PNNL-33499

A Real-Time Operations Manual for the IEEE 118 Bus Transmission Model

September 2022

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Prepared for the U.S. Department of Energy
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Abstract

This document presents a sample operations manual for the IEEE 118 Bus Model, which is a synthetic test case developed in 1962 from a section of the transmission grid operated by American Electric Power (AEP). The model is one of the most used synthetic test cases for development of power system applications and is referenced by over 9000 papers.

However, the model lacks any context for use with real-time energy management system (EMS) applications, including common considerations, such as generator ramp rates, reactive capabilities, operating limits, and other information typically used by power system operators for real-time decision making.

This manual divides the IEEE 118 Bus Model into three operating areas, defines various operating limits, and sets recommended operating procedures for responding to a few types of emergency operating conditions. The manual can be used in support of a wide variety of human-in-the-loop evaluation methodologies for new advanced power applications.

This operations manual was used as the primary point of reference for former Peak RC operations engineering staff participating in a human factors study conducted in Sept 2021 in the PNNL EIOC. The ability of operators to resolve contingency analysis violations using this manual also served as a baseline for measuring technical performance, cognitive workload, and human-machine trust for evaluation of a machine learning recommender tool that provided control action suggestions to the operator.

Acknowledgments

This operating manual is based on PJM Manual 03 and the Cascadia Operating Guide for Synthetic Systems, developed by Incremental Systems Corporation and PowerData Corporation for training of power system operators in real-time simulation environments.

The research described in this paper is part of the MARS Initiative at Pacific Northwest National Laboratory. It was conducted under the Laboratory Directed Research and Development Program at PNNL, a multiprogram national laboratory operated by Battelle for the U.S. Department of Energy under Contract DE-AC05-76RL01830.

Acronyms and Abbreviations

AGC	Automatic Generation Control
AVR	Automatic Voltage Regulation
BA	Balancing Authority
CEII	Critical Energy Infrastructure Information
DTS	Dispatcher Training Simulator
EIOC	Electric Infrastructure Operations Center
EMS	Energy Management System
kV	Kilovolt
MW	Megawatt
MVAr	Megavolt-ampere-reactive
NERC	North American Electric Reliability Corporation
IEEE	Institute of Electrical & Electronics Engineers
IROL	Interconnection Reliability Operating Limit
ISO	Independent System Operator
MSSC	Most Severe Single Contingency
NOA	North Operating Area
OTS	Operator Training Simulator
RC	Reliability Coordinator
RRT	Reliability-Related Task
RTA	Real-Time Assessment
SCADA	Supervisory Control and Data Acquisition
SOA	South Operating Area
TOP	Transmission Operator
TSO	Transmission System Operator
WOA	West Operating Area

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1.0 Introduction and Background

1.1 Overview of Grid Operations

Safe, secure, and economic operation of the bulk electric system (BES) is largely dependent on the competency, situational awareness, and performance of human power system operators working with the assistance of advanced power applications provided as part of an energy management system (EMS) [1]. The job of power system operators (also sometimes referred to as grid dispatchers) is to monitor the transmission system 24/7 and make real-time hour-by-hour decisions on control actions needed to maintain the reliability of the grid. Power system operators within a region are typically spread across multiple organizational entities and control centers. Figure 1 below provides a grid architecture perspective on the interactions and interfaces between various human actors and entities between generation, transmission, and distribution in a deregulated market environment.

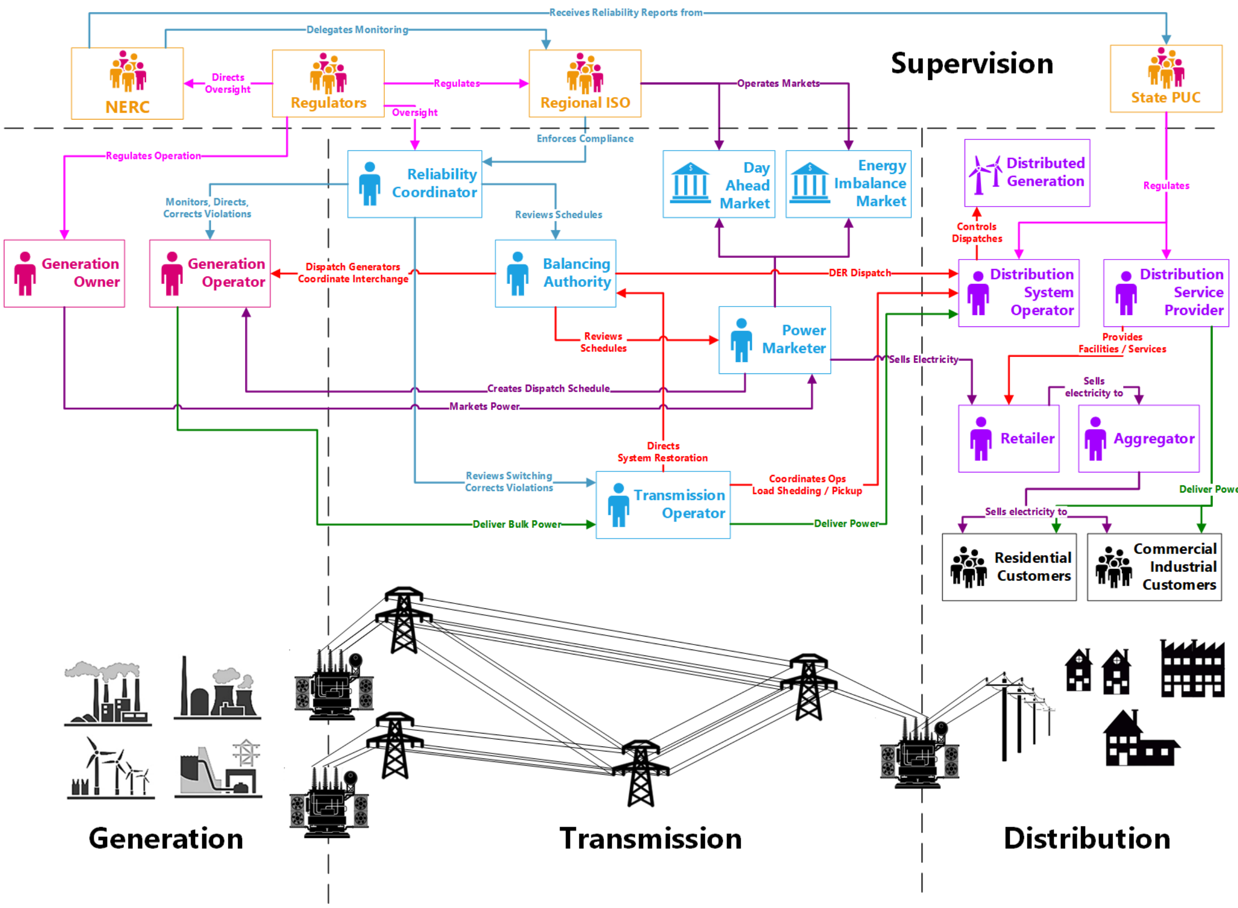

Figure 1: A grid architecture view of the interactions between power system operators and other human actors in real-time operation of the bulk electric system

Real-time operation of the bulk transmission grid is conducted by three groups of power system operators certified by the North American Electric Reliability Corporation

- Reliability Coordinator (RC) – responsible for assuring the reliability of the BES through real-time reliability assessments and approving planned outages, generation schedules, and control actions
- Balancing Authority (BA) – responsible for managing generation dispatch, frequency balancing, and scheduling interchange between different areas
- Transmission Operator (TOP or TSO) – responsible for developing control action plans, operating substation equipment through supervisory control and data acquisition (SCADA) systems, and coordinating with field crews

The reliability of the bulk electric system is ensured by a number of regulatory organizations and the North American Electric Reliability Corporation (NERC), which oversees the real-time operation of the grid, establishment of reliability standards, and certification of power system operators. NERC works in close collaboration with other regulator entities and defers most day-to-day supervisory tasks to regional independent system operators (ISO).

1.2 Decarbonization and Operational Impacts

The electric grid is being reshaped rapidly by numerous efforts to decarbonize and modernize the electric grid at both the transmission and distribution level. At the bulk transmission level, conventional thermal power plants (which have historically served base energy load and provided system stability through physical inertia and spinning reserves) are being displaced by intermittent renewables. Meanwhile, at the feeder level, customer rooftop solar, distributed generation, bi-directional power flows, and shifting load profiles are introducing increasing uncertainty into the validity and accuracy of traditional operations methods.

Some entities, such as NY-ISO, anticipate that increasing penetration of intermittent renewables will disrupt current operational paradigms based on load-following automatic generation control (AGC) [2]. They also anticipate the possibility of being unable to complete typical reliability-related tasks using traditional approaches to maintaining operating reserves, frequency balancing, voltage control, interchange scheduling, and black-start capability. As a result, a new generation of advanced power applications will be needed to ensure reliable, resilient, robust, safe, and economical operations. This new generation of applications will need to operate in a data-rich environment, leveraging multiple sources of data not available to current energy management system (EMS) .

Research is published every year introducing novel algorithms and optimization methods for power systems problems. However, few of these methods are adopted by industry due to a wide range of operational considerations that are frequently ignored [3]. Utility engineers and operators will likely reject technologies that do not consider operational requirements, such as line crew safety, existing operational procedures, work clearances, customer acceptability, workforce rules, data management, and integration with legacy systems.

1.3 Cross-cutting through Real-Time Simulation

Development, testing, and integration of the next generation of advanced power applications will require the collaboration and involvement of stakeholders from numerous technical fields. It will also require participation from regulators, executives, manufacturers, and a range of technical experts including system operators, operations engineers, application developers, and data scientists. Each of these stakeholders have different areas of focus, and it is difficult to find a common language for resolving communication barriers. Figure 2 below presents the mental silos of a few key stake holders in the development of new applications and technologies.

Crosscutting between these silos of expertise can be achieved through creation of storyboarded events in a real-time simulation environment mimicking a utility control room, such as at the Electricity Infrastructure Operations Center at Pacific Northwest National Laboratory (PNNL). The creation of a real-time simulation environment with scenarios that are representative of both normal operations and emergency events is conducive to creating discourse, collaboration and mutual understanding between these key stakeholders.

Real-time simulation using an operator training simulator (OTS) or dispatcher training simulator (DTS) was first introduced by [4] in the 1980s and became more common during the 1990s [5], [6]. The DTS/OTS provides a controlled environment for explaining key technical issues, practicing emergency operations procedures, and engaging in human-

Figure 2: A comparison of the siloed perspectives of various key technical players in the development of new advanced power applications and smart grid technologies.

in-the-loop role playing without the stress and possibility of physical equipment damage during real-time operations. Most DTS systems provide an exact replica of the EMS and SCADA interfaces familiar to power system operators with a real-time simulation of the power system with accurate long-term dynamic models. Figure 4 depicts the architecture of two widely used training simulators – the GE Grid Dispatcher Training Simulator (DTS) and the IncSys/PowerData PowerSimulator OTS.

In the 30 years since, simulation-based training has become the standard for maintaining the proficiency of the roughly 6,000 power system operators working in control centers across North America [1]. Power system simulation with a DTS is also used by many utilities for operator competency evaluation, engineering studies, power system model evaluation, offline testing of advanced applications, and post-event analysis. As a result of the August 2003 Blackout, realistic simulation-based training using a dispatcher training simulator (DTS) is now required for all transmission operators, balancing authorities, and reliability coordinators as a result of the August 2003 blackout, per North American Electric Reliability Corporation (NERC) Standard PER-005-2 [7].

Although the use of DTS software for and evaluation of new smart grid tools [8], [9] is well-known within industry, most academic and research programs have been slow to adopt more realistic simulation tools. Part of this challenge has been due to the high cost of licensing such tools, uploading large-scale power system models, and creating realistic operational scenarios. For this reason, a compact operations manual for the widely used IEEE 118 Bus Model is introduced, to help provide additional realism for technology evaluation and classroom instruction using commonly available simulation tool, such as PowerWorld.

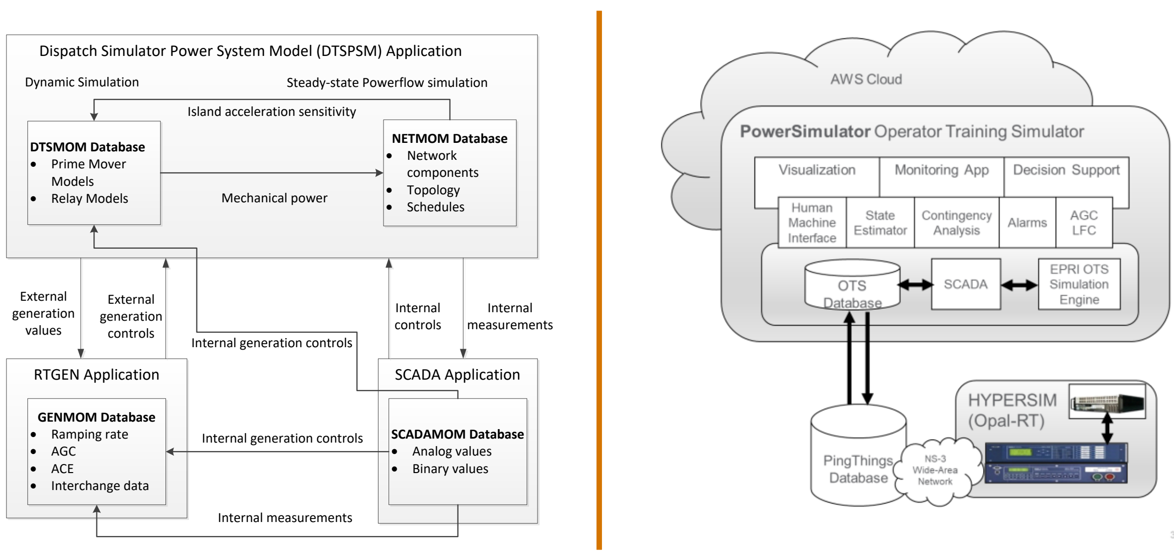

Figure 3: Architecture of the GE Dispatcher Training Simulator (left) and IncSys / Powerdata PowerSimulator (right), reproduced with permission of GE Grid and Incremental Systems Corp.

1.4 Human Factors Impacting Grid Operations

Given the complex operations environment that power systems operators and operations engineers face, the human component of the system is flexible, adaptive, and able to handle the dynamic nature of operations. However, there are many opportunities for that same human component to fail. Human factors research is critical to understanding and characterizing those tasks, activities, and environments where the human can be relied on. It also highlights those actions that pose special risks to the system because the human component doesn't fit very well. Additionally, human factors are present across transmission, generation, and distribution areas and is of increasing concern when smart technologies and manual response demands are considered. This section will briefly discuss the role of human factors research and its application to understanding operator performance with existing and emerging technologies.

With respect to the IEEE 118 bus model, simulation studies that aim to measure operator performance may be of interest to the reader. We provide some questions one may ask and methods that can facilitate answering those question. An example of how to conduct a human factors study is included in [10] and was conducted at the PNNL's Electric Infrastructure Operations Center [11].

1.4.1 Adoption of New Technologies

Human-in-the-loop evaluation using a real-time simulation environment enables researchers and developers to evaluate their effectiveness of their tools on operator competence and effectiveness. An initial set of questions can be derived from the operator competence criteria listed by [1]:

- *Does the tool affect the ability of the operator to perform normal tasks (e.g. writing switching orders) in an optimum manner?*
- *Does the tool affect the ability of the operator to recognize problems and take corrective actions in a timely manner?*
- *Does the tool affect the ability of the operator to recognize opportunities and take advantage of them?*
- *Does the tool affect the ability of the operator to interact and communicate with the correct people to perform various tasks?*
- *Does the tool affect the ability of the operator to respond properly to cyber-physical threats and emergencies in a calm and collected manner?*
- *Does the tool affect the ability of the operator to prioritize tasks and identify the most important tasks for maintaining the reliability of the grid?*
- *Does the tool affect the distribution of workload among the operator and other operations staff?*

The questions above are just a handful of the human-machine teaming considerations that affect the adoption of new tools by utilities. However, a full discussion of human-machine teaming, operator trust, and adoption barriers is beyond the scope of this report.

Within a human-centric evaluation process for advanced power applications and new smart grid technologies, the realism of the evaluation environment is critical to replicating the stress and complexity of a utility control room. A key component is mimicking the real-time operational software environment and displays used by power system operators. This can be provided by a variety of real-time simulation software, whose role is discussed in the next section.

