outages were divided into seven groups. Classification of cascading outages was performed based on the branches that were overloaded on Tier 1. The advantages of such grouping include:

- Easier to analyze the initiating events and their impact.
- Easier to visualize the events.
- Decreasing the number of various mitigation measures that prevent cascading, since one global set of mitigation measures may be identified for the entire group.

The number of initiating events in each group is summarized in Table 2.

Table 2. Grouping Cascading Outages

Group Number	Number of Different "N-1" Contingencies	Number of Initiating Events
Group 1	9	11
Group 2	7	8
Group 3	9	7
Group 4	6	4
Group 5	5	4
Group 6	4	2
Group 7	3	2

Table 2 shows the number of various "N-1" contingencies comprising the "N-2" contingencies and the number of these initiating "N-2" contingencies in each Initiating Event group.

B. Determining Remedial Actions to Prevent Cascading Outages

At first, a set of global preventive measures for each initiating event group was determined.

Transformer Tap Change and Phase-Shifter Adjustment measures were found effective in alleviating Tier 1 overloads and stopping cascading.

All cascading outages were stopped by applying remedial actions on Tier 1. These measures completely alleviated all violations after the initiating events, and, thus, cascading was prevented.

1) Remedial Actions for Group 1

All initiating events that form the largest group, Group 1, cause Tier 1 overloads on one of the two 345 kV lines. Dispatching generation (MW Dispatch measure) at one of the Con Edison's generators completely alleviates all overloads on Tier 1 after 11 initiating events and stops cascading.

Applying MVAr dispatch measure at the same generator prior dispatching real power reduces the amount of MW dispatch in over 2 times for six out of eleven initiating events.

As an alternative measure, changing transformer tap ratio may be implemented. Changing transformer tap ratio measure decreases, but does not completely relieve the overload. Thus, the overloaded branch is still tripped as a part of the cascading process, and this forms Tier 1. However, when Tier 1 branch is successively tripped, the cascading stops without causing the steady-state stability violation. Thus, changing transformer tap ratio measure was sufficient to decrease the value of the overload on Tier 1 such that collapse was prevented. This is the case when remedial actions stopped cascading on Tier 1.

2) Remedial Actions for Group 2

All initiating events that form Group 2 also cause Tier 1 overloads on one of the two 345 kV lines. Note that these lines differ from the lines which are overloaded as a result of initiating events that belong to Group 1.

Applying Transformer Phase-Shifter Adjustment measure at four phase-shifters, followed by MVAr dispatch measure at one bus completely alleviates all overloads on Tier 1 after eight initiating events and stops cascading.

3) Remedial Actions for Group 3

All initiating events that form Group 3 cause Tier 1 overloads on one 138 kV line.

Applying Transformer Phase-Shifter Adjustment measure at one phase-shifter completely alleviates all overloads on Tier 1 after seven initiating events and stops cascading. As an alternative measure, MVAr dispatch at several buses may be used to completely alleviate Tier 1 overloads.

4) Remedial Actions for Group 4

All initiating events that form Group 4 cause Tier 1 overloads on one 345/138 kV transformer.

Applying Transformer Phase-Shifter Adjustment measure at three phase-shifters completely alleviates all overloads on Tier 1 after four initiating events and stops cascading.
As an alternative measure, MVAr dispatch at several buses may be used to completely alleviate Tier 1 overloads.

5) Remedial Actions for Group 5

All initiating events that form Group 5 cause Tier 1 overloads on two branches: a 138 kV line and a 345/138 kV transformer. Changing transformer tap position at three voltage controlling transformers and applying minor MW dispatch at one generator completely alleviates all overloads on Tier 1 after four initiating events and stops cascading.

6) Remedial Actions for Group 6

Two initiating events that form Group 6 cause two overloads each. Applying Transformer Phase-Shifter Adjustment measure at three phase-shifters completely alleviates all overloads on Tier 1 after two initiating events and stops cascading.

7) Remedial Actions for Group 7

Two initiating events that form Group 7 cause four overloads each. Changing transformer tap position and applying Transformer Phase-Shifter Adjustment measure completely alleviates all overloads on Tier 1 after two initiating events and stops cascading.

