Wide Area Blackout Prevention
Using Advanced System Models

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1. Introduction

Commercially available network analysis tools need to be enhanced as the United States grows to rely on renewable energy for electrification of energy consumption, with widespread rooftop solar panels and offshore wind turbine generators, more electric vehicles on the road, and fewer traditional energy production facilities than in previous decades. Enhancing these tools, known as models, will help electric utilities to better understand the risk of wide area blackouts as energy production and consumption patterns shift.

Traditional load flow models include thousands of lines, buses, transformers, generators, and loads. These models accurately represent the steady state operation of the electric energy grid. They fall short, however, when extreme, unlikely, but predictable, events occur. It's important to remember that these models were developed during the 1960s and 1970s when mainframe computers were state of the art technology, climate change was unheard of, electric vehicles were in the distant future, and air conditioning was only installed in homes owned by the well to do.

Although the 1970s models were a tremendous advancement over previous methods, simplifications have since been introduced to allow results to be produced in less time. Eventually, the 1970s models were adapted for use with today's desktop computers and laptops, and modified so that results are displayed in seconds on one-line diagrams on video monitors.

With today's computational capability, traditional load-flow models need to be enhanced to accurately predict the reliability and robustness of the electric energy grid. Plus, traditional load-flow models should be enhanced to predict the performance of niche areas of the electric energy grid. Niche areas could be metropolitan areas that experience a voltage dip when a three-phase fault occurs on a nearby transmission line.

Enhanced models will be developed by electrical engineers and software developers with contributions from meteorologists, mechanical engineers, chemical engineers, automotive engineers, and database developers. The contributions of these experts will change load models, but not system configurations.

Enhanced models will allow the implementation of power factor biased, undervoltage load shedding schemes that prevent the collapse of the electric energy grid within a state or across many states.

Enhanced models will provide an added level of assurance that saboteurs cannot create statewide blackouts, unusual weather conditions do not overstress the electric energy grid, and unlikely, but predictable, events are mitigated with minimal customer impacts. Electric utilities' goal should be to anticipate challenges and initiate corrective actions before challenges become real world events with news media attention. Enhanced models will allow them to achieve this goal.

2. Noteworthy Incidents

Wide area blackouts are rare occurrences that generate worldwide media coverage. Afterwards, blue ribbon commissions study reams of data that were recorded during the event, recommend improvements that will prevent anything like this from happening again, and declare that the possibility of another wide area blackout will be near zero after their recommendations are implemented. Historically, the focus has been on the switching error, the protective relay, or the line sag that triggered the blackout. The focus has not been on enhancing the models that are used to analyze the energy grid.

Three noteworthy incidents have occurred in the last two decades in the United States that reinforce the need for updated models.

1. On August 14, 2003, the Northeast Blackout hit the northeastern United States and parts of Canada, resulting in a total loss of electric power across the entire region. The outage, the largest area blackout in history, occurred when multiple transmission lines sagged.

   Power was lost in the major metropolitan areas of New York City, Detroit, Cleveland, Toronto and Ottawa, Canada. More than 45 million people were without power for several hours to several days. The event led to 11 deaths and cost over $5 billion in losses and recovery. This event resulted in the creation of NERC as the watchdog of the electric energy grid.
2. On September 8, 2011, the Southwest Blackout occurred when a single, three phase, 500 KV air break switch was opened out of sequence in Arizona. While the initial fault was cleared in 67 milliseconds, inadequate blackout prevention barriers failed to ensure that rapid post fault recovery occurred.

   This event left almost 3 million customers in Arizona, California, and parts of Mexico without power for several hours during the hottest time of day, from late afternoon into evening. It disrupted flights and created chaotic rush hour traffic. After this event, NERC reinforced requirements that regional transmission operators update system models when large generating stations are retired.
3. On April 7, 2015, the Washington, D.C., Area Low-Voltage Disturbance occurred when a connector failed in a span of a 230 KV transmission line and the circuit breaker at one end of the line failed to open. This event persisted for one minute before the degraded grid voltage scheme at nearby nuclear power plants actuated.

   Because this event occurred in April, when air conditioning load is minimal, a wide area blackout did not follow. However, had the voltage disturbance occurred in August, all of Washington, D.C., and the surrounding areas would have lost power.

Incidents like this could happen again today; in fact, a single fault on a hot summer's day could create a wide area blackout. Enhanced models would help electric utilities prepare for and prevent such events.

3. Traditional Models

Traditional load-flow models are used to calculate exact steady state voltages and currents at all elements in a network, and real and reactive power flows across every line, transformer, and generator. The assumption is that the capability and status of every energy source is known and that the load can be modeled as a constant resistance or a constant power load. Loads in traditional models are based on peak loads that were recorded in summer or winter and scaled for use in spring or fall.

Traditional models allow users to analyze:

- Line, transformer, and generator MVA, MW and MVAR
- Line, transformer, and generator outages
- Seasonal load variations
- Voltage control by switching capacitor banks and reactors (inductors)

- Voltage control by varying reactive production of energy sources
- Voltage control by varying reactive production of static var compensators
- Voltage control by changing taps on transformers
- Reactive power flow control by changing taps on transformers
- Real power flow control by varying production of energy sources
- Real power flow control by changing taps on phase-shifting transformers

Traditional models, developed by electrical engineers, include thousands of transmission lines, distribution lines, power transformers, large generators, constant resistance (aggregate) load representations, constant power (aggregate) load representations, and small energy source (aggregate) load representations. When working with transmission system models, aggregates can be 1 to 10 MVA equivalents.