A variety of barriers has can prevent the adoption of a new tool, even when its benefit is demonstrated. Some are basic institutional barriers, such as insufficient time provided to train operators on a new technology [12]. Other barriers are established by user attitudes towards and perceptions of the tool. Perhaps the capabilities of a tool were oversold and therefore operator expectations of the system are too high, such as if the tool does not support existing processes. Tools should be designed with the current workflows of operators in mind, relying upon user knowledge and experience [13].

There may also be concerns regarding the accuracy or explainability of a tool that could be mitigated by both additional training and additional development in collaboration with end users [14]. The ability of an operator to understand any recommendations or decisions made by a tool is key to establishing trust. The availability of the information used to inform those recommendations by request, and the clarity of the presentation and communication of that information, supports this trust-building process.

Limited training can lead to a loss of productivity or accuracy, particularly when time pressure drives rapid decision-making. Additionally, as technology advances and machines take on additional tasks that were once human-centered, feelings of a loss of autonomy can occur [15]. Some inherent user attributes such as resistance to change and poor technical literacy can also impede the adoption of a tool.

The National Institute of Standards and Technology (NIST) has published a framework for the development of smart systems that include both physical and computational components. Created by the Cyber-Physical Systems Working Group, this document captures many of the key concepts and issues that stakeholders should consider when introducing such innovative systems [16].

1.4.2 Measuring Performance and Decision-Making

As a critical component of power systems, it's important to utilize the right methods when assessing operator performance. Performance in these systems can be divided into physical task components (moving equipment, button presses, accurate keystrokes, etc.) and cognitive task components (mental math, recalling procedures in order, event detection and recognition, etc.). Depending on the goals of a particular assessment, there are specific methods from the human factors literature that can be deployed with a simulation to understand operator cognitive load, measure physical limitations, identify where errors are likely to occur, and more.

Error Quantification. In power generation, special attention has been paid to human-centered workflows and performance in nuclear power generation. Human Reliability Analysis (HRA) is a regularly performed set of evaluations in nuclear power plants (NPP) that quantify and qualify operator error probabilities, workflows, and estimate time needed and time available for various tasks. As an area of practice and academic study, HRA can be seen as containing two major components, human factors evaluation methodologies and mathematical formulation of accurate error probabilities. One methodology in HRA is the error-cause removal programme (ECRP), a prevention-focused approach that solicits direct input from workers to identify error-prone activities and provide recommendations. A historically common probability tree method, technique for the human error rate prediction (THERP) [17] performs a task analysis to identify critical human actions in human failure events. Actions are related by sequential steps and branched based on success or failure. Probabilities are assigned to each success or failure and total task error probabilities (failures) are summed across the outcomes. Measuring and modeling errors extends beyond NPP environments, and the methods are relatively easy to extrapolate, albeit attaining base probabilities remains an active area of research.

Situation Awareness. Although the IEEE 118 Bus Model presented here is small by comparison to real world operations, it is large enough to study operator situation awareness around grid events. Operators are expected to monitor several grid measurements, be aware of emerging environment conditions, and perform additional tasks simultaneously. Understanding where the operator loses track of vital information can aid in deriving the limits of what an operator should be expected to do. Situation awareness (SA) is the perception of elements in time and space, comprehension of their semantic meaning, and the projection of their status in the future [18]. Popular methods for measuring SA include surveying techniques, observations, and so-called freeze and probe methods where the participants are asked to stop a simulation and provide answers to SA-related queries by an experimenter. Areas where such studies can be conducted include tracking location specific grid events and multi-tasking control room environments.

The two aforementioned human factors topics are frequently referred to in power systems human factors studies. With the emergence of new technologies, there are many opportunities for other human factors studies to provide insight [19]. We propose that the provided IEEE 118 Bus Model provides a great testbed for human factors studies with operators or to proof out concepts for projects without access to a full OTS/DTS and large-scale transmission grid models.

1.5 Operations Manual Application in Human Factors Experiments

The operations manual for the IEEE 118 Bus Model presented in this document was used as the primary point of reference for former Peak RC operations engineering staff participating in a human factors study conducted in Sept 2021 in the PNNL EIOC (Figure 4). Each experiment trial used a single operations engineer working to resolve real-time contingency analysis violations. The participant's performance using the information contained in this manual was used as the baseline for measuring the impact of introducing an AI-based recommender tool that suggested generation redispatch and load shedding actions [20] for each scenario. The experiment framework and results, along with a set of qualitative and quantitative techniques are introduced in [10], [21], [22], including cognitive sequence workflow diagrams combined with comparative analysis of system penalty, action penalty, cognitive-based trust, affect-based trust, and cognitive workload metrics. The operations manual was also used as a training tool to familiarize participants with the IEEE 118 Bus Model through completion of the black start restoration sequence detailed in Section 10 of this document.

Figure 4: Human factors experiment environment in the PNNL EIOC. A print copy of the IEEE 118 Bus Model operations manual (presented in this report) can be seen on the table for use by participants in resolving contingency analysis violations.

2.0 The IEEE 118 Bus Model Operations Manual

2.1 Background of the Test Case

This document presents a sample operations manual for the IEEE 118 Bus Model, which is a synthetic test case developed in 1962 from a section of the transmission grid operated by American Electric Power (AEP). The model is one of the most used synthetic test cases for development of power system applications and is mentioned or referenced by over 9000 papers.

Synthetic test cases, such as the IEEE 118 Bus Model and other IEEE test cases are models are essential for providing a basis for developing new power applications, comparing optimization results, and initial benchmarking of application performance without the restrictions associated with critical electric infrastructure information (CEII). The vast majority of power system model and display information for the North American bulk electric transmission and distribution systems are considered CEII and can only be shared on a strict need-to-know basis with Non-Disclosure Agreements between utilities, vendors, and consultants.

Although the IEEE 118 Bus Model has been one of the most popular model for sharing application results within research and academia, the model lacks any context for use with real-time energy management system (EMS) applications, including common considerations, such as generator ramp rates, reactive capabilities, operating limits, and other information typically used by power system operators for real-time decision making. The source files for the model [23], [24] only specify the line impedances, generator setpoints, and min/max generator reactive capabilities (some of which are highly unrealistic, including 100 MW rated units with 300 MVAr of reactive capability).

This manual divides the IEEE 118 Bus Model into three operating areas, defines various operating limits, and sets recommended operating procedures for responding to a few types of emergency operating conditions. It is anticipated that the document can serve as a reference guide and real-time reference for projects using the IEEE 118 Bus Model for human-in-the-loop evaluations and demonstration of research tools.

2.2 Operations Manual Scope

This document does not attempt to cover the vast array of topics found in the typical set of operations manuals used by transmission utilities. Most Independent System Operators (ISO) in North America have publicly available copies of their operating procedures with CEII data omitted or placed in separate manuals. These include the manuals of

- California Independent System Operator (CAISO) [25]
- Electric Reliability Council of Texas (ERCOT) [26]
- PJM Interconnection [27]
- New York Independent System Operator (NYISO) [28]

- Midland Independent System Operator (MISO) [29]

Each utility or ISO develops their own set of operating procedures in compliance with standards set by the NERC electric reliability standards. Transmission system operations manuals are typically divided into several categories including (but not limited to)

- Normal Operating Conditions
    - Acceptable operating limits
    - Automatic reserve sharing
    - Balancing authority operations
    - Communication & coordination
    - Equipment outage scheduling
    - Protection standards
    - Reliability coordination
    - Remedial action schemes
    - Transmission operations
- Abnormal Operating Conditions
    - Telephone system failure
    - Inter-control center communications protocol (ICCP) data link failure
    - EMS application failure
- Emergency Operating Conditions
    - Capacity shortage operations
    - Extreme heat / cold weather operations
    - Geomagnetic disturbance operations
    - Heavy load, low voltage operations
    - Hurricane / tropical storm operations
    - Light load, high voltage operations
    - Response to sabotage / cyber-attack
- System Restoration
    - Black start restoration plan
    - Communications & notifications
    - Restoration philosophy
- Transmission Planning
- Market Operations

2.3 System Overview

The IEEE 118 Bus System consists of a highly meshed 138 kV network tied together by a radial 345kV backbone. Figure 5 presents a semi-geospatial view of the network with line lengths proportional to their impedances. 138kV are colored black and 345kV lines are colored red.

The system is divided into three operating areas. The West Operating Area is lightly loaded and contains about 2500 MW of generation resources. The North Operating Area contains one large load center at the TIDD 345/138 kV facility (buses 59 and 63). The South Operating Area is heavily loaded and can experience voltage issues due to the large load center at the HOLSTO~1 138kV facility (bus 90) and lack of nearby voltage control resources. There are two sets of several very long 138 kV lines within the West and North areas that are subject to IROLs.

2.3.1 Balancing Areas

The system is divided into three areas:

- West Operating Area (WOA) consists of all facilities west of EASTLI 345 kV (bus 38) and west of TRENTO 138kV (bus 24)
- North Operating Area (NOA) consists of all facilities east of EASTLI 345 kV (bus 38) and north of SPORN 345kV (bus 68)
- South Operating Area (SOA) consists of all facilities east of TRENTO 138kV (bus 24) and south of SPORN 345 kV (bus 68)

Each balancing area operator is responsible for dispatching generation within their area, monitoring interchange, and ensuring that the Area Control Error (ACE) for their area remains within limits.

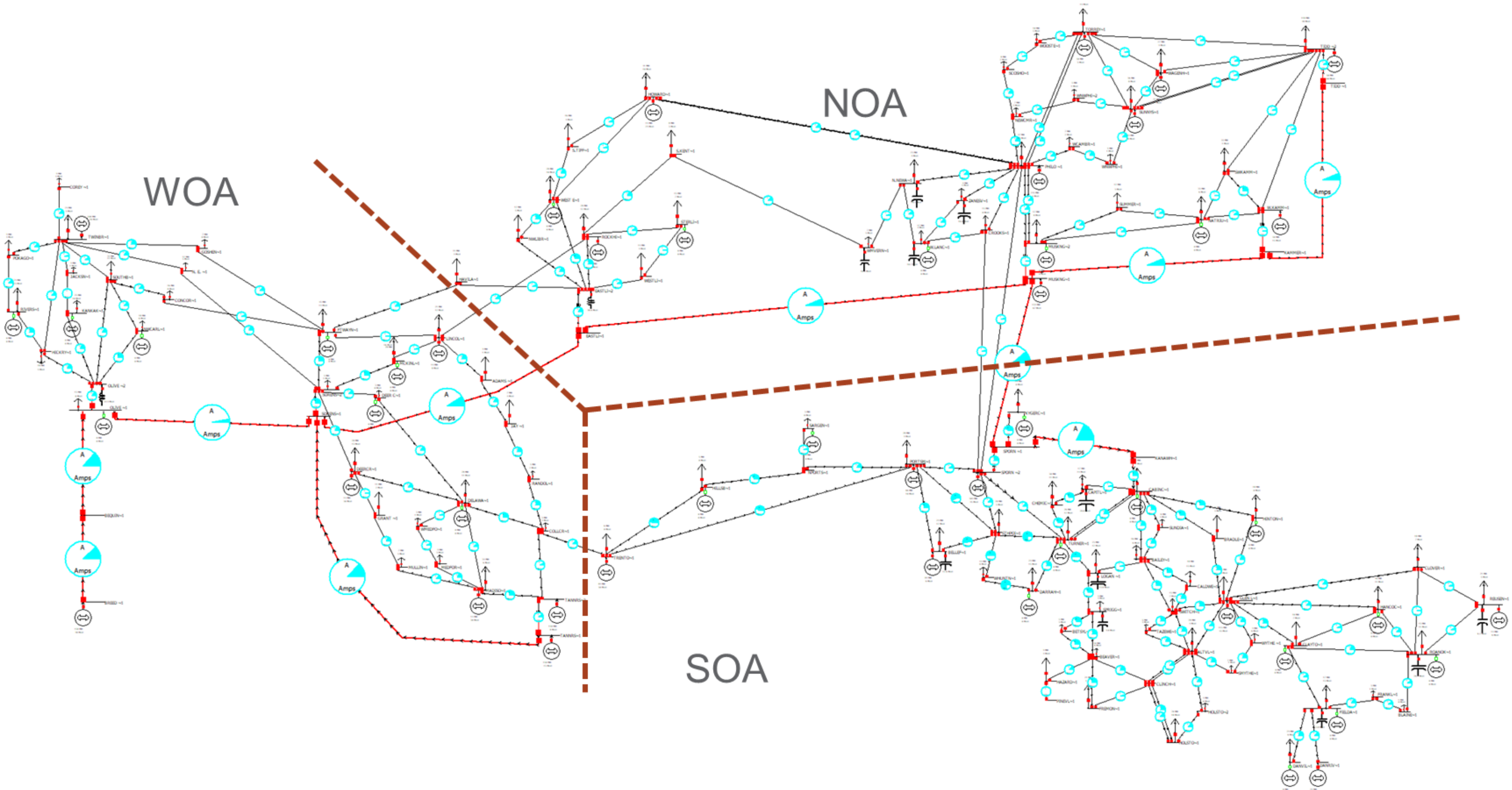

Figure 5: Semi-geospatial representation of the IEEE 118 Bus Model divided into West, North, and South operating areas.

2.3.2 Reliability Coordination

The 118 Bus System Transmission System Operators (TSO) and Reliability Coordinators (RC) shall perform a Real-Time Assessment (RTA) every 5 minutes. RTA is defined by NERC as "an evaluation of system conditions using Real-time data to assess existing (pre-Contingency) and potential (post- Contingency) operating conditions. The assessment shall reflect applicable inputs including, but not limited to, load, generation output levels, known Protection System and Special Protection System status or degradation, Transmission outages, generator outages, Interchange, Facility Ratings, and identified phase angle and equipment limitations" [30].

The requirement to perform RTA is defined by the following NERC standards:

- TOP-001-3 R13: Each TOP shall ensure that an RTA is performed at least once every 30 minutes. [Time Horizon: Real-time Ops]

- IRO-008-2 R4: Each RC shall ensure that an RTA is performed at least once every 30 minutes.

The objective of an RTA is to assure acceptable pre- and post-contingent system performance in real-time. Acceptable system performance for the pre-contingency and post-contingency state is that there is no exceedance of System Operation Limits (SOLs) and Interconnection Reliability Operating Limits (IROLs).

IROLs are defined as SOLs that, if violated, could adversely affect reliability of Bulk Electric System (BES) due to instability, cascading outages, or uncontrolled separation of the grid. RCs and TOPs have typically 15 to 30 minutes to mitigate IROLs identified in pre-contingent state.

The 118 Bus TSOs and RCs shall use a combination of assessment tools including

- EMS Alarm and SCADA applications
- Real-time Contingency Analysis
- Offline Contingency Analysis
- Offline Power Flow Studies
- Reliability & Situational Awareness Checklists

The recommended Reliability & Situational Awareness Checklist is provided in Section 2.10.

2.4 Generation Resources

The generation resources for the 118 Bus System are grouped by each operating area. Some larger baseline units are needed to maintain system reliability. When these units are offline, IROL limits may apply.

2.4.1 West Operating Area

The West Operating Area (WOA) contains a total of 2576 MW of generation resources. The majority of units in WOA are fast-ramping hydro and gas-turbine units. An overview of WOA is provided in Figure 6. A summary of generation units with limits and fuel types is provided in Table 1.

BREED (bus 10) is a baseline coal generator that is typically kept online to provide reactive power control. If the BREED unit must be taken offline, then the BEQUIN-BREED 345 kV Line (path 9 – 10) must be switched out to prevent system overvoltage due to the very high charging MVAr of the 345kV line.

If the TWINBROOK (bus 12) unit is offline, then the south-to-north flow on the lines from SORENS (bus 17) to TWINBROOK must be reduced to below 80% of the line limit due to a voltage collapse IROL.