C. Determining Remedial Actions to Mitigate the Consequences of Cascading Outages

The proposed framework also allows the planning and operations engineers to determine remedial actions in order to alleviate voltage collapse after cascading had happened. Thus, the consequences of a cascading outage after all cascading tiers occur are mitigated.

Load curtailment measure was used as the uniform measure. This approach may be also used for ranking cascading outages.

The amount of load curtailment which is necessary to alleviate steady-state stability violations after each cascading outage was computed. Then, cascading outages were ranked based on the amount that is needed to be curtailed in order to alleviate these steady-state stability violations.

Cascading outages that have the same number of Tiers in the cascading chain were ranked. Thus, ranking was performed for cascading outages that had caused collapse in the same number of Tiers. Note that grouping of initiating events as described in Section IV.A was not utilized.

For the majority of the cascading outages, a small number of loads (from one to six load buses) participated in load shedding. Loads at seven or more buses needed to be curtailed only for five cascading outages.

This is an effective approach for ranking cascading outages. The amount of unserved load, in addition to the number of tiers in the cascading chain, the values of overloads, and amount of load and generation lost as a result of the cascading outage, may be served as an important component in the algorithm for ranking cascading outages.

V. Planned Future Work

The three projects described in Section II will serve as the basis for a more detailed and comprehensive framework for predicting and preventing cascading outages in the Con Edison's network.

The upcoming NYSERDA (New York State Research and Development Agency) research project with Con Edison and V&R Energy, will allow Con Edison's planning and operations engineers to analyze the cascading outages as both steady-state and transient stability phenomena. The proposed scope of work includes the following aspects:

- Predicting the cascading outages by quickly identifying initiating events and possible cascading chains, and accurately modeling protection relays and optimizing relay settings.
- If possible, determining preventive actions to halt cascading, such as under-voltage load shedding, under-frequency load shedding, generator re-dispatch or using other active and reactive sources available in the power system network, [14].
- Appling effective islanding techniques, including under-frequency load shedding.
- Visualizing initiating events, their spread, severity and control actions to prevent cascades, in order to improve situational awareness of Con Edison operators and increase their preparedness to address the next contingency.

In the future the scope may be extended to develop effective black start strategies to expedite the system restoration, in case a major blackout had not been prevented.

As a result of this project, Con Edison will obtain an effective solution for the following issues related to the assessment of cascading outages:

- Improving reliability of Con Edison grid by predicting and preventing major blackouts due to the cascading outages.
- Addressing NERC planning standards by assessing potential cascading outages and having the capability to mitigate them.
- Addressing cascading outages causing transient instability since transient instability is one the major limitations in the NY System.
- Demonstrating effective islanding techniques.
- Improving Con Edison's TNVS visualization system by incorporating the results of cascading outages analyses.

VI. Conclusion

This present paper describes a framework for preventing cascading outages in order to prevent major blackouts, improve the reliability of Con Edison's transmission network and comply with NERC standards.

Con Edison has been very actively involved in a number of research and proof-of-concept studies devoted to prediction and prevention of cascading outages caused by thermal overloads.

An extensive analysis of cascading outages was performed and their effect on the Con Edison's transmission network was investigated.

The analysis of the cascading outages used a lower branch tipping threshold than is currently being used by the industry in order to (a) exercise the new software, Potential Cascading Modes (PCM) in a more extensive manner, and (b) obtain a more conservative result.

The planning and extreme events were analyzed for 2007 NYISO Summer Peak planning case. The study results show that Con Edison has a robust network that is designed such that it can withstand cascading outages. Though cascading chains are relatively short (three and less tiers), the existing controls in the network may be optimized such that the cascading is prevented.

Various sets of remedial actions which prevent the cascades were automatically identified based on the priorities specified by Con Edison. Transformer Tap Change and Phase-Shifter Adjustment measures were found very effective in alleviating overloads and stopping cascading in the Con Edison's network.

The study also included ranking of cascading outages based on the amount of load shed that would be needed to mitigate steady-state stability violations caused by the cascading outages.