Figure 1 is an illustration of the model used to create a load-flow study. Figure 1 emphasizes the fact that traditional modeling fails to include many factors that are essential to creating accurate system models, for example, accurate customer load models. Calculated values are available for transmission line impedances, typical values are available for distribution line impedances, nominal values are available for transformer impedances, and theoretical values are available for generator impedances and generator capability.

Traditional models are developed for peak load conditions, scaled for other load conditions, and modified to analyze specific outages, future conditions, etc. Traditional models provide very good results for steady state and quasi-steady state load conditions.

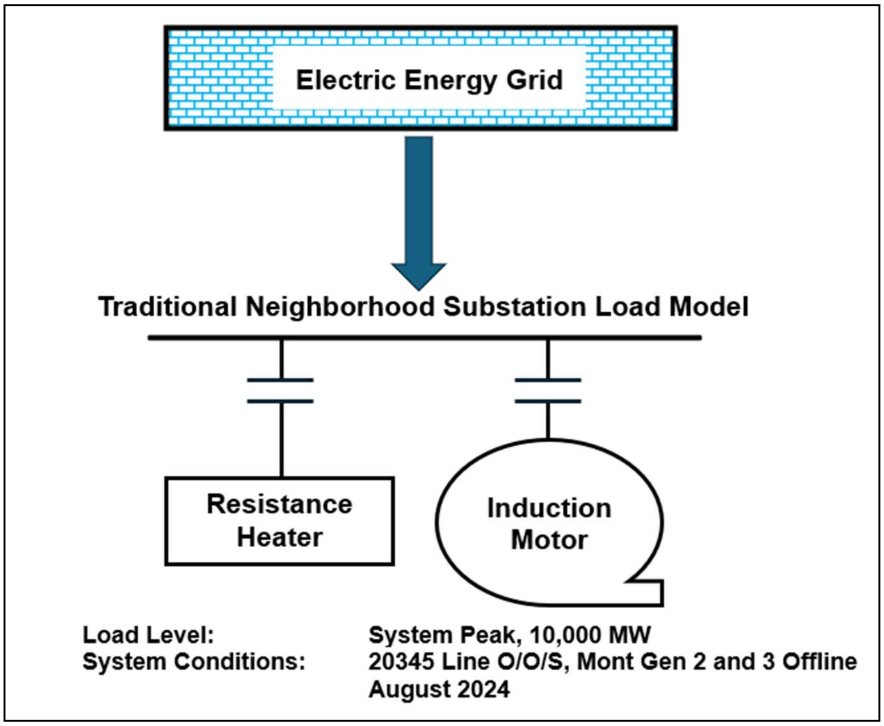

Figure 1: Traditional Load-Flow Model, Emphasis on Customer Load

4. ASDOP Models

An alternative to traditional models, Auxiliary System Design Optimization Program (ASDOP) was developed in the late 1970s for the design and analysis of auxiliary electric systems in energy production facilities. Although ASDOP had the capability to perform load-flow studies and motor-start studies, ASDOP was not embraced by the electric utility industry for transmission system load-flow studies.

The methodology that was utilized with ASDOP is the basis for enhanced models. The major difference between ASDOP models and load-flow models is that ASDOP models include detailed motor data for all 50 horsepower and larger motors. This granularity allows users to understand the impact of voltage dips and motor operation on the electric system. In effect, ASDOP is useful when analyzing loads served by neighborhood substations.

5. Enhanced Models

Enhanced models provide a better understanding of distributed energy sources, electric vehicle charging, air conditioner response to voltage dips, and motor acceleration after three phase faults are cleared. In effect, enhanced models include better representations of components that are connected to load buses. Enhanced models need to include environmental, time of day, fault duration, air conditioner, renewable energy source, and electric vehicle considerations.

Enhanced models need to be peer reviewed by a team that includes meteorologists, mechanical engineers, automotive engineers, solar energy developers, wind power developers, and software developers in addition to electrical engineers. The goal of the peer review teams is to provide an assurance that simplifications introduced by load-flow developers are appropriate.

A short explanation of considerations that need to be introduced in enhanced electric grid models is as follows.

- Ambient Environmental Conditions

  With large conventional generators, environmental considerations revolve around the Carnot cycle where energy production is a function of ambient temperature. Conventional energy production facilities can produce more energy on cold days than on hot days. Conventional energy production facilities produce electric energy for 24 hours a day, 365 days each year.

  Wind turbine generators produce energy as a function of wind speed, which varies throughout the day. In ideal locations, wind turbine generators produce electric energy for 14 hours during most days.

  Solar panels produce energy as a function of daylight hours, cloud cover, incident angle of sunrays, and cloud speed. Fast moving clouds cause rapid changes in energy production from solar panels. Wildfire smoke can reduce energy production for several days. Solar panels produce electric energy for 10 to 12 hours a day during sunny days.

  System operators should perform load-flow studies that include environmental conditions for each hour during the upcoming ninety days. System planners should perform load-flow studies that include environmental conditions for each hour during the upcoming decade. These studies can be automated so that the person performing the study does not need to initiate 8740 individual studies.

- Season and Time of Day

  Both the season and the time of day impact energy production and energy consumption. There is a step increase in load every morning and every evening. Wind and solar energy production experience daily step changes. To a novice, nighttime charging of electric vehicles seems like a good idea. To a system operator, daytime charging of electric vehicles is preferred on sunny days in April, May, and other low load periods when renewable energy production is high.

System operators should perform load-flow studies for each hour during the upcoming ninety days. System planners should perform load-flow studies for each hour during the upcoming decade.