Table 1: West Operating Area Generation Resources

Station	Bus Number	Gen / Fuel Type	Rated Min MW	Rated Max MW	Ramp Rate (MW/min)
BREED	10	Coal	150	550	20
DEERC	113	Gas Turbine	25	100	20
DEERCR	31	Hydro	8	107	200
DELAWA	32	Gas Turbine	25	100	20
FTWAYN	15	Gas Turbine	10	100	20
KANKAK	6	Hydro	5	100	200
LINCOL	19	Hydro	5	100	200
MADISO	27	Hydro	5	100	200
MCKINL	18	Gas Turbine	25	100	20
NWCARL	4	Hydro	5	100	200
OLIVE	8	Hydro	5	100	200
RIVERS	1	Hydro	5	100	200
TANNERS-1	26	Coal	100	414	15
TANNERS-2	25	Coal	100	320	10
TWINBROOK	12	Combined Cycle	100	185	7

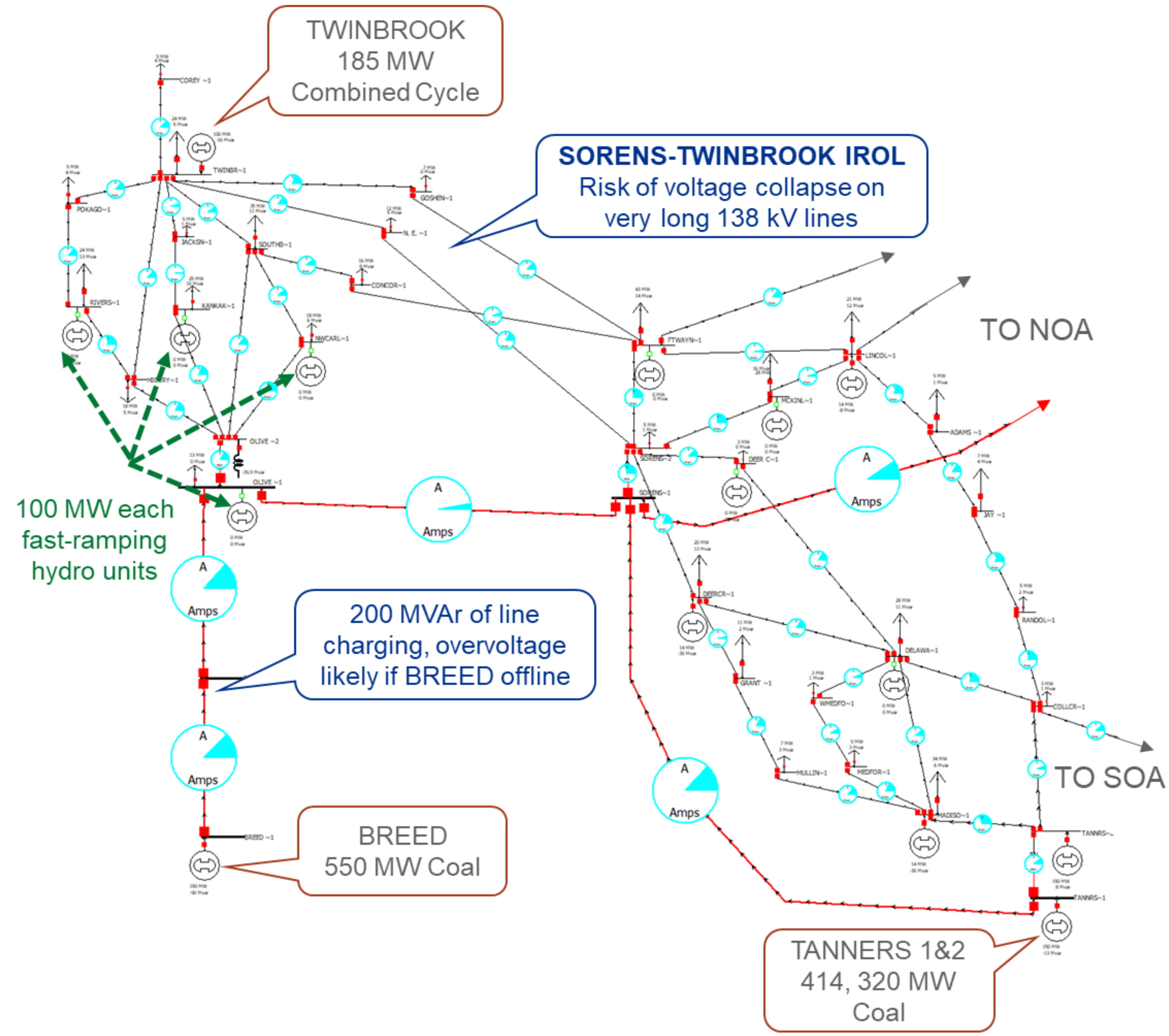

Figure 6: Overview of WOA generation resources and operational constraints

2.4.2 North Operating Area

The North Operating Area (NOA) contains a total of 2769 MW of generation resources. The majority of unit are slow-ramping coal and combined cycle units. None of the generation units in the North Area are critical for maintaining system reliability. A review of available resources and constraints in NOA are presented in Table 2 and Figure 7.

Table 2: North Operating Area Generation Resources

Station	Bus Number	Gen / Fuel Type	Rated Min MW	Rated Max MW	Ramp Rate (MW/min)
HOWARD	42	Hydro	8	100	200
MUSKNG-1	65	Coal	100	491	20
MUSKNG-2	66	Coal	100	492	20
NATRIU	62	Gas Turbine	25	100	20
PHILO	49	Combined Cycle	50	304	10
ROCKHI	34	Hydro	8	100	200
STERLI	36	Gas Turbine	25	100	20
SUNNYS	56	Gas Turbine	25	100	20
TIDD	59	Combined Cycle	50	255	10
TORREY	54	Combined Cycle	50	148	6
W.KAMM	61	Combined Cycle	50	260	10
W.LANC	46	Gas Turbine	25	119	20
WAGENH	55	Gas Turbine	25	100	20
WEST E	40	Hydro	8	100	200

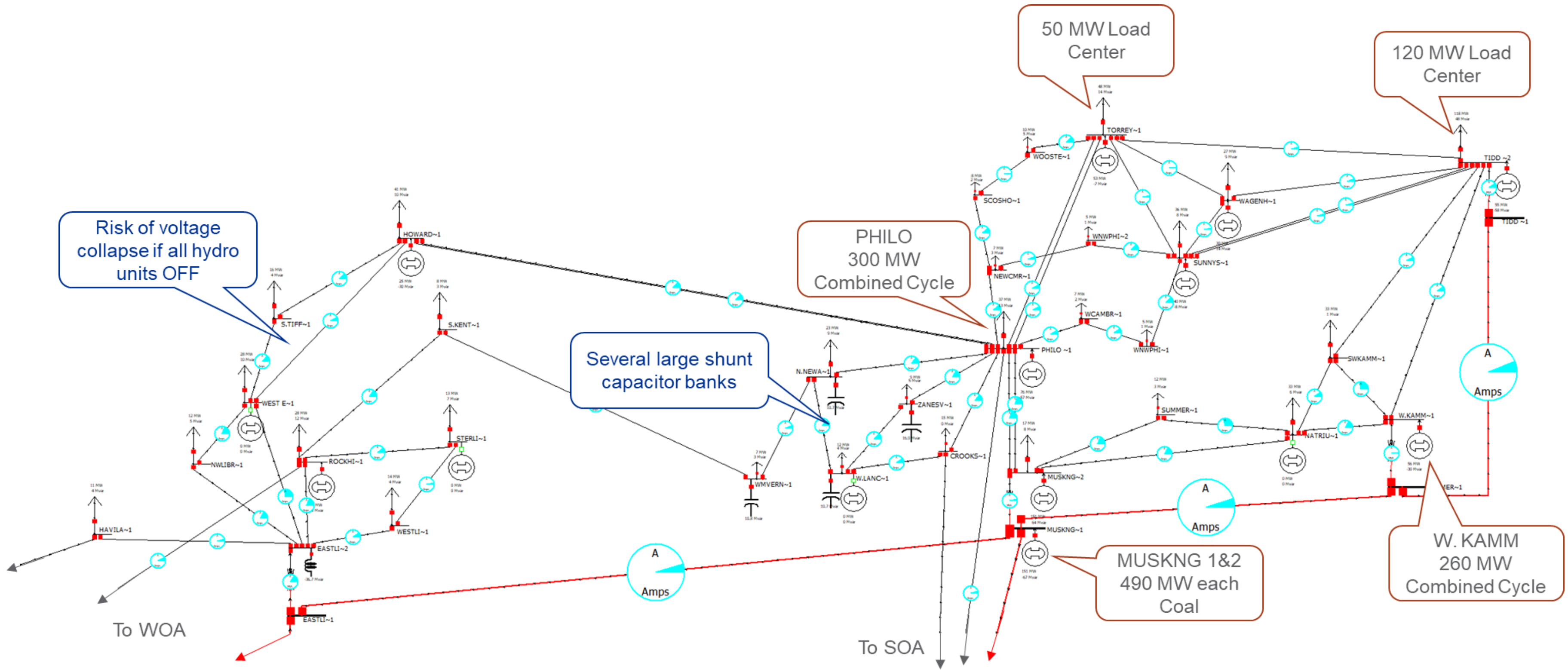

Figure 7: Overview of NOA generation resources and operational constraints

2.4.3 South Operating Area

The South Operating Area (SOA) contains a total of 3305 MW of generation resources. The majority of generators in SOA are coal and gas turbine units.

SPORN (bus 69) and CABINC (bus 80) are baseline coal units that typically need to stay online to provide voltage support. If both units are online, the system will be in a weakened state and at risk of cascading outages if the PHILO-SPORN IROL is violated.

GLEN L (bus 100) is a combined cycle unit that is the nearest / only voltage support resource for the load center at HOLSTO (bus 90). If the GLEN L unit is forced offline during high load conditions, load shedding may be necessary to keep the system within voltage limits.

Table 3: South Operating Area Generation Resources

Station	Bus Number	Gen / Fuel Type	Rated Min MW	Rated Max MW	Ramp Rate (MW/min)
BELLEF	74	Hydro	5	100	200
CABINC	80	Coal	150	577	15
CLAYTO	103	Hydro	8	140	200
DANRIV	111	Gas Turbine	25	136	25
DANVIL	112	Gas Turbine	25	100	20
DARRAH	76	Gas Turbine	25	100	20
FIELDA	110	Gas Turbine	25	100	20
GLEN L	100	Combined Cycle	100	352	15
HANCOC	104	Gas Turbine	25	100	20
HILLSB	72	Hydro	10	100	200
HINTON	99	Gas Turbine	25	100	20
KYGERC	116	Gas Turbine	25	100	20
PORTSM	70	Gas Turbine	30	100	20
REUSEN	107	Hydro	8	100	200
ROANOK	105	Gas Turbine	25	100	20
SARGEN	73	Hydro	5	100	200
SPORN-2	69	Coal	80	800	30
TURNER	77	Gas Turbine	25	100	20

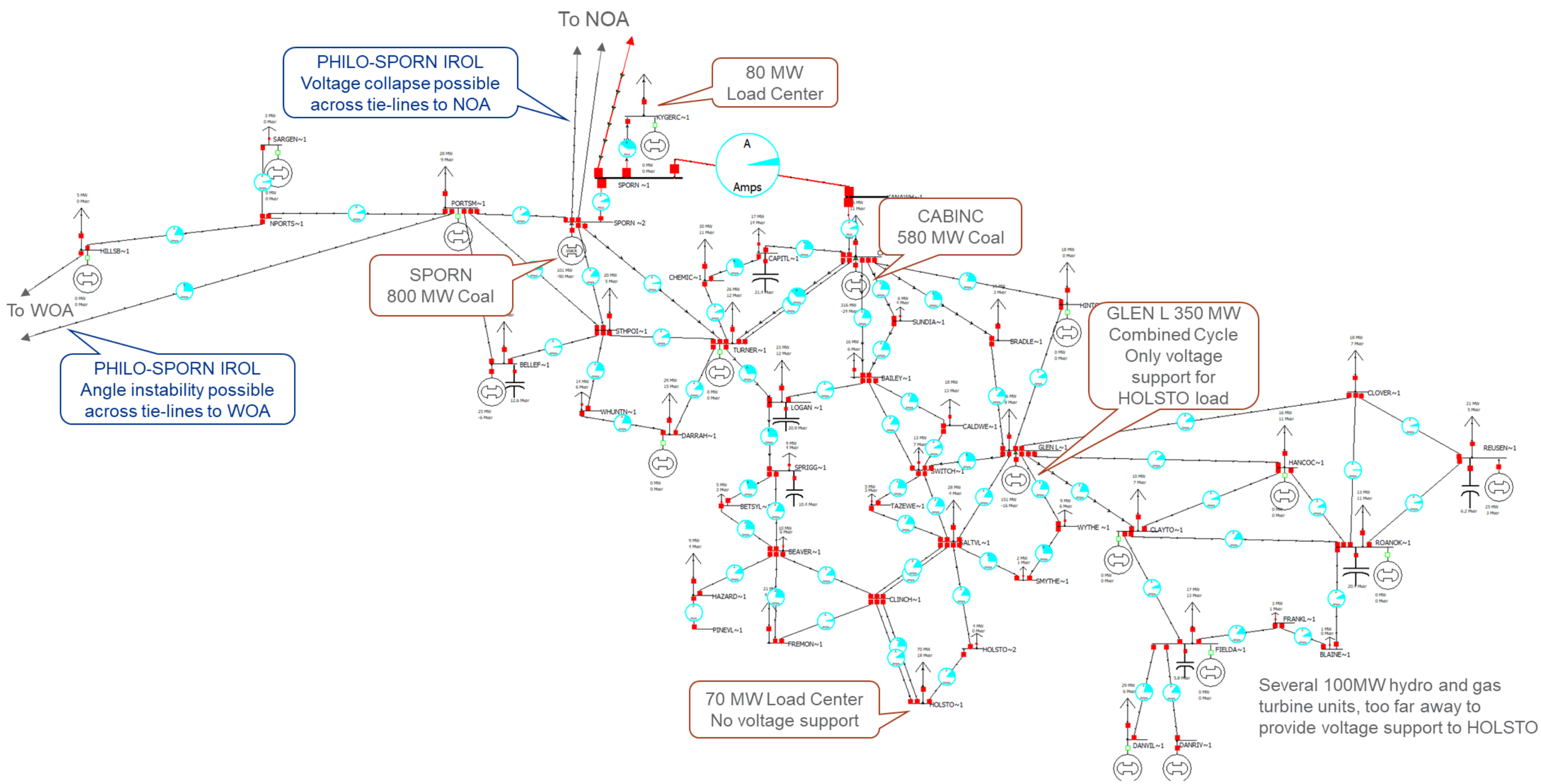

Figure 8: Overview of SOA generation resources and operational constraints

2.4.4 Generator Start Times

Following a unit trip or system blackout, the following unit constraints are in effect:

- BREED — unit will be available 2 hours after station service power has been restored
- TANNERS 1 & 2 — units will be available 2 hours after service has been restored
- MUSKNG 1 & 2 — units will be available 2 hours after service has been restored
- CABINC (bus 80) – unit will be available 4 hours after station service power has been restored
- SPORN (bus 69) – unit will be available 4 hours (cold start) after station service power has been restored. The unit has the ability to run back to house load at KYGERC after a blackout. If the unit does trip after a major event, it will remain hot for 30 min and can be cranked immediately within that timeframe.

2.5 Reactive Resources

2.5.1 West Operating Area

The West Operating Area (WOA) contains only a single static reactive device, which is a 40 MVAr bus reactor at the OLIVE2 138 kV facility (bus 5). Generator MVAr limits for the units in WOA are listed in Table 5 below.

Table 4: North Operating Area Static Reactive Shunt Devices

Station	Bus Number	Shunt Capacitor	Shunt Reactor
OLIVE-2	5		-40 MVAr

Table 5: West Operating Area Generation MVAr Limits

Station	Bus Number	Rated Min MVAr	Rated Max MVAr
BREED	10	-147	200
DEERC	113	-30	40
DEERCR	31	-30	40
DELAWA	32	-14	42
FTWAYN	15	-10	30
KANKAK	6	-30	50
LINCOL	19	-8	24
MADISO	27	-30	40
MCKINL	18	-16	50
NWCARL	4	-30	40
OLIVE	8	-30	40
RIVERS	1	-5	15
TANNERS-1	26	-100	150
TANNERS-2	25	-47	140
TWINBROOK	12	-35	120

2.5.2 North Operating Area

The North Operating Area contains a bus reactor at the EASTLI 132kV bus and a set of small shunt capacitors at four of the substations east of MUSKNG 345/132 facility. The location and rating of each static reactive control device are summarized in Table 6 below. Generator MVAr limits for the units in NOA are listed in Table 7 below.