As the next step, Con Edison is planning to perform a comprehensive analysis of cascading outages, and assess cascading outages from the steady-state and transient stability perspectives. Frequency issues and relay operation will be studied within the transient stability approach. This will permit the Con Edison operators and planners to accurately model protection relays and optimize relay settings. The main objectives of the upcoming project are to improve situational awareness of Con Edison operators and increase their preparedness to address the next contingency, and to visualize the cascades and control actions needed to prevent them within Con Edison's TNVS visualization system.

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VIII. Biographies

Matt Koenig (M' 77) has held positions of increasing responsibility in System Operations, Computer Applications Engineering, Energy Services, and Distribution Engineering at Con Edison of New York Inc.. over the last 28 years. He is currently the Section Manager for Long Range Planning and Analysis within the Transmission Planning Department at Con Edison of New York, Inc., where he has been responsible for development of the Long Range Transmission plan as well as evaluation and utilization of advanced methods in power system studies.

Patrick Duggan (M' 65, SM' 79) graduated from Manhattan College in Riverdale, NY in 1968. His employment experience has been with the Consolidated Edison Company of NY, Inc. He is currently an R&D Project Manager responsible for engineering, operations and maintenance related R&D projects for various Substation, Transmission and System Operations organizations, and assists specific efforts in additional areas, such as Cybersecurity, Con Edison's 3rd Generation System of the Future efforts, Transmission Probabilistic Risk Assessment and substation condition based maintenance and automation. Pat has held a variety of management and technical positions in Nuclear Power Instrumentation and Controls, Project Management, Construction and Electrical Engineering- Generation and Controls. Pat's experience has included key roles in the development of fault current limiters, potential applications of superconductivity, as a member of IEEE NPEC and NPEC SC-6 on Safety Systems nuclear industry standards, regulatory interfaces, and a variety of major projects and programs. Pat is currently the Utility Chairman for EPRI's Superconductivity Task Force and represents Consolidated Edison on the Board of the Coalition for Commercial Application of Superconductors and the Board and multiple Work Groups of the GridWise Alliance.

Jade Wong is a project manager for the Research and Development department of Consolidated Edison of New York. For the last eight years she has focused on the underground transmission network. Her previous experience includes SCADA and control room, man-machine interface. She has a Bachelor of Engineering (Electrical Engineering) degree from the City College of New York, and a Master's degree in Electrical Engineering from Columbia University.

Michael Vaiman (M' 91) has over 40 years of power industry experience. He received his MSEE degree from Kaunas Polytechnic University, Lithuania in 1961, Ph.D. degree from Moscow University of Transportation Engineering, Russia in 1969, and D.Sc. degree from St. Petersburg Polytechnic University, Russia in 1986. He was a full professor, Department of Automatic Control and Telecommunications at Moscow University of Transportation Engineering, Russia until 1991. Since 1992 Dr. Vaiman is a President and Principal Engineer at V&R Energy Systems Research, Inc. His main areas of interest are power system stability and control, power flow and optimal power flow analysis, computer modeling of power system networks, selection of remedial actions for stability preservation; dynamic stability analysis.

Marianna Vaiman (M' 97) received her BSEE and MSEE degrees from Moscow University of Transportation Engineering, Russia. She has 17 years of experience in power system studies. In 1992 she joined V&R Energy Systems Research, Inc. (V&R), where she is currently Principal Engineer and Executive Vice President. She leads the work in the following areas at V&R: Software Development, Consulting Activities, Research & Development Activities. She has over 15 publications devoted to the issues of power system stability and control.

Mark Povolotskiy received his MS degree in Mathematics & Physics from Nezhin State University, Nezhin, Ukraine in 1978 and Ph.D. degree in Physics & Mathematics from Institute for Geophysics, Ukrainian Academy of Science, Ukraine in 1990. Dr. Povolotskiy has over 30 years of R&D experience. His main areas of interest include mathematical modeling of the power system networks, and deterministic and probabilistic approaches to the analysis of the power system. He joined V&R Energy Systems Research, Inc. in 2001, where he is currently a Senior Support Engineer working in the areas of Software Support and Consulting Services. He has over 35 published works, including one patent.