- Fault Duration

  When motors stall during fault conditions, fault recovery loads can be substantially different than the loads were before the fault occurred. To minimize increased fault recovery loads, three phase faults near 230 KV, 345 KV, 500 KV and 765 KV substations must be cleared as quickly as possible. During peak load periods, three phase faults must be cleared in less than 100 milliseconds. Otherwise, motors driving high torque loads will stall in locations where voltage dips to less than 70%.

  System operators should perform fault recovery studies for each hour during the upcoming ninety days. System planners should perform fault recovery studies for each hour during the upcoming decade.

- Renewable Energy Sources

  All renewable energy sources are intermittent energy sources. Solar panels that produce energy during daylight hours can be intermittent energy sources during daytimes with fast moving clouds. Wind turbine generators are, by their very nature, intermittent sources.

  System operators should perform load-flow studies with intermittent renewable energy for each hour during the upcoming ninety days. System planners should perform load-flow studies with intermittent renewable energy for each hour during the upcoming decade.

- Electric Vehicles

  All new electric vehicle (EV) chargers should be equipped with bidirectional chargers that allow energy to flow both into the EV battery from the electric energy grid, and back to the grid. During some hours, the charger will be connected to the EV and operated in standby mode. During other hours, the charger will be in charge mode. If power system frequency rises above 60.02 hertz while the charger is in standby mode, the charger will automatically transition to the charge mode until frequency returns to 60 hertz. If power system frequency drops below 59.98 hertz while the charger is in charge mode, the charger will automatically transition to the standby mode until frequency returns to 60 hertz. If power system frequency drops below 59.95 hertz, the charger will transition to the grid support mode until frequency returns to 60 hertz.
  System operators should perform load-flow studies with electric vehicles in grid support mode and in charge mode for each hour during the upcoming ninety days. System planners should perform load-flow studies with electric vehicles in the grid support mode and in the charge mode for each hour during the upcoming decade.

- Aggregate Loads and Renewable Energy Sources

  Electric vehicle chargers, consumer loads and renewable energy sources should be represented as aggregates in increments of 1 MVA to 10 MVA where each element in each aggregate has similar electrical characteristics. Each load bus should include aggregated values for resistive loads, fan and pump motors, air conditioner motors, power supplies, electric vehicles, and renewable energy sources.

Figure 2 shows an enhanced neighborhood substation model where motor models vary with motor voltage, motor speed, motor torque, fan/pump/compressor speed, and fan/pump/compressor torque.