Table 6: North Operating Area Static Reactive Shunt Devices

Station	Bus Number	Shunt Capacitor	Shunt Reactor
EASTLI-2	37		-35 MVAr
N. NEWA	45	10 MVAr	
W. LANC	46	10 MVAr	
WMVERN	44	10 MVAr	
ZANESV	48	10 MVAr	

Table 7: North Operating Area Generator MVAr Limits

Station	Bus Number	Rated Min MVAr	Rated Max MVAr
HOWARD	42	-30	40
MUSKNG-1	65	-67	200
MUSKNG-2	66	-67	200
NATRIU	62	-20	20
PHILO	49	-85	210
ROCKHI	34	-8	24
STERLI	36	-8	24
SUNNYS	56	-8	15
TIDD	59	-60	150
TORREY	54	-30	40
W.KAMM	61	-100	150
W.LANC	46	-30	40
WAGENH	55	-8	23
WEST E	40	-30	40

2.5.3 South Operating Area

The South Operating Area contains several shunt reactors to help support the large load centers in the area. Static reactive resources are summarized in Table 8 below. Generator MVAr limits for the units in SOA are listed in Table 9.

Table 8: South Operating Area Static Reactive Shunt Devices

Station	Bus Number	Shunt Capacitor	Shunt Reactor
BELLEF	74	12 MVAr	
CAPITL	79	20 MVAr	
FIELDA	110	6 MVAr	
LOGAN	82	20 MVAr	
REUSEN	107	6 MVAr	
ROANOK	105	20 MVAr	
SPRIGG	82	10 MVAr	

Table 9: South Operating Area Generation Resources

Station	Bus Number	Rated Min MVAr	Rated Max MVAr
BELLEF	74	-6	9
CABINC	80	-165	280
CLAYTO	103	-15	40
DANRIV	111	-30	40
DANVIL	112	-30	40
DARRAH	76	-8	23
FIELDA	110	-8	23
GLEN L	100	-50	155
HANCOC	104	-8	23
HILLSB	72	-30	40
HINTON	99	-30	40
KYGERC	116	-30	40
PORTSM	70	-10	32
REUSEN	107	-30	40
ROANOK	105	-8	23
SARGEN	73	-30	40
SPORN-2	69	-300	300
TURNER	77	-20	70

2.6 Interconnection Reliability Operating Limits

The IEEE 118 Bus System contains the following Interconnection Reliability Operating Limits (IROL). If violated, control action must be taken to return the system within limits in 30 minutes.

2.6.1 SORENS-TWINBROOK IROL

2.6.1.1 IROL Description

The SORENS-TWINBROOK IROL applies to south-to-north flow from the SORENS 345/138 kV facility (buses 17 and 30) to TWINBROOK 138kV facility (bus 12):

- N.E. – SORENS~2 138kV line (Path 16-17)
- FT WAYNE – GOSHEN 138kV line (Path 14-15)

Both circuits are relatively long 138kV lines on parallel paths from the SORENS 345/138 kV facility to the TWINBROOK 138kV facility in the far northwest corner of the system. The IROL limits of the two lines are independent and apply whether either or both 138kV lines are in service. The impact of the IROL can be seen in Figure 9.

When the generating unit at TWINBROOK is offline, the IROL value is the same or lower than the SOL of the lines. When the unit is offline, exceeding the IROL will lead to voltage collapse. The IROL does not apply to reverse flow (north-to-south) from TWINBROOK to SORENS.

Table 10: SORENS-TWINBROOK IROL Description

Interface / FACILITY Name	N.E. – SORENS2 138kV (Path 16-17)	FT WAYNE – GOSHEN 138kV (Path 14-15)
Classification	IROL	IROL
SOL Limit	Normal Limit: 75 MVA Emergency Limit: 90 MVA	Normal Limit: 75 MVA Emergency Limit: 90 MVA
IROL Limit with TWINBROOK unit ON	IROL Limit: 90 MVA	N/A
IROL Limit with TWINBROOK unit OFF	IROL Limit: 90 MVA	IROL Limit: 75 MVA
IROL Limit with TWINBROOK unit OFF and OLIVE~2 Reactor switched IN	IROL Limit 75 MVA	IROL Limit: 55 MVA
IROL time to resolve	30 minutes	
Type of limitation	Voltage collapse	
Associated contingencies	Loss of OLIVE 345-138kV transformer Loss of OLIVE~2 138 kV Bus Loss of OLIVE-SORENS 345kV line	

2.6.2 IROL Resolution

Contact the WOA System Operator to determine mitigation steps to correct the IROL exceedance and establish a timeframe for completion of steps.

- Contact TWINBROOK generator operator to start unit or increase output
- Reduce flow from SORENS to TWINBROOK by
- Increase generation at RIVERS, KANKAK, and/or NW CARL facilities
- Shed load at SOUTHB facility (bus 11)
- Ensure that OLIVE2 138kV bus reactor is switched out

Verify mitigation action being taken and evaluate if the action being taken will relieve the IROL exceedance within 30 minutes If actions are not sufficient, instruct additional actions to return system within limits up to including the shedding of additional load.

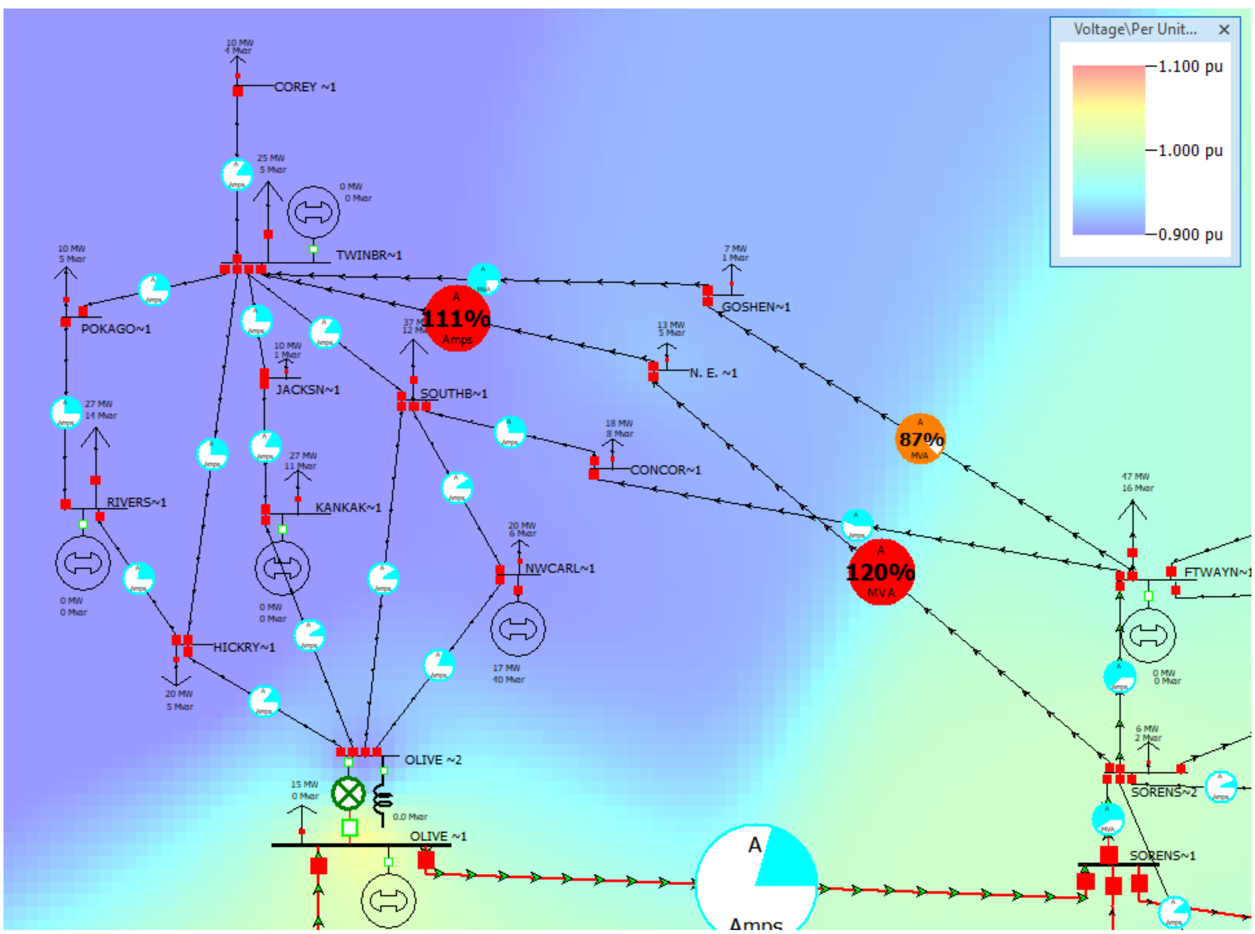

Figure 9: SORENS-TWINBROOK IROL with both Paths 14-15 and 16-17 in service. Voltage collapse conditions (deep purple) are clearly seen in the upper left of the network.

2.6.3 PHILO-SPORN IROL

2.6.3.1 IROL Description

The PHILO-SPORN IROL applies to flow from PHILO 138kV facility (bus 49) to the SPORN 345/138 kV facility (buses 68 and 69):

- PHILO – SPORN2 138kV line (Path 49-69)
- CROOKS – SPORN2 138kV line (Path 47-69)

Both circuits are relatively long 138kV tie lines on parallel paths from the PHILO 138kV facility in NOA to the SPORN 345/138 kV facility in SOA.

When both CABINC and SPORN generation units are offline, total SOA imports (pre-contingency) must be reduced to 450 MW due to risk of voltage collapse and angle instability. If the 345kV path is lost, the import is forced to flow across two very long 138kV paths which exceed their transient stability limits, as shown in Figure 10.

The IROL does not apply if both CABINC and SPORN generators are online.

Table 11: PHILO-SPORN IROL Description

Interface / FACILITY Name	**PHILO – SPORN2 138kV line (Path 49-69)**	**CROOKS – SPORN2 138kV line (Path 47-69)**
Classification	IROL	IROL
SOL Limit	Normal Limit: 150 MVA Emergency Limit: 180 MVA	Normal Limit: 150 MVA Emergency Limit: 180 MVA
IROL Limit with KYGERC unit ONLINE	IROL Limit: 165 MVA at SPORN	IROL Limit: 165 MVA at SPORN
IROL Limit with Capacitor Banks switched OUT	IROL Limit: 150 MVA at SPORN	IROL Limit: 150 MVA at SPORN
IROL time to resolve	30 minutes	
Type of limitation	Voltage collapse, angle instability, system separation	
Associated contingencies	Loss of MUSKNG – SPORN 345kV Line Loss of MUSKNG 345kV bus Loss of SPORN 345 kV bus Loss of SPORN 345/138kV xfmr and SPORN-KANAWH 345kV line	

2.6.3.2 IROL Resolution

Contact the SOA and NOA System Operators to determine mitigation steps to correct the IROL exceedance and establish a timeframe for completion of steps.

- Contact CABINC and SPORN generator operators to determine timeframe to restart units
- Reduce flow from PHILO to SPORN by
- Increase generation at available SOA facilities
- Shed load at KYGERC facility (bus 11)
- Start other units near SPORN (e.g. PORTSMOUTH, DARRAH, and TURNER) to provide reactive power support
- Ensure that BELLEF (bus 74) and CAPITL (bus 79) capacitors are switched in
- Reduce SOA imports to 450 MW
- Ensure SPORN 345/132 kV and KANAWH 345/132 kV transformer LTC taps are set to neutral.

Verify mitigation action being taken and evaluate if the action being taken will relieve the IROL exceedance within 30 minutes If actions are not sufficient, instruct additional actions to return system within limits up to including the shedding of additional load.

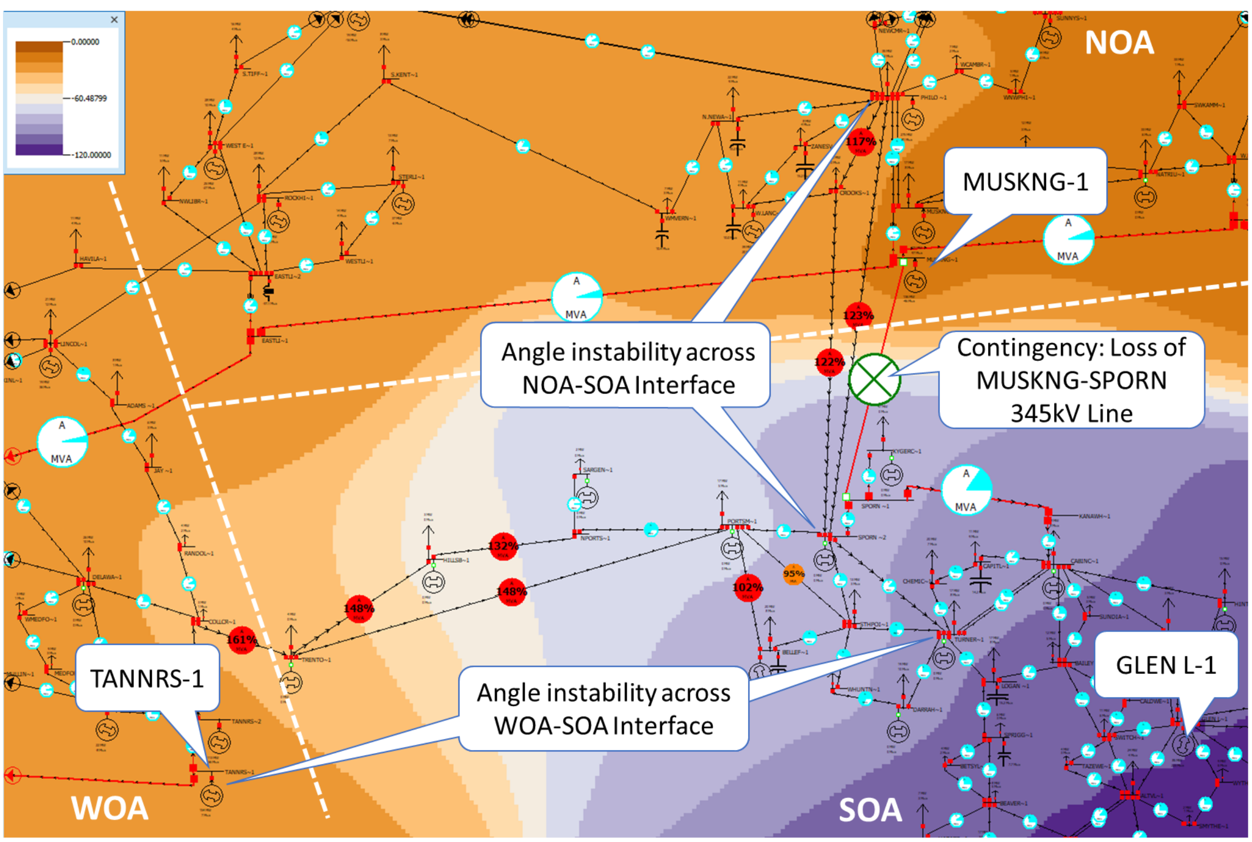

Figure 10: Impact of PHILO-SPORN IROL, with a transient angle difference of nearly 90°

2.7 System Operating Limits

2.7.1 Bus Voltage Limits

Per the requirements of NERC Standard VAR-001-6 R1, a voltage schedule is provided with target voltage values and associated tolerance bands.

Per the requirements of NERC Standard VAR-001-6-R3, the System Operator is responsible for ensuring that voltages and reactive power flows are managed to stay within the established voltages schedule. The 118 Bus System does not have an Under Voltage Load Shed program, and so the system must be operated on a pre-contingency basis in order to avoid load shedding due to voltage violations.

A set of low and high voltage limits have been established for the 118 Bus System, ranging from Load Dump to Emergency High. The established voltage limits for the system are presented in Table 12 below.

Table 12: Voltage Limits for the 118 Bus System

Voltage Level	Load Dump	Emergency Low	Normal Low	Normal High	Emergency High
345 kV	310 kV 0.90 pu	317 kV 0.92 pu	328 kV 0.95 pu	362 kV 1.05 pu	380 kV 1.10 pu
138 kV	124 kV 0.90 pu	127 kV 0.92 pu	131 kV 0.95 pu	145 kV 1.05 pu	151 kV 1.10 pu

Acceptable control actions for mitigating voltage violations are classified into categories of non-cost, off-cost, and load shedding, as summarized in Table 13 below.

Table 13: Acceptable Voltage Control Actions

Non-Cost Actions	Off-Cost Actions	Load Shedding
Cap / reactor switching	Generation re-dispatch	Load shedding (non-critical load)
Adjusting AVR setpoints	Generation startup/shutdown	Load shedding (firm load)
Line switching	Interchange re-scheduling	

2.7.1.1 Actual System Violations

The System Operator is responsible for managing reactive equipment and reactive power flows such that the system remains between the Normal Low and Normal High voltage limits.

If a limit violation develops, the system is to be returned to within normal continuous voltage limits and the system is to be returned to within emergency voltage limits for the simulated loss of the next most severe contingency consistent with the timelines in the charts below.

Table 14: Acceptable Actions and Timeline for Actual System Voltage Violations

Voltage Limit Violated	Acceptable Control Action	Time to Correct
Emergency High	All effective non-cost and off-cost actions	Within 5 minutes
Normal High	All effective non-cost and off-cost actions	Within 15 minutes
Normal Low	All effective non-cost and off-cost actions EXCEPT load shedding	Within 15 minutes, load shedding not used
Emergency Low	All effective actions INCLUDING load shedding if voltages are decaying	Within 5 minutes
Load Dump Low	All effective actions INCLUDING load shedding if voltage collapse possible	Immediately

2.7.1.2 Simulated Post-Contingency Violations

As part of the Real-Time Reliability Assessment conducted by the System Operator, real-time contingency analysis and/or offline contingency analysis studies must be run.

If contingency analysis results for any single n-1 contingency indicate voltage violations, control action must be taken within the established timeframe to mitigate any potential violations on a pre-contingency basis.

In addition, the post-contingency voltage, resulting from the simulated occurrence of a single n-1 contingency outage, should not be lower than the Emergency Low voltage limit or higher than the Emergency High voltage limit. Furthermore, calculated post-Contingency flow on a Facility should not be above the highest Emergency Rating.

Control actions should be taken on a pre-contingency basis in order to maintain system reliability after any malfunction or failure occurs. Acceptable pre-contingency actions include switching of capacitors or reactors, adjustment of AVR setpoints, generation redispatch, and transaction curtailment. These actions can be used pre-contingency to control post-contingency operation so as not to exceed emergency ratings on a simulated basis.

Table 15: Acceptable Actions and Timeline for Simulated Post-Contingency Voltage Violations

Voltage Limit Violated	Acceptable Control Action	Time to Correct
Emergency High	All effective non-cost actions	Within 30 minutes
Normal High	All effective non-cost actions	N/A
Normal Low	All effective non-cost actions	N/A
Emergency Low	All effective non-cost and off-cost actions EXCEPT load shedding	Within 15 minutes
Load Dump Low	All effective actions INCLUDING load shedding if voltage collapse possible	Within 15 minutes
Post-Contingency IROL Transfer Limit	All effective actions INCLUDING load shedding if voltage collapse possible	Within 15 minutes

2.7.2 Transformer Limits

If a transformer rating is exceeded, System Operators should immediately act to reduce the loading on the transformer up to and including shedding load. Transformer ratings are summarized in Table 16 below.

Table 16: Normal and Emergency Transformer Ratings

From Name	From Number	To Name	To Number	Normal MVA Limit	Emergency MVA Limit	Nominal Voltage
EASTLI~1	38	EASTLI~2	37	500	550	345
HAZARD~1	86	PINEVL~1	87	50	60	138
KAMMER~1	64	W.KAMM~1	61	500	550	345
KANAWH~1	81	CABINC~1	80	800	900	345
MUSKNG~1	65	MUSKNG~2	66	800	900	345
OLIVE ~1	8	OLIVE ~2	5	800	900	345
SORENS~1	30	SORENS~2	17	500	550	345
SPORN ~1	68	KYGERC~1	116	200	250	345
SPORN ~1	68	SPORN ~2	69	800	900	345
TANNRS~1	26	TANNRS~2	25	500	550	345
TIDD ~1	63	TIDD ~2	59	500	550	345

2.7.3 Transmission Line Limits

System operating limits for the IEEE 118 Bus Model are defined using two types of ratings:

- **Normal (Continuous) Rating:** Equipment can operate at this level for any length of time without incurring damage

- **Emergency Rating:** Following a contingency, the 30-minute short term emergency limit for transmission lines is 120% of the continuous rating.

2.7.3.1 Actual System Violations

For loading above the short-term emergency limit, System Operators should immediately act to reduce the violation up to and including shedding load within 5 minutes.

2.7.3.2 Simulated Post-Contingency Violations

As part of the Real-Time Reliability Assessment conducted by the System Operator, real-time contingency analysis and/or offline contingency analysis studies must be run. Contingency Analysis is a type of power flow study with contingent component removed from the network (n-1). The Contingency Analysis output includes limit violations (SOLs, IROLs) and alarms that are sent to the operator.

If contingency analysis results for any single n-1 contingency indicate line flow violations, control action must be taken within the established timeframe to mitigate any potential violations on a pre-contingency basis.

The post-contingency line flow, resulting from the simulated occurrence of a single n-1 contingency outage, should not exceed Emergency Thermal Limit of any line.

Control actions should be taken on a pre-contingency basis in order to maintain system reliability after any malfunction or failure occurs. Acceptable pre-contingency actions include line switching, adjustment of AVR setpoints, generation redispatch, and transaction curtailment. These actions should be used pre-contingency to control post-contingency operation so as not to exceed emergency ratings on a simulated basis.

Table 17: Normal and Emergency Transmission Line Ratings

From Name	From Number	To Name	To Number	Normal MVA Limit	Emergency MVA Limit	Nominal Voltage
BEQUIN~1	9	BREED ~1	10	1200	1500	345
EASTLI~1	38	MUSKNG~1	65	1200	1500	345
MUSKNG~1	65	SPORN ~1	68	1200	1500	345
OLIVE ~1	8	SORENS~1	30	1200	1500	345
OLIVE ~1	8	BEQUIN~1	9	1200	1500	345
SORENS~1	30	EASTLI~1	38	1200	1500	345
SPORN ~1	68	KANAWH~1	81	1200	1500	345
TANNRS~1	26	SORENS~1	30	1200	1500	345
TIDD ~1	63	KAMMER~1	64	1200	1500	345
ADAMS ~1	20	JAY ~1	21	150	180	138
BAILEY~1	96	SUNDIA~1	97	215	230	138
BEAVER~1	85	CLINCH~1	89	75	90	138
BEAVER~1	85	FREMON~1	88	75	90	138
BEAVER~1	85	HAZARD~1	86	75	90	138
BELLEF~1	74	STHPOI~1	75	150	180	138
BETSYL~1	84	BEAVER~1	85	75	90	138
BLAINE~1	108	FRANKL~1	109	150	180	138
BRADLE~1	98	GLEN L~1	100	150	180	138
CABINC~1	80	BAILEY~1	96	215	230	138
CABINC~1	80	HINTON~1	99	150	180	138
CABINC~1	80	BRADLE~1	98	150	180	138
CABINC~1	80	SUNDIA~1	97	215	230	138
CALDWE~1	95	BAILEY~1	96	150	180	138
CAPITL~1	79	CABINC~1	80	150	180	138
CHEMIC~1	78	CAPITL~1	79	75	90	138
CLAYTO~1	103	ROANOK~1	105	75	90	138
CLAYTO~1	103	HANCOC~1	104	150	180	138
CLAYTO~1	103	FIELDA~1	110	215	230	138
CLINCH~1	89	SALTVL~1	92	75	90	138
CLINCH~1	89	HOLSTO~1	90	150	180	138
CLINCH~1	89	SALTVL~1	92	215	230	138
CLINCH~1	89	HOLSTO~1	90	150	180	138
CLOVER~1	106	REUSEN~1	107	150	180	138

From Name	From Number	To Name	To Number	Normal MVA Limit	Emergency MVA Limit	Nominal Voltage
COLLCR~1	23	TRENTO~1	24	150	180	138
COLLCR~1	23	TANNRS~2	25	150	180	138
CONCOR~1	13	FTWAYN~1	15	150	180	138
CROOKS~1	47	SPORN ~2	69	150	180	138
CROOKS~1	47	PHILO ~1	49	150	180	138
DARRAH~1	76	WHUNTN~1	118	75	90	138
DARRAH~1	76	TURNER~1	77	150	180	138
DEERCR~1	31	DELAWA~1	32	150	180	138
DELAWA~1	32	WMEDFO~1	114	75	90	138
DELAWA~1	32	DEER C~1	113	150	180	138
EASTLI~2	37	WEST E~1	40	75	90	138
EASTLI~2	37	NWLIBR~1	39	150	180	138
FIELDA~1	110	DANVIL~1	112	150	180	138
FIELDA~1	110	DANRIV~1	111	215	230	138
FRANKL~1	109	FIELDA~1	110	75	90	138
FREMON~1	88	CLINCH~1	89	150	180	138
FTWAYN~1	15	SORENS~2	17	215	230	138
FTWAYN~1	15	HAVILA~1	33	150	180	138
FTWAYN~1	15	LINCOL~1	19	150	180	138
GLEN L~1	100	CLAYTO~1	103	215	230	138
GLEN L~1	100	HANCOC~1	104	150	180	138
GLEN L~1	100	CLOVER~1	106	150	180	138
GLEN L~1	100	WYTHE ~1	101	150	180	138
GOSHEN~1	14	FTWAYN~1	15	75	90	138
GRANT ~1	29	DEERCR~1	31	75	90	138
HANCOC~1	104	ROANOK~1	105	150	180	138
HAVILA~1	33	EASTLI~2	37	150	180	138
HICKRY~1	3	TWINBR~1	12	75	90	138
HICKRY~1	3	OLIVE ~2	5	150	180	138
HINTON~1	99	GLEN L~1	100	150	180	138
HOLSTO~1	90	HOLSTO~2	91	150	180	138
HOLSTO~2	91	SALTVL~1	92	150	180	138
HOWARD~1	42	PHILO ~1	49	150	180	138
HOWARD~1	42	PHILO ~1	49	150	180	138
JACKSN~1	7	TWINBR~1	12	150	180	138

From Name	From Number	To Name	To Number	Normal MVA Limit	Emergency MVA Limit	Nominal Voltage
JAY ~1	21	RANDOL~1	22	150	180	138
KANKAK~1	6	JACKSN~1	7	150	180	138
LINCOL~1	19	ROCKHI~1	34	150	180	138
LINCOL~1	19	ADAMS ~1	20	75	90	138
LOGAN ~1	82	BAILEY~1	96	215	230	138
LOGAN ~1	82	SPRIGG~1	83	215	230	138
MADISO~1	27	DELAWA~1	32	150	180	138
MADISO~1	27	MEDFOR~1	115	75	90	138
MADISO~1	27	MULLIN~1	28	150	180	138
MCKINL~1	18	LINCOL~1	19	150	180	138
MULLIN~1	28	GRANT ~1	29	75	90	138
MUSKNG~2	66	SUMMER~1	67	150	180	138
N. E. ~1	16	SORENS~2	17	75	90	138
N.NEWA~1	45	PHILO ~1	49	150	180	138
N.NEWA~1	45	W.LANC~1	46	75	90	138
NATRIU~1	62	SUMMER~1	67	75	90	138
NATRIU~1	62	MUSKNG~2	66	150	180	138
NEWCMR~1	51	WNWPHI~2	58	75	90	138
NEWCMR~1	51	SCOSHO~1	52	75	90	138
NPORTS~1	71	SARGEN~1	73	75	90	138
NPORTS~1	71	HILLSB~1	72	75	90	138
NWCARL~1	4	SOUTHB~1	11	150	180	138
NWCARL~1	4	OLIVE ~2	5	150	180	138
NWLIBR~1	39	WEST E~1	40	75	90	138
OLIVE ~2	5	SOUTHB~1	11	150	180	138
OLIVE ~2	5	KANKAK~1	6	150	180	138
PHILO ~1	49	WCAMBR~1	50	150	180	138
PHILO ~1	49	SPORN ~2	69	150	180	138
PHILO ~1	49	MUSKNG~2	66	215	230	138
PHILO ~1	49	NEWCMR~1	51	150	180	138
PHILO ~1	49	MUSKNG~2	66	215	230	138
PHILO ~1	49	TORREY~1	54	75	90	138
PHILO ~1	49	TORREY~1	54	75	90	138
POKAGO~1	2	TWINBR~1	12	150	180	138
PORTSM~1	70	STHPOI~1	75	75	90	138

From Name	From Number	To Name	To Number	Normal MVA Limit	Emergency MVA Limit	Nominal Voltage
PORTSM~1	70	BELLEF~1	74	75	90	138
PORTSM~1	70	NPORTS~1	71	150	180	138
RANDOL~1	22	COLLCR~1	23	150	180	138
RIVERS~1	1	POKAGO~1	2	75	90	138
RIVERS~1	1	HICKRY~1	3	75	90	138
ROANOK~1	105	REUSEN~1	107	150	180	138
ROANOK~1	105	BLAINE~1	108	150	180	138
ROANOK~1	105	CLOVER~1	106	150	180	138
ROCKHI~1	34	S.KENT~1	43	75	90	138
ROCKHI~1	34	EASTLI~2	37	150	180	138
ROCKHI~1	34	STERLI~1	36	150	180	138
S.KENT~1	43	WMVERN~1	44	75	90	138
S.TIFF~1	41	HOWARD~1	42	75	90	138
SALTVL~1	92	SMYTHE~1	102	75	90	138
SALTVL~1	92	GLEN L~1	100	150	180	138
SALTVL~1	92	SWITCH~1	94	150	180	138
SALTVL~1	92	TAZEWE~1	93	150	180	138
SCOSHO~1	52	WOOSTE~1	53	75	90	138
SORENS~2	17	DEER C~1	113	150	180	138
SORENS~2	17	DEERCR~1	31	150	180	138
SORENS~2	17	MCKINL~1	18	150	180	138
SOUTHB~1	11	CONCOR~1	13	150	180	138
SOUTHB~1	11	TWINBR~1	12	150	180	138
SPORN ~2	69	TURNER~1	77	150	180	138
SPORN ~2	69	STHPOI~1	75	215	230	138
SPORN ~2	69	PORTSM~1	70	215	230	138
SPRIGG~1	83	BEAVER~1	85	150	180	138
SPRIGG~1	83	BETSYL~1	84	75	90	138
STHPOI~1	75	WHUNTN~1	118	150	180	138
STHPOI~1	75	TURNER~1	77	75	90	138
SUNNYS~1	56	TIDD ~2	59	75	90	138
SUNNYS~1	56	TIDD ~2	59	75	90	138
SUNNYS~1	56	WNWPHI~2	58	75	90	138
SUNNYS~1	56	WNWPHI~1	57	75	90	138
SWITCH~1	94	GLEN L~1	100	150	180	138

From Name	From Number	To Name	To Number	Normal MVA Limit	Emergency MVA Limit	Nominal Voltage
SWITCH~1	94	BAILEY~1	96	150	180	138
SWITCH~1	94	CALDWE~1	95	150	180	138
SWKAMM~1	60	NATRIU~1	62	150	180	138
SWKAMM~1	60	W.KAMM~1	61	150	180	138
TANNRS~2	25	MADISO~1	27	215	230	138
TAZEWE~1	93	SWITCH~1	94	150	180	138
TIDD ~2	59	W.KAMM~1	61	150	180	138
TIDD ~2	59	SWKAMM~1	60	150	180	138
TORREY~1	54	TIDD ~2	59	75	90	138
TORREY~1	54	SUNNYS~1	56	150	180	138
TORREY~1	54	WAGENH~1	55	75	90	138
TRENTO~1	24	HILLSB~1	72	75	90	138
TRENTO~1	24	PORTSM~1	70	75	90	138
TURNER~1	77	LOGAN ~1	82	215	230	138
TURNER~1	77	CABINC~1	80	150	180	138
TURNER~1	77	CABINC~1	80	75	90	138
TURNER~1	77	CHEMIC~1	78	150	180	138
TWINBR~1	12	COREY ~1	117	75	90	138
TWINBR~1	12	N. E. ~1	16	75	90	138
TWINBR~1	12	GOSHEN~1	14	75	90	138
W.KAMM~1	61	NATRIU~1	62	150	180	138
W.LANC~1	46	ZANESV~1	48	75	90	138
W.LANC~1	46	CROOKS~1	47	150	180	138
WAGENH~1	55	TIDD ~2	59	75	90	138
WAGENH~1	55	SUNNYS~1	56	75	90	138
WCAMBR~1	50	WNWPHI~1	57	75	90	138
WEST E~1	40	HOWARD~1	42	75	90	138
WEST E~1	40	S.TIFF~1	41	75	90	138
WESTLI~1	35	EASTLI~2	37	150	180	138
WESTLI~1	35	STERLI~1	36	150	180	138
WMEDFO~1	114	MEDFOR~1	115	75	90	138
WMVERN~1	44	N.NEWA~1	45	150	180	138
WOOSTE~1	53	TORREY~1	54	75	90	138
WYTHE ~1	101	SMYTHE~1	102	75	90	138
ZANESV~1	48	PHILO ~1	49	150	180	138

2.8 Reserve Sharing Agreement

The 118 Bus System Balancing Authorities formed a Reserve Sharing Group. This allows each area to maintain their minimum operating reserves at a lower value than if they functioned independently. The Most Severe Single Contingency for generation for each BA is listed below:

- WOA: BREED – 550 MW
- NOA: MUSKNG 1 or 2 – 490 MW
- SOA: SPORN – 800 MW

Each BA contributes operating reserves to cover the MSSC of the group in proportion to their own generation MSSC as shown below. This amount may need to be adjusted based on available transmission capacity on tie-line interfaces, which is 1200 MW with all lines in service:

Table 18: Contributions of Each Balancing Area to Operating Reserves

Balancing Authority	Member MSSC	Percent	Contributing Amount
West	550 MW	30%	240 MW
North	490 MW	30%	240 MW
South	800 MW	40%	320 MW
TOTAL	1840 MW	100%	800 MW

The 118 Bus System Reserve Sharing Group operates according to the following agreement:

- The minimum reserve requirement for the group will be 800 MW to cover the loss of the largest generating unit; which may be BREED, MUSKNG, or SPORN at full output.
- BAL-002-2: Any loss of generation exceeding 200 MW (25% of the largest contingency) will be used to trigger a reportable balancing contingency and a reserve sharing event.