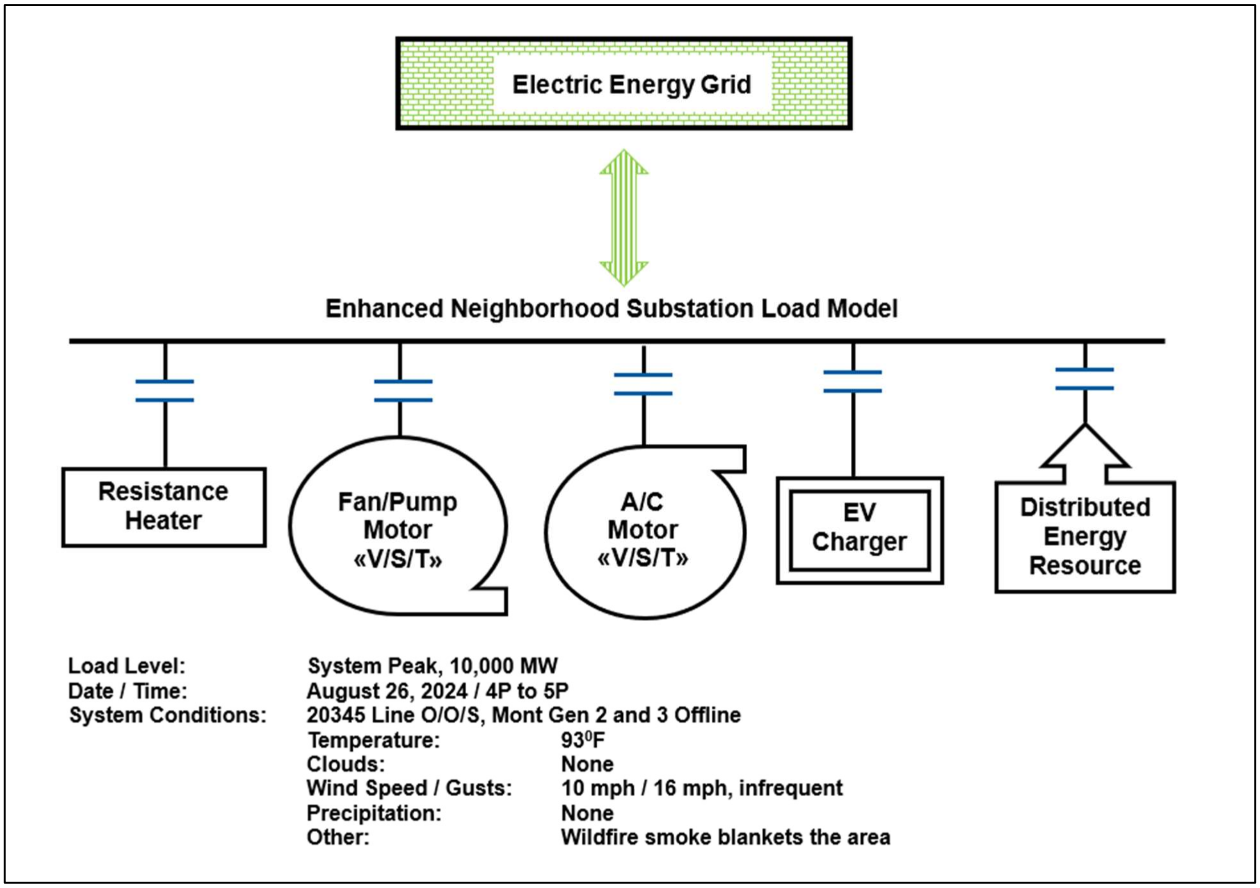

Figure 2: Enhanced Load-Flow Model, Emphasis on Customer Load

6. Fault Recovery

Fault recovery models are challenging in that electric utilities need to understand the types of customer loads that are being powered. This includes resistance heaters, fan and pump motors, air conditioning motors, power supplies, and electric vehicles. Plus, they need to understand the aggregate value of each type of load for the time of year that is being studied – spring, summer, fall, winter – and the time of day – morning, afternoon, evening, or night. In addition, electric utilities need to understand the performance of each load type during fault recovery conditions.

For the load bus shown in Figure 3, loads are categorized as resistance, fan and pump motors, air conditioner motors, and power supplies. Electric vehicles can be customer loads or energy sources. Distributed energy sources as well as capacitors and reactors that are used for voltage control need to be included.

Summer loads may be the most essential for electric utilities to understand because of the significant increase in daily load due to air conditioning usage. As summers continue to get hotter, and hot weather lasts longer, air conditioning usage will increase. Other seasonal loads are not considered in this whitepaper, but can be modeled for client use.

Summer Loads

In metropolitan areas, air conditioners will be 50% of summer load, resistance loads will be 10%, fans and pumps will be 20%. Electric vehicles and power supplies represent the remainder. Miscellaneous loads are included in aggregate. Rooftop solar panels are anticipated to be placed on 25% of single family homes.

All motors are assumed to be induction motors. Although sewage treatment plants and water treatment plants may be equipped with synchronous motors, the number of synchronous motors is such a small part of the total system load that synchronous motors are modeled as induction motors.

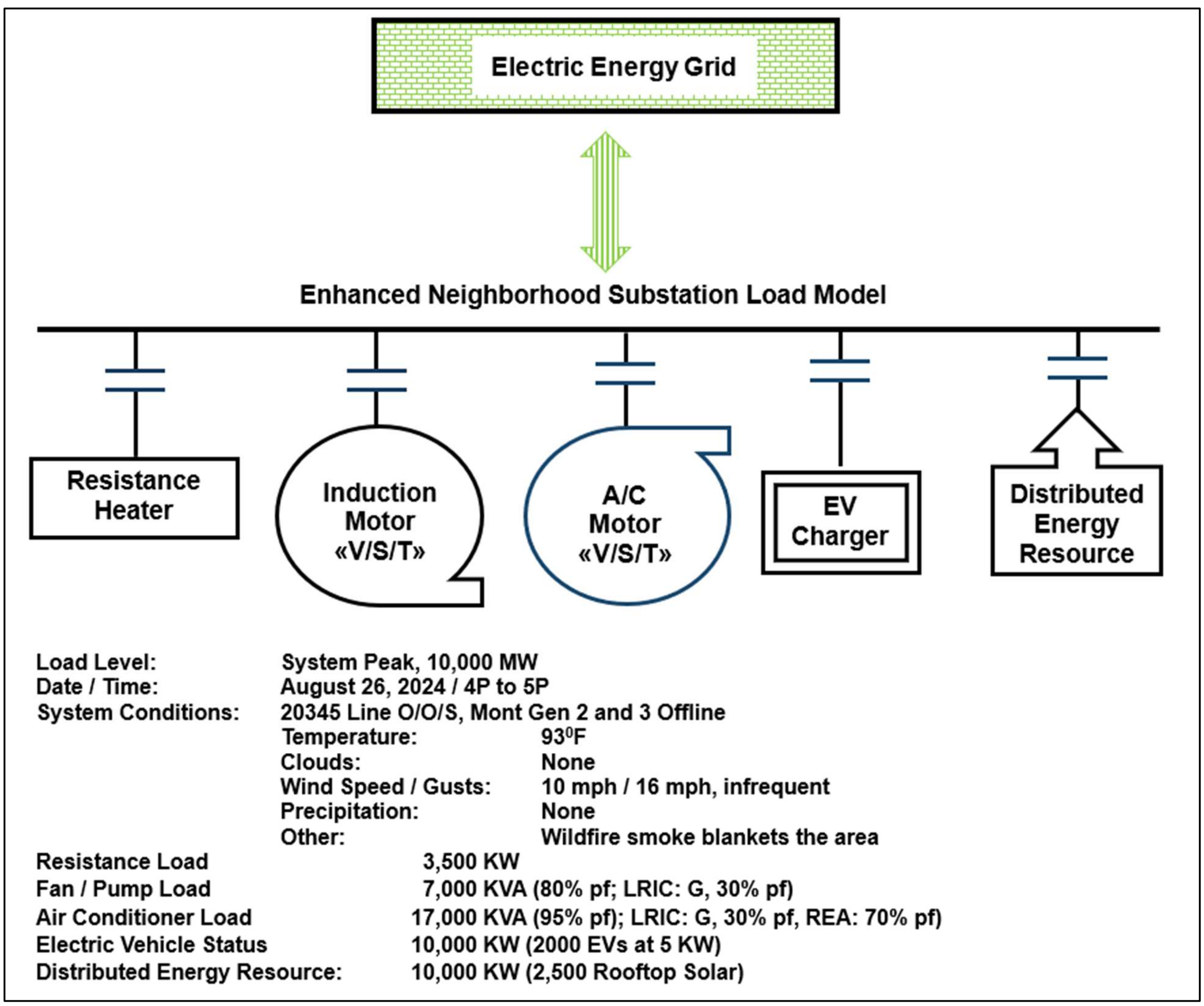

Figure 3: Enhanced Load-Flow Model with Load Values

Summer Fault Recovery Loads

Air conditioner motors stall when voltage dips to less than 70% for 100 milliseconds because compressors are positive displacement pumps that compress refrigerant gas. This is significant because the impedance and power factor of a reaccelerating air conditioner motor is much less than the impedance and power factor of a motor that is rotating at normal slip.

Fan and pump motors, on the other hand, slow down, but do not stall when voltage dips occur. If a fault persists for more than one second and motor voltage dips to 50%, most fan and pump motors will stall.

Table 1 is a compilation of the apparent power (volt-amps), real power (watts), and excitation energy (vars) for loads served by typical neighborhood substation. The numbers in the following tables have been unitized to simplify the discussion. The values represent measured values for 120 volt fans, water pumps, window air conditioners, battery chargers, laptops, incandescent lights, and LEDs. Actual values for these load types will vary as the design of household appliances changes with the year of manufacture and materials used to fabricate each appliance.

Table 1: Load Representations – System Normal			
Load	**Kilo Volt-Amps**	**Kilo Watts**	**Kilo Vars**
Resistive	1,000 KVA	1,000 KW	0 KVAR
Fans	1,000 KVA	800 KW	600 KVAR
Pumps	1,000 KVA	800 KW	600 KVAR
Air Conditioner	1,000 KVA	950 KW	312 KVAR
LEDs	1,000 KVA	800 KW	600 KVAR
Laptops	1,000 KVA	350 KW	937 KVAR

Table 2 shows load when voltage dips to 70% of nominal. The amount of energy drawn by fan and pump motors decreases because the speed of a fan and pump motor is dependent on the intersection of the motor torque curve with the load torque curve. The amount of energy drawn by an air conditioner motor increases because the load torque curve is a function of backpressure in the condenser.

Table 2: Load Representations – 70% Voltage Dip			
Load	**Kilo Volt-Amps**	**Kilo Watts**	**Kilo Vars**
Resistive	500 KVA	500 KW	0 KVAR
Fans	500 KVA	325 KW	380 KVAR
Pumps	520 KVA	364 KW	371 KVAR
Air Conditioner	1,200 KVA	1,140 KW	375 KVAR
LEDs	0 KVA	0 KW	0 KVAR
Laptops	1,000 KVA	350 KW	937 KVAR

Table 3 shows customer load when voltage is 70% of nominal, and air conditioner motors are accelerating from the stalled condition to normal operating speed. During short duration voltage dips, fan and pump motors slow down but do not stall, and reacceleration occurs quickly. During the tests we performed, air conditioners continued accelerating as we recorded voltage, current, watts, vars, and volt-amps.

Table 3: Load Representations – 70% Voltage during Fault Recovery			
Load	**Kilo Volt-Amps**	**Kilo Watts**	**Kilo Vars**
Resistive	500 KVA	500 KW	0 KVAR
Fans	500 KVA	325 KW	380 KVAR
Pumps	520 KVA	364 KW	371 KVAR
Air Conditioner	2,536 KVA	1,775 KW	1,811 KVAR
LEDs	0 KVA	0 KW	0 KVAR
Laptops	1,000 KVA	350 KW	937 KVAR

The recovery conditions shown in Table 3 will persist until air conditioner motors accelerate to at least 80% speed, or until motor overloads actuate and open the power circuit to air conditioner motors. (All induction motors draw starting current with a low power factor, until motor speed reaches 80% and quickly transition to running current, with a high power factor, at motor speeds above 80%.)

The importance of Table 3 data is that if voltage at a neighborhood substation dips below 70% of nominal for more than 50 milliseconds during peak load conditions, reacceleration KVA can be 160% of peak KVA, reacceleration KW can be 130% of peak KVA, and reacceleration KVAR can be 250% of peak KVAR for 10 to 20 seconds after a fault is cleared. With values of this magnitude, a fault that causes a 70% voltage dip could result in a wide area blackout.

7. Prescient Perspectives

The need for fault recovery calculations is based on Prescient's analysis of the Northeast Blackout on August 14, 2003, the Southwest Blackout on September 8, 2011, and the Washington, D.C., Area Low-Voltage Disturbance on April 7, 2015.

During the Northeast Blackout and the Southwest Blackout, step changes in excitation energy (vars) were noted. This occurred because motors driving high torque (air conditioner) motors stalled. When voltage dips occur, fan and pump motors coast down, but do not stall, as load decreases with motor speed.

During the Washington, D.C. Area Low-Voltage Disturbance, the weather was mostly cloudy 70°F with few air conditioners in use. This is likely why the disturbance did not create a wide area blackout.

The Southwest Blackout was triggered when a 500 KV, three phase air break switch was inadvertently opened. All protective relay schemes operated as designed and even though the fault was cleared in less than 70 milliseconds, a wide area blackout occurred.

The Washington, D.C. Area Low-Voltage Disturbance was triggered by the failure of a 230 KV four bolt compression connector that allowed a span of a transmission line to fall to the ground. When the 230 KV circuit breaker connected to this line failed to open, the fault persisted for more than one minute.

Prescient's perspectives are also based on design base accident calculations that our subject matter experts developed for nuclear power plants. For design base accident conditions, ASDOP was used to show that groups of large pump motors could be started, discharge valves could be opened, and coolant flow could be established within 60 seconds. Although ASDOP methodology is more exacting that load-flow methodology, ASDOP does provide a roadmap to innovation.