The allocation of the loss of the 800 MW generating unit will be covered in proportion to the largest unit in each operating area.

Contingency Reserve will be implemented as an Interchange Schedule. The Area with the unit loss will send a notification of the event and the amount of the loss to the other members of the group. The other members will immediately adjust their interchange schedules for their obligation with a 1-minute interchange ramp.

2.9 Black Start Restoration Procedure

2.9.1 SPORN House-Load Plan Summary

The goal of the 118 Bus Black Start Restoration Procedure is to bring all large units to minimum load and energize all 345kV lines in the network. After system blackout, the SPORN coal unit can run back to house load using load at KYGERC bus. It can also be cranked using the KYGERC black-start gas turbine. Visual summaries of each phase of the restoration plan are included in Appendix A.

- Build path to CABINC and energize SPORN-KANAWH 345kV line
- Build path to PHILO (restart unit) and MUSKNG, energize SPORN-MUSKNG 345kV line
- Build path to KAMMER (restart unit), energize MUSKNG-KAMMER 345kV line
- Build path to TIDD, energize KAMMER-TIDD 345kV line
- Energize MUSKNG-EASTLI 345kV line, build path to HOWARD, stabilize voltages
- Build path to SORENS, energize EASTLI-SORENS 345kV line
- Stabilize voltage, energize SORENS-OLIVE 345kV line
- Stabilize voltage, energize SORENS-TANNER 345kV line

2.9.2 SPORN House-Load Plan Procedure

The SPORN-2 generating unit is able to run back to the unit minimum and form a stable island serving the load at KYGERC (bus 116). After a regional blackout, this unit should stay online and can be used as a black start resource. If the unit does trip offline, use the gas turbine at KYGERC to crank SPORN within the 30 min hot start period of the unit.

At no point during the restoration should the voltage of buses with 345kV transformers exceed 1.10 pu or permanent equipment damage may be incurred.

1) Ensure that SPORN unit is in isochronous mode (equivalent to slack bus in quasi-static snapshot power flow solvers) and all taps are set to neutral.

2) Energize the SPORN2 – TURNER 138kV line (path 69 – 77). Pick up 20 MW of load at TURNER (bus 77).

3) Energize both TURNER – CABINC 138kV lines (path 77 – 80). Pick up 40 MW of load at CABINC (bus 80) and start unit auxiliaries to bring the CABINC unit online

4) Energize the SPORN1 – KANAWH 345kV line (path 68 – 81) and energize the KANAWH-CABINC 345/138kV transformer.

5) Energize the SPORN – PHILO 138kV line (path 49 – 69). Pick up 20 MW of load at PHILO (bus 49). Start the unit at PHILO and ramp up to its minimum output.

6) Energize both PHILO – MUSKNG2 138kV lines (path 49 – 66) and energize unit auxiliaries for MUSKNG2 generator.

7) Energize the SPORN1 – MUSKNG1 345kV line (path 65 – 68) and energize the MUSKNG1 – MUSKNG2 345/138kV transformer. Ensure that voltages do not exceed 1.10 pu.

8) Energize the MUSKNG2 – NATRIU 138kV line (path 62 – 66) and pick up 30 MW of load at NATRIU (bus 66).

9) Energize the NATRIU – W. KAMM 138kV line (path 61 – 62) and start the unit at W. KAMM at its unit minimum.

10) Energize the MUSKNG1 - KAMMER 345kV line (path 64 – 65) and energize the KAMMER – W. KAMM 345/138kV transformer

11) Energize the W. KAMM – TIDD2 138kV line (path 59 – 61) and pick up 30 MW of load at TIDD2 (bus 59). Picking up more load at TIDD2 is not recommended due to possible voltage collapse over the extremely long 138kV line

12) Start the TIDD2 unit at its unit minimum and pick another 70 MW of load at TIDD2 is 20 MW blocks.

13) Energize the KAMMER – TIDD1 345kV line and TIDD1 – TIDD2 345/138kV transformer.

14) Ensure the voltage at MUSKNG1 345kV bus (bus 65) is 1.02 pu or lower. If so, energize the EASTLI1 – MUSKNG1 345kV line (path 38 – 65). Energize the EASTLI1 – EASTLI2 345/138kV transformer. Switch in the 35 MVAr bus reactor on the EASTLI2 138kV bus.

15) Energize the EASTLI2 – WEST E 138kV line (path 37 – 40) and pick up 20 MW of load at WEST E (bus 40). Start the unit at WEST E at its unit minimum.

16) Energize the WEST E – HOWARD 138kV line (path 40 – 42) and pick 20 MW of load at HOWARD (bus 42). Start the generator at HOWARD at its unit minimum. Energize both HOWARD – PHILO 138kV lines (path 42 – 49).

17) Energize the EASTLI2 – HAVILA 138kV line (path 37 – 33) and pick up 10 MW of load at HAVILA (bus 33).

18) Energize the HAVILA – FT WAYNE 138kV line (path 15 – 33) and pick of 20 MW of load at FT WAYNE (bus 15).

19) Ensure the voltage at EASTLI1 is less than 1.03 pu or lower. If so, energize the SORENS – EASTLI1 345kV line (path 30 – 38). Energize the SORENS1 – SORENS2 345/138kV transformer.

20) Energize the SORENS2 – FT WAYNE 138kV line (path 15 – 17) and pick up and additional 20 MW of load at FT WAYNE.

21) Energize the SORENS2 – DEERCR 138kV line (path 17 – 31) and SORENS2 – DEERC 138kV line (path 17 – 113). Start the generators at DEERCR (bus 31) and DEERC (bus 113) at their unit minimums.

22) Ensure the voltage at SORENS1 345kV (bus 30) is 1.02 pu or lower. If so, energize the OLIVE1 – SORENS1 345kV line (path 8 – 30). Energize the OLIVE1 – OLIVE2 345/138kV transformer. Switch in the 40 MVAr bus reactor at OLIVE2 (bus 5).

23) Energize the OLIVE2 – NW CARL 138kV line (path 4 – 5) and start the generator at NW CARL (bus 5) at its unit minimum

24) Energize the NW CARL – SOUTHB (path 4 – 11) and pick up 30 MW of load at SOUTHB (bus 11)

25) Ensure that the bus voltage at SORENS1 345kV (bus 30) is 1.02 pu or lower. If so, energize the SORENS1 – TANNERS1 345kV line (path 26 – 30). Energize the unit auxiliaries for TANNERS units.

26) As the generator units at CABINC, MUSKNG, and TANNERS reach their unit start times, bring each generator online and up to minimum load by picking up load at TORREY (bus 54), SUNNYS (bus 56), SWKAMM (bus 60), CHEMIC (bus 30), and DARRAH (bus 76).

The BREED unit (bus 10) cannot be energized until the rest of WOA is fully energized due to the extremely high charging MVAr of the BEQUIN – BREED 345kV line and lack of any other shunt reactors for voltage control.

2.9.3 Black Start Sequence Illustrations

This section contains illustrations for each of the steps given for black starting the IEEE 118 Bus Model using the SPORN-2 Unit.

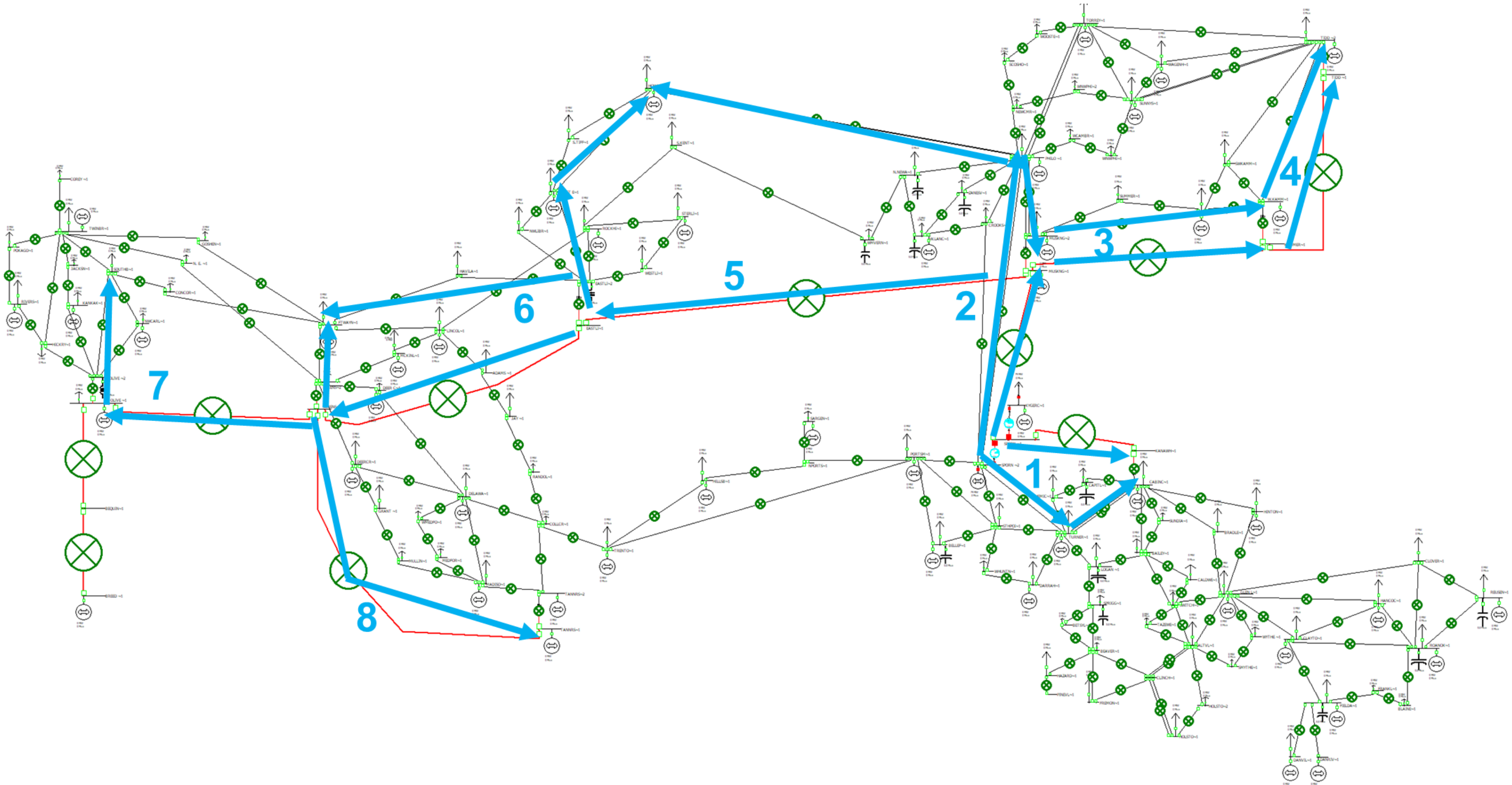

Figure 11: Summary of the 7 phases of the black start restoration strategy presented in Section 10.

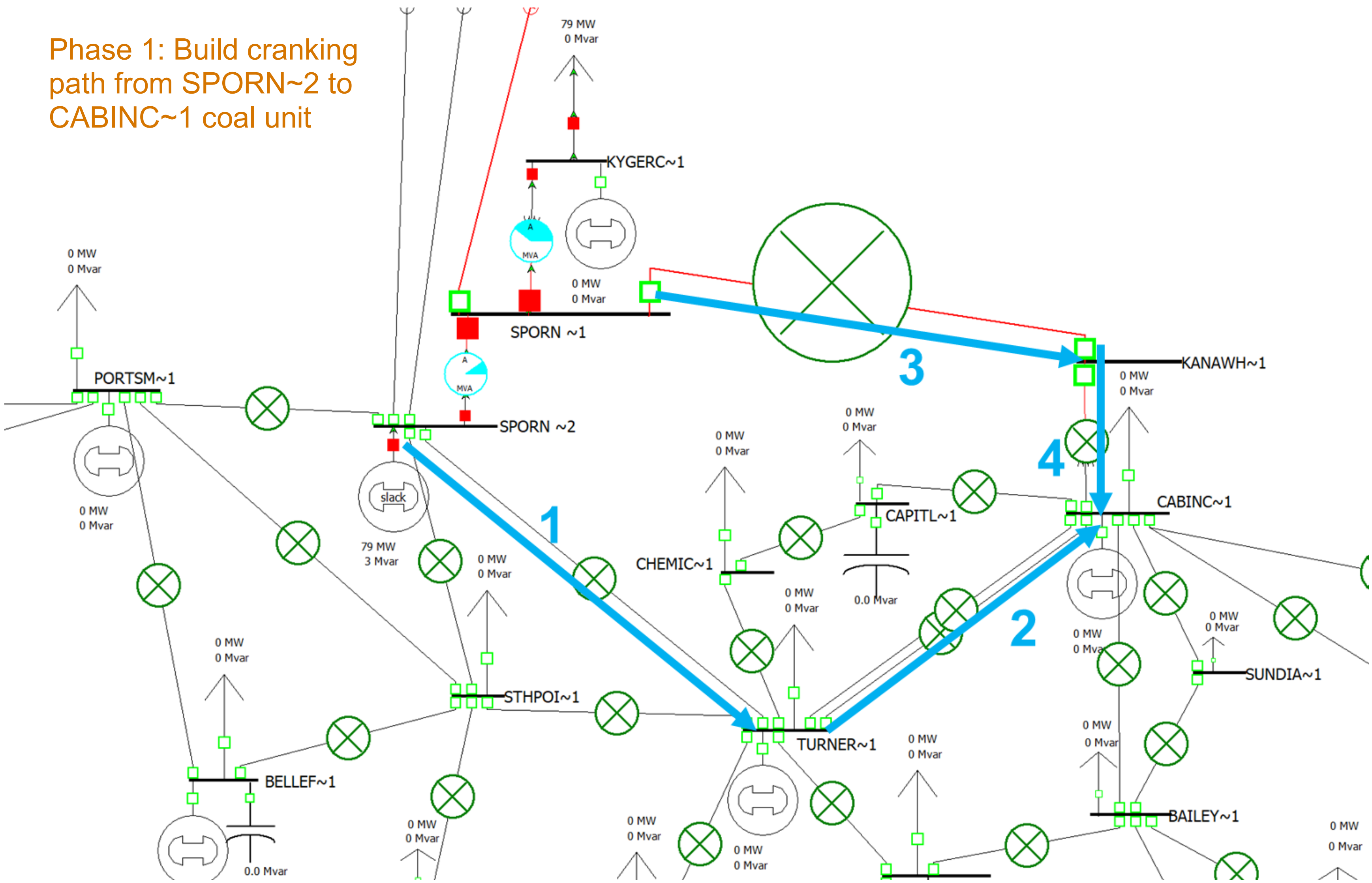

Figure 12: The first phase builds a cranking path from SPORN-2 to the CABINC-1 coal unit