In simplest terms, MW and MVAR transfer across the electric energy grid are based on the flowing equations:

$$\mathbf{MW_{Transfer}} = \frac{\mathbf{KV_{Source}} \times \mathbf{KV_{Load}}}{\mathbf{Z_{Transfer\ Impedance}}} \times \sin \boldsymbol{\delta}$$

$$\mathbf{MVAR_{Transfer}} = \frac{\mathbf{KV^2_{Source}} - \mathbf{KV^2_{Load}}}{\mathbf{Z_{Transfer\ Impedance}}}$$

During normal operating conditions, KV_{Source} and KV_{Load} are nearly the same value. During fault recovery conditions, KV_{Load} can be 70% to 80% of KV_{Source}.

During fault recovery conditions, transfer impedance magnitude will be reduced and transfer impedance phase angle will increase as the dominant factor is the impedance of the load. The result is that MW transfer change is different than the MVAR transfer change. Staged fault testing is needed to validate theoretical results developed with traditional or enhanced models.

8. Staged Fault Tests

Staged fault tests will be required to convince electric utility executives, regulators, and subject matter experts of the need for advanced models. The alternative is to download data after the next multistate blackout and task a blue ribbon commission to explain the reasons for the blackout.

Traditionally, staged fault tests were expensive and difficult to perform. During the 1970s, I witnessed a staged fault test that was conducted in Hazleton, Pennsylvania with participation by Bell Telephone. This test was conducted to validate proposed corrective actions. However, data recorded during the staged fault revealed that all proposed corrective actions were unacceptable and other solutions were required.

Modern staged fault tests can be performed at minimal cost with little risk of damage to substation equipment and no risk to personnel. The difference is that traditional staged faults were initiated by swinging a conductive object into an energized line, while a modern staged fault is initiated by closing a staged fault circuit breaker that opens immediately upon closing. The fault duration should be less than 100 milliseconds.

Our estimate is that a staged fault at a neighborhood substation (12.47 KV) can be set up in two days and performed within a day. This staged fault test should cost less than $150,000.

A staged fault at a higher voltage substation (69 KV) can be set up in five days and performed within a day. This staged fault test should cost less than $250,000.

Staged fault testing at higher voltages will require additional set up time as all equipment cannot be mounted on a single trailer.

Analysis of fault data and preparation of a technical report should take less than two weeks. Staged fault tests should be performed at selected substations across the United States when the ambient temperature is above 85°F.

9. Enhanced Model Details

Enhanced models need to demonstrate the impact of all of the considerations discussed in this whitepaper. This means that system operators will need to conduct numerous sets of load flow studies every day. The first set will be load-flow calculations that establish initial conditions for a variety of environmental conditions. The second will be load-flow calculations for planned outages for a variety of environmental conditions. The third set will be fault recovery calculations that are used to optimize energy production for a variety of environmental conditions.

Prescient's vision is that these enhanced studies will be automated. Shift technical advisors will receive alerts at the beginning of each shift that identify concerns that need to be reviewed, including: low voltage conditions, high voltage conditions, and overload conditions during normal operations; single facility out of service condition; and two facilities out of service conditions.

10. Enhanced Model Applications

Enhanced model applications will require multiple steps, outlined below:

Step 1: Create 100% and 70% voltage load models for neighborhood substations.

> As KVA equivalent and associated power factor of various loads change with voltage, a 100% model and a 70% model are needed. The 70% model is a motor acceleration model. The 100% model is a motor rotating at speed model.

Step 2: Use a short circuit program to develop voltage profiles.

Short circuit studies are used to determine the geographical area where voltage is reduced when a three phase fault occurs. For example, Figure 8, copied from NERC's technical report "Washington, D.C., Area Low-Voltage Disturbance Event of April 7, 2015," published September 2015, illustrates voltages that were recorded during a 230 KV three phase fault that persisted for one minute.

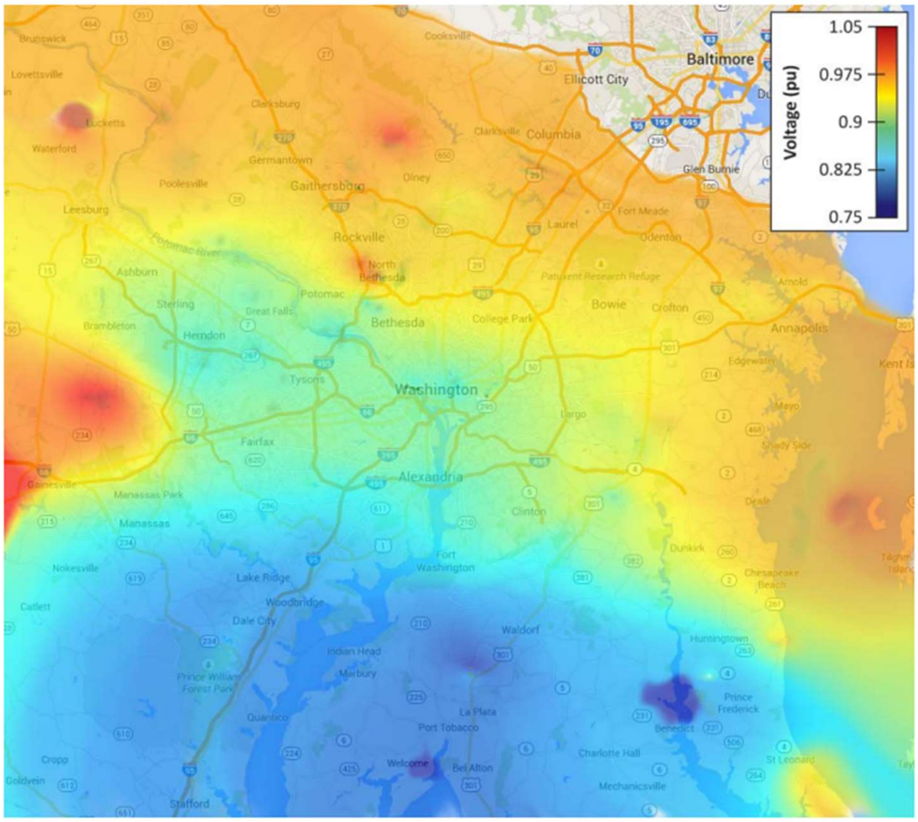

Figure 8. Noticeable Depression in Voltage due to Chalk Point Breaker Remaining Closed