Phase 2: Build cranking path from SPORN~2 to PHILO, energize 345kV line

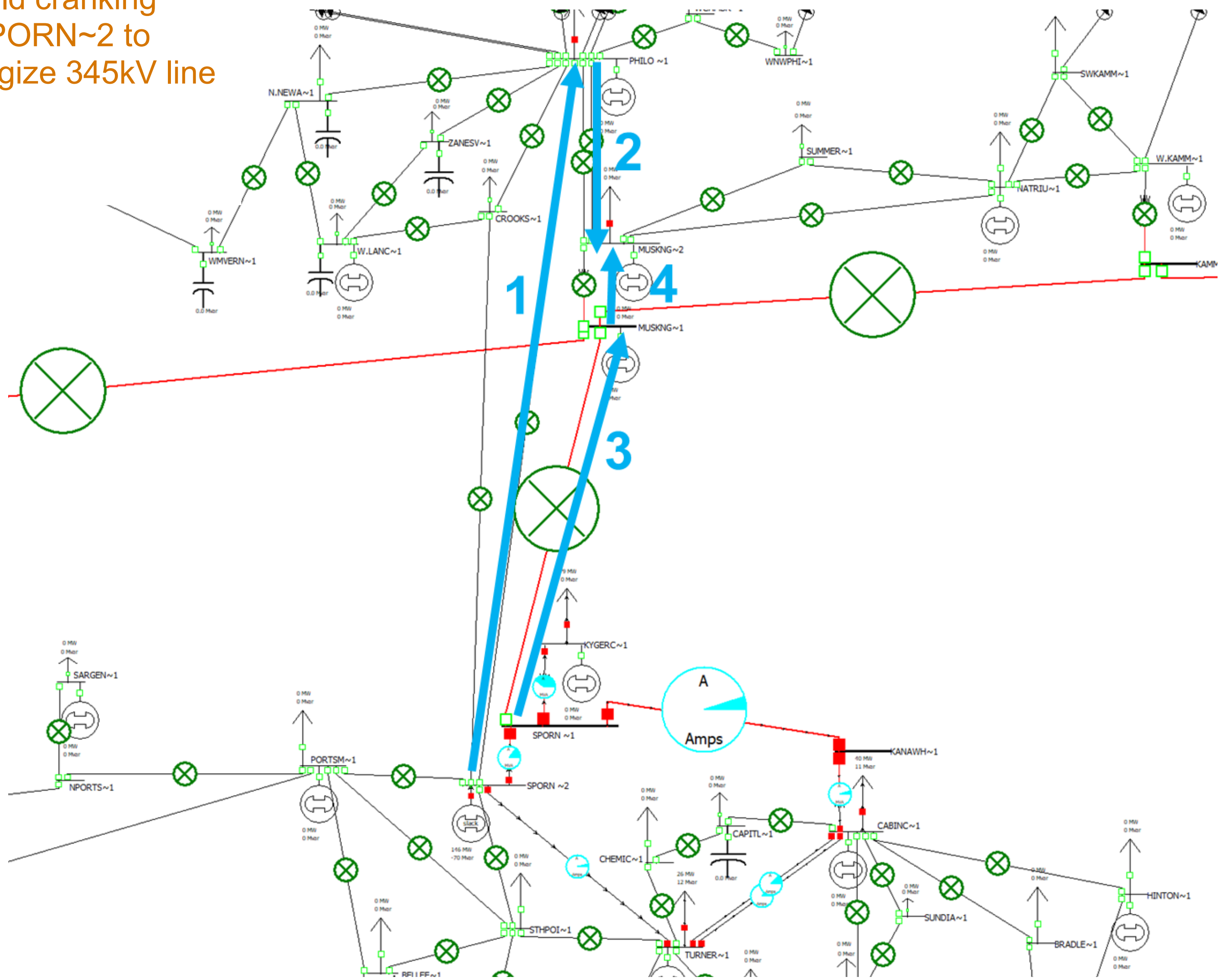

Figure 13: The second phase builds a cranking path from SPORN-2 to the PHILO combined cycle unit

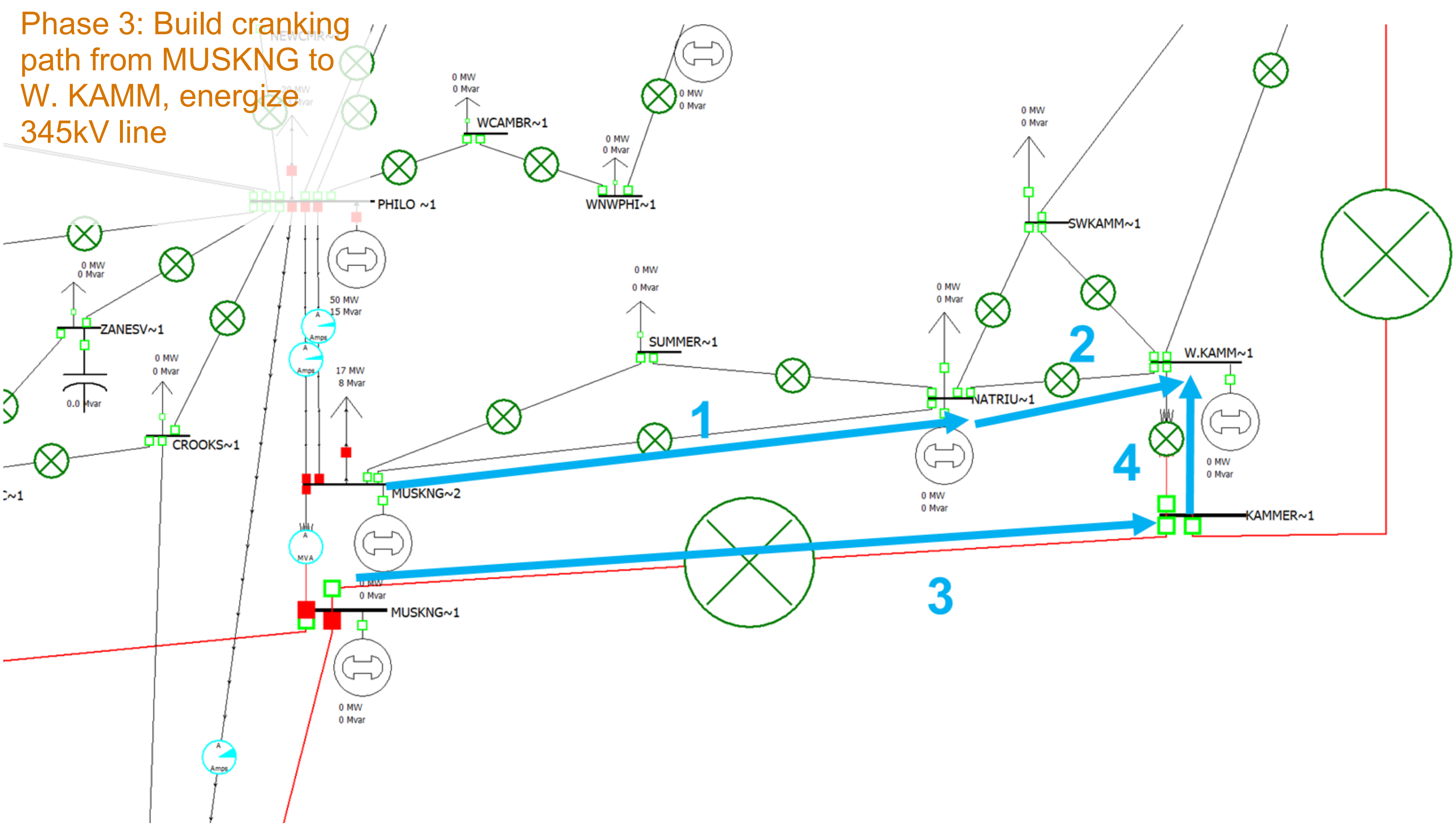

Figure 14: The second phase builds a path from MUSKNG to the W. KAMM combined cycle unit

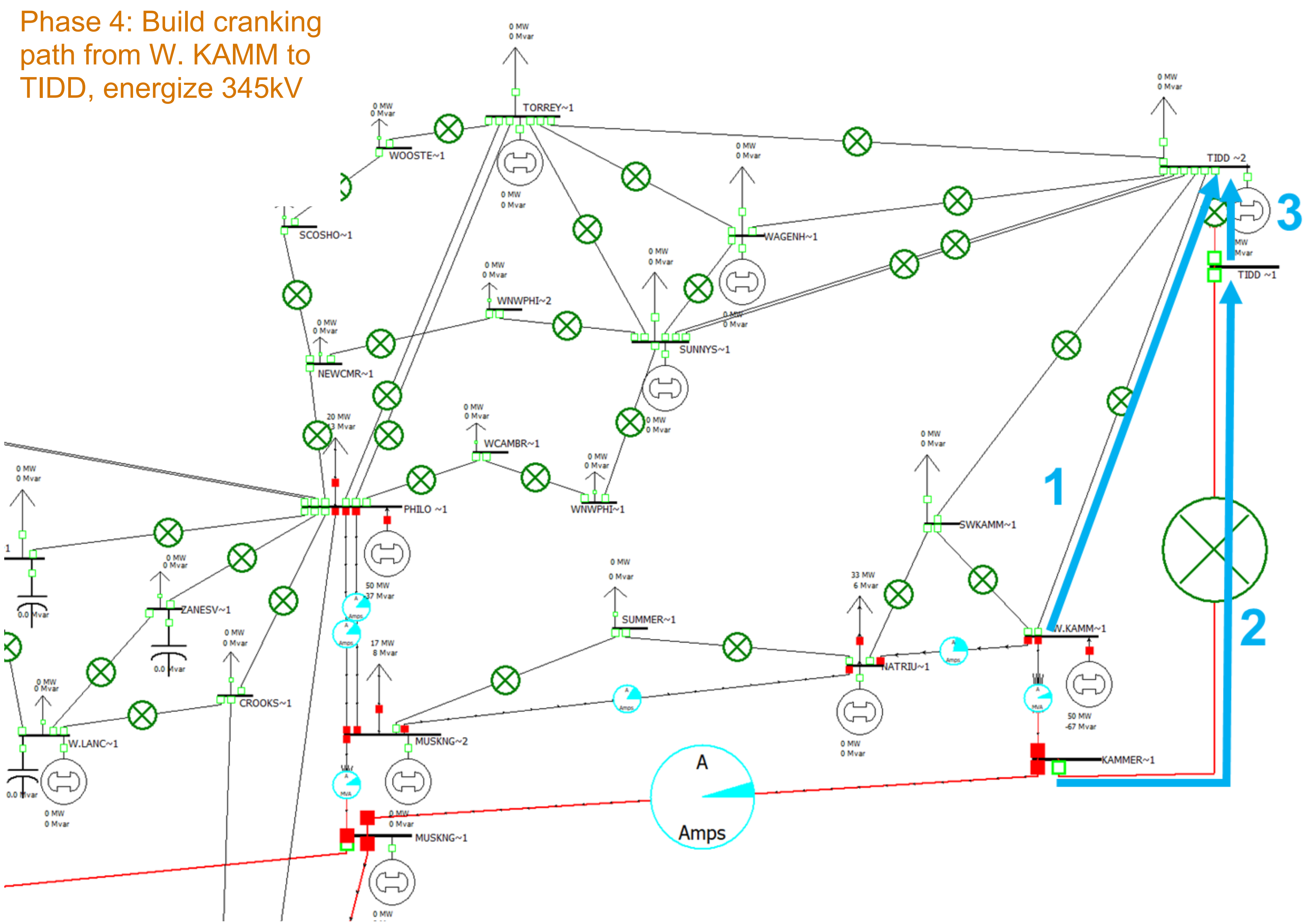

Figure 15: The fourth phase builds a path from W. KAMM to the load center at TIDD

Phase 5: Build cranking path from SPORN~2 to MUSKNG coal units

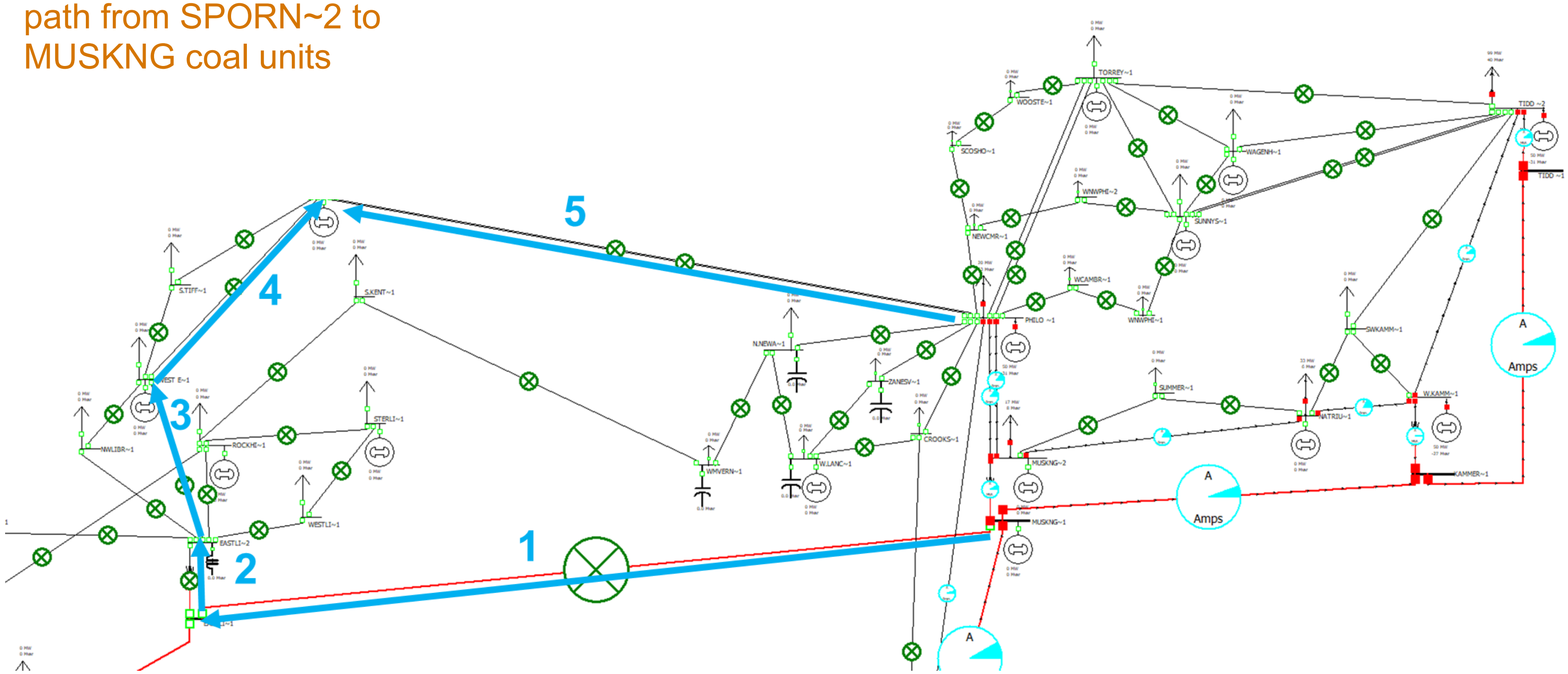

Figure 16: The fifth phase builds a loop from MUSKNG to HOWARD on the 138kV and 345kV network