NERC | Washington, D.C., Area – Low-Voltage Disturbance Event of April 7, 2015 | September 2015
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Step 3: Use the 100% load model at neighborhood substations where voltage is greater than 80% and the 70% load model at neighborhood substations where voltage is less than 80%.

This is an iterative model. Some fault locations will be more challenging than other fault locations. Over time, technical advisors will develop a tabulation of critical locations.

Step 4: Perform FIDVR load flow study with transformer taps fixed at normal position.

Traditional load flow studies are developed for steady state conditions and load tap changer controllers are assumed to actuate to maintain voltage within specified limits. FIDVR events are short time phenomena that need to be resolved within ten seconds.

If calculated FIDVR voltage is less than 80%, install power factor biased undervoltage relaying.

11. Grid Collapse Detection

Electric utilities need to install undervoltage schemes that actuate during fault recovery conditions in addition to underfrequency relaying schemes that detect excessive load conditions.

Figure 4 illustrates the Time Voltage Profile for three buses in a transmission system network when a fault occurs near Bus A. Voltage at Bus A is near zero for 80 milliseconds until the fault is cleared by opening circuit breakers. Voltage at Bus B is 30% and Voltage at Bus C is 60% until the fault is cleared. As soon as the fault is cleared, bus voltage increases to 80% and recovers to 100% as motors reaccelerate.

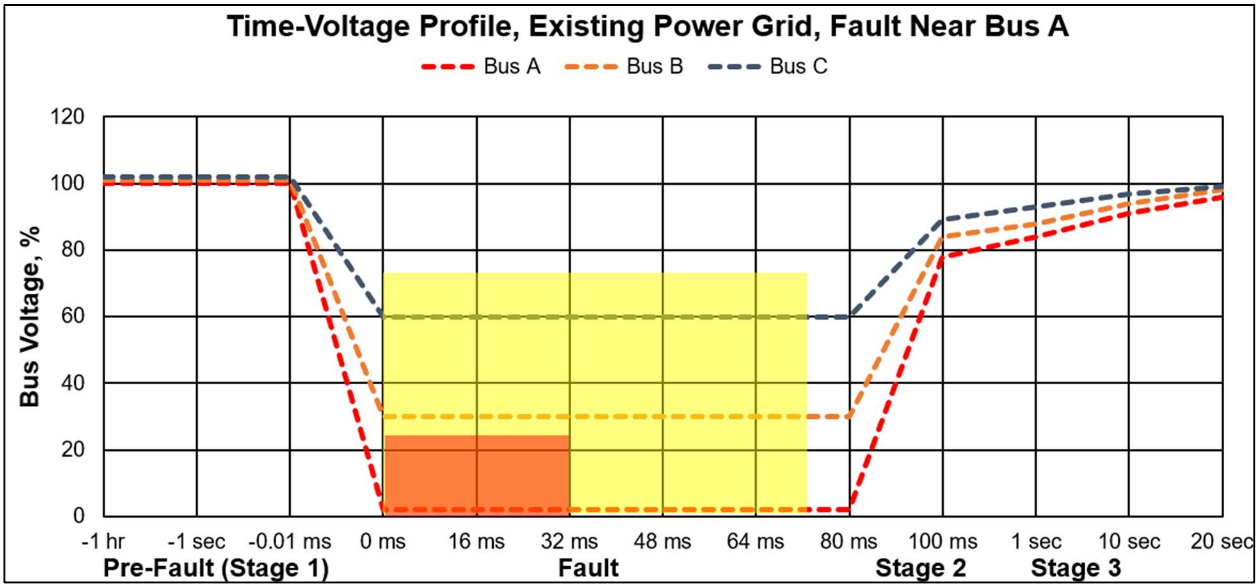

Figure 4: Time Voltage Profile for a Transmission System Fault

The area enveloped in orange represents the time when voltage is less than 25% and motors either coast down or stall. The area enveloped in yellow represents the time when voltage is less than 70% and air conditioner motors stall. The lines between 80 milliseconds and 100 milliseconds illustrate voltage recovery during reacceleration of fan and pump motors. The lines after 100 milliseconds illustrate voltage recovery during air conditioner motor reacceleration.

Figure 5 illustrates time voltage curves for a power factor biased, undervoltage relay. Time Voltage Group 1 setting group (TVG1) is the characteristic curve for an undervoltage relay that actuates in 3 seconds when bus voltage is 40%. TVG2 is the characteristic curve for an undervoltage relay that actuates in 6 seconds when bus voltage is 40%.

These undervoltage relays will receive inputs from voltage transformers that monitor bus voltage and current transformers that monitor transformer current. The actuating time is a function of power factor. If the undervoltage relay is set on the TVG1 curve and voltage does not recover to 90% in 5.5 seconds and power factor is 70%, load shedding will occur as a substantial number of motors are continuing to accelerate at 5.5 seconds. If the undervoltage relay is set on the TVG1 curve and voltage does not recover to 90% in 8.0 seconds and power factor is 100%, load shedding will occur as voltage will not recover unless the amount of load is reduced.

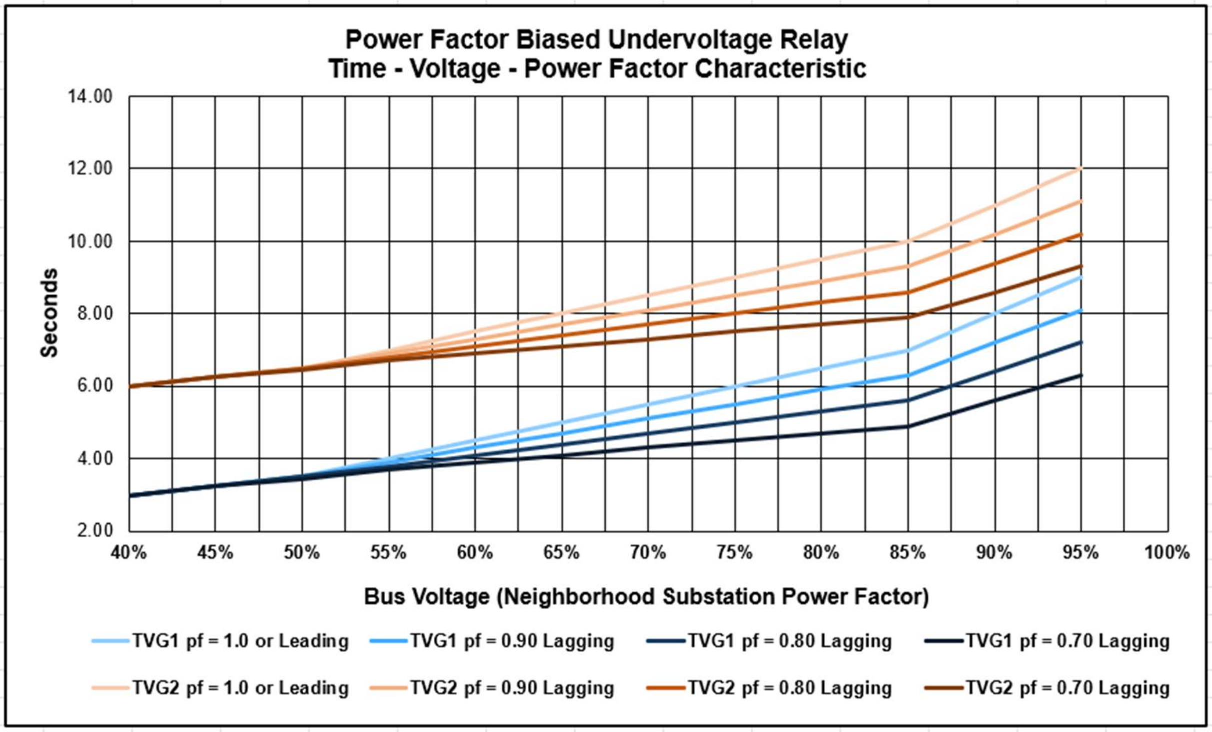

Figure 5: Power Factor Biased Undervoltage Relay Curves

Power factor biased undervoltage relays are a theoretical concept that is not available at this time. The basis for these characteristics is that as power factor improves, the need for load shedding decreases. The concern is whether to consider load shedding in less than 3 seconds when power factor is as low as 40%.

12. Future Models

With the introduction of renewable energy sources, electric vehicles, the electrification of energy, and the reduction in traditional energy sources, frequency excursion modeling will become an important operational consideration. This means that system frequency calculations will need to be performed as often as load flow calculations.

For example, electric vehicle chargers will need to be equipped with normal and grid support algorithms. As long as frequency is between 59.98 hertz and 60.02 hertz, electric vehicle chargers will operate in the normal mode. When frequency rises above 60.02 hertz, electric vehicle chargers will transition to the overfrequency load and enter the charge mode whether or not the time is within the normal charge band. When frequency is between 59.92 hertz and 59.98 hertz, electric vehicle chargers will transition to standby mode. When frequency is below

59.92 hertz, electric vehicle chargers will transition to the underfrequency support mode and discharge to the energy grid until battery charge drops to 50% of rated.

The effect will be that standby energy costs will be reduced as electric vehicle batteries will be used to support the energy grid for 10 minutes until additional energy sources are brought on line.

13. About the Authors

Tony Sleva is a seasoned engineering manager, electrical engineer, project manager, and a thought leader in next-generation power system concepts. His contributions extend beyond leadership, encompassing roles as a continuing education instructor, training program developer, forensic investigator, author, and research engineer. At Prescient Transmission Systems, Tony spearheads the development of innovative services and technologies, focusing on areas such as wildfire risk assessment, power outage prevention, and broader advancements in power system engineering.

Alyssa Sleva-Horine is the lead technical editor and business manager for Prescient Transmission Systems. She is an advocate for climate-friendly, next generation solutions for the electric energy grid.

Prescient Transmission Systems provides consulting services for electric utilities in a variety of areas, including physical security, wildfire risk reduction, renewable energy integration, electric vehicle integration, system modeling, and energy balancing. Our focus is on making improvements to the grid using today's data collection technology more effectively.

As subject matter experts, our staff has assessed equipment failures for electric utilities, energy producers, insurers, and large industrial customers. We are passionate about sharing our vision of the next generation electric energy grid. We see change as an opportunity as we prepare for a future with climate change.