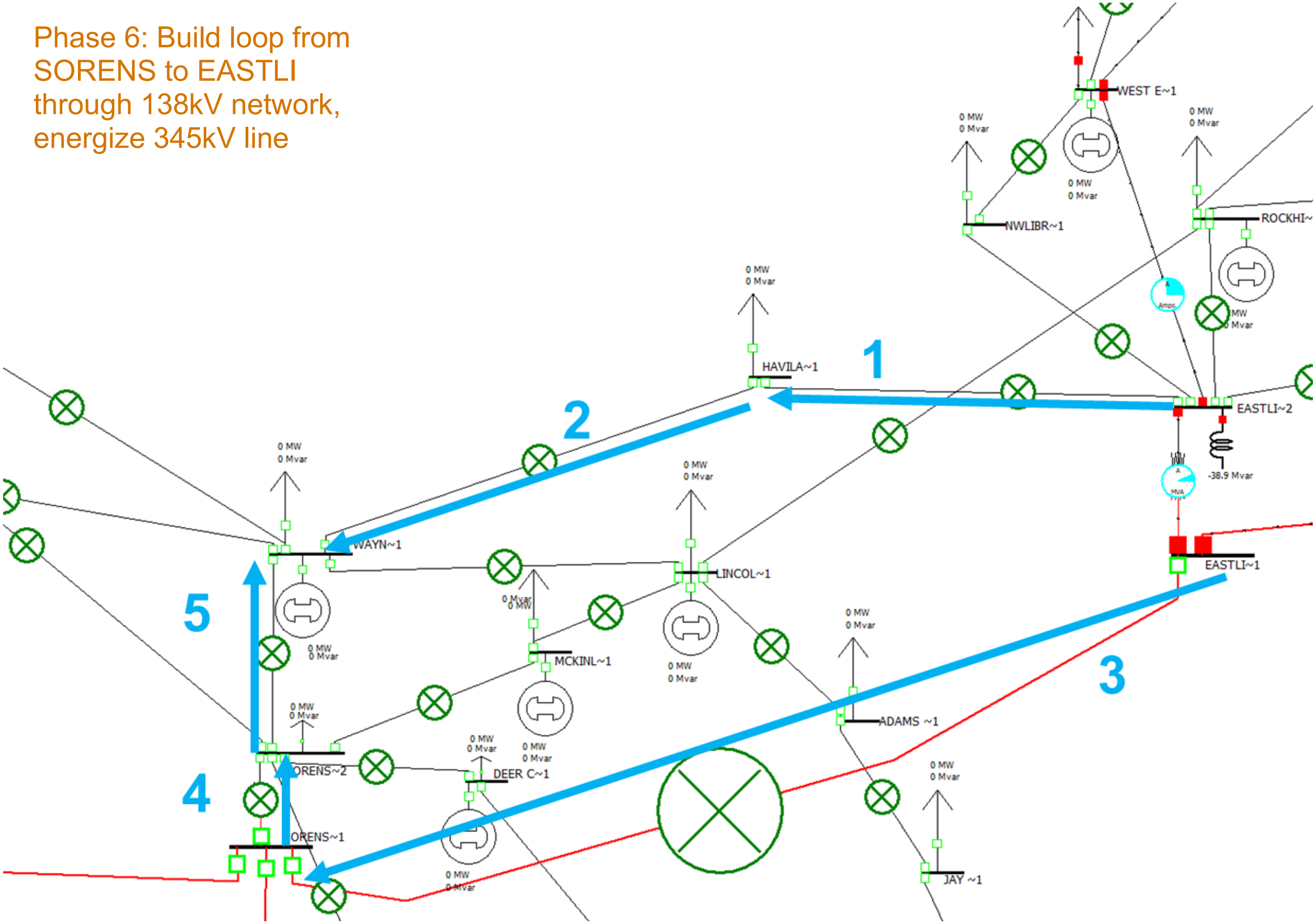

Figure 17: The sixth phase builds a loop from EASTLI to SORENS through the 138kV and 145kV networks

Phase 7: Prepare to energize OLIVE-SORENS 345kV line

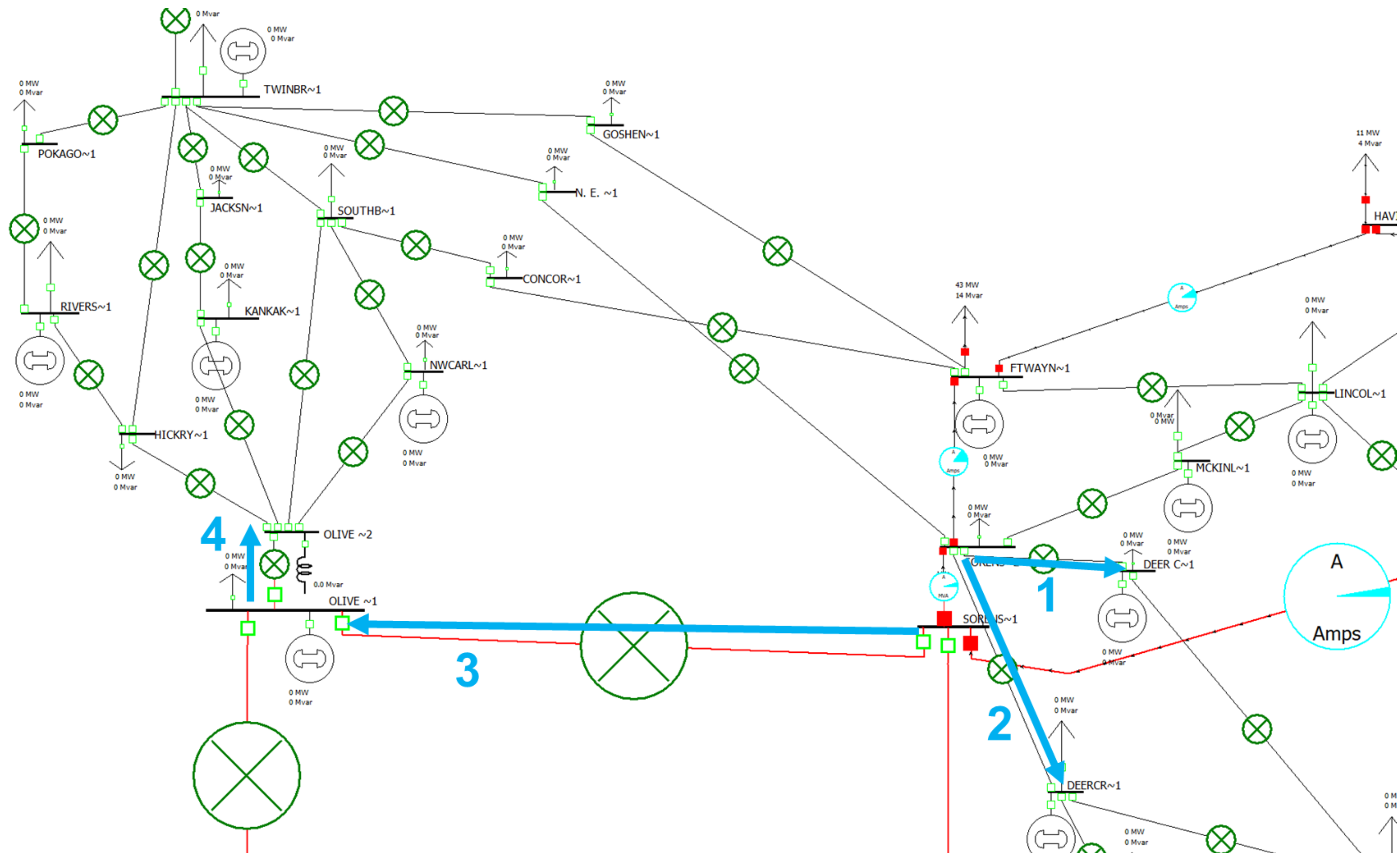

Figure 18: The seventh phase energizes the OLIVE substation through the 345kV network

Phase 8: Prepare to energize SORENS-TANNRS 345kV line

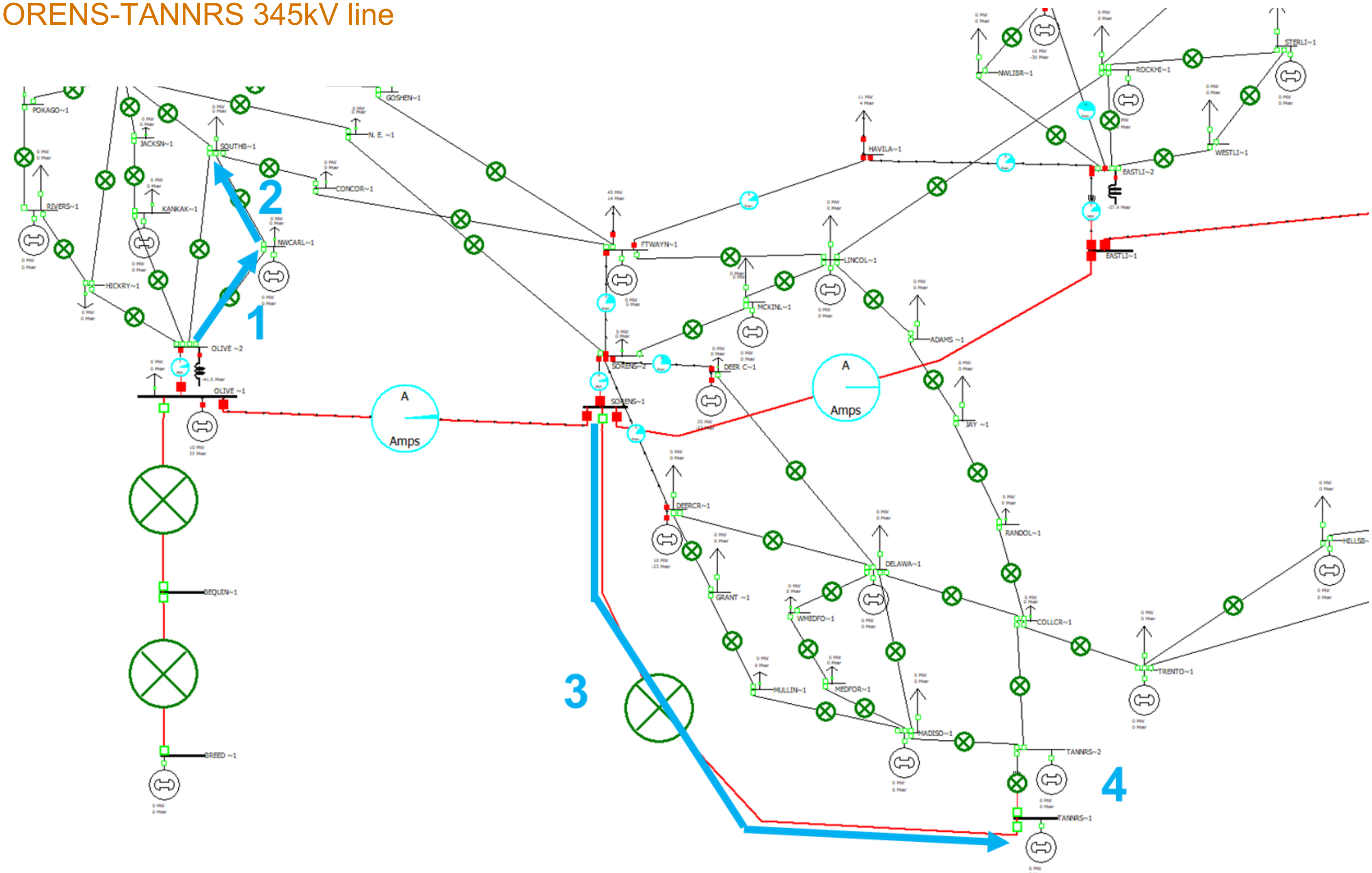

Figure 19: The last phase energizes the 345kV path from SORENS to TANNRS

Completed Black Start Procedure Result

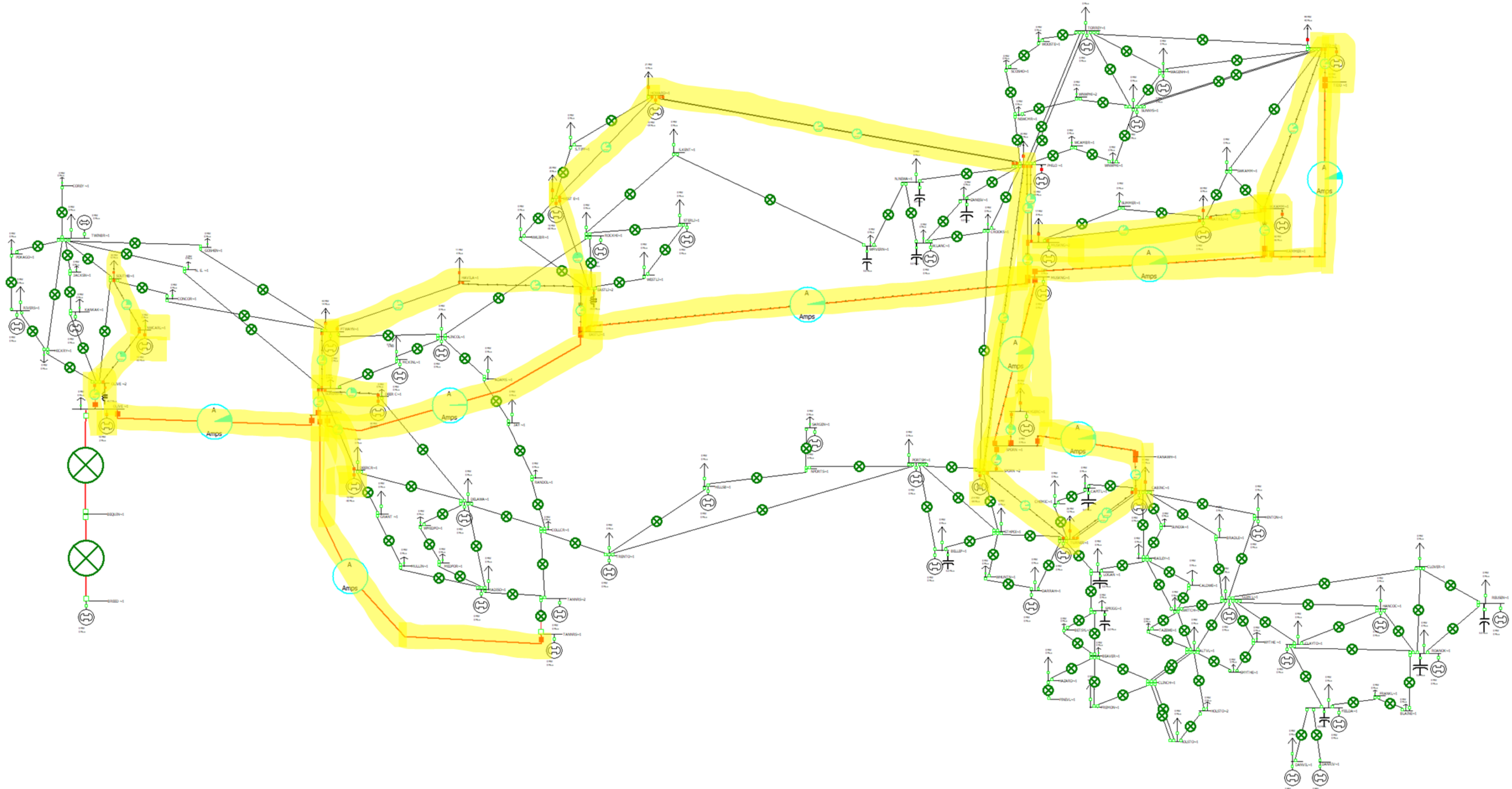

Figure 20: Completed black start procedure with energized lines and substation highlighted in yellow.

2.10 Real-Time Reliability Assessment Checklist

This checklist is to be used by operators of the IEEE 118 Bus Model for performing real-time reliability assessments during normal operating conditions and after occurrence of any contingency.

Event: ______________________________

- ☐ **Situational Awareness**
  - ☐ Frequency
    - ☐ Stable?
      - ☐ Steady State
      - ☐ Transient State
  - ☐ **Threats to system?**
    - ☐ Weather
    - ☐ Sabotage
    - ☐ Cyber
  - ☐ **N-1 Secure?**
    - ☐ **Contingency Analysis**
      - ☐ Next credible incident Most Severe Single Contingency (MSSC) ______________________________

        What are the results of the next MSSC?
        - ☐ **Outages?**
          - ☐ Generation
            - Units ______________________________
            - Fuels ______________________________
          - ☐ Transmission ______________________________
          - ☐ Distribution – affecting transmission system ______________________________
        - ☐ **Overloads?**
          - ☐ Lines ______________________________
          - ☐ Equipment ______________________________
        - ☐ **Voltage**
          - ☐ Flashover ______________________________
          - ☐ Collapse ______________________________

- ☐ **Visibility**
  - ☐ Station
    - ☐ Breaker Status
    - ☐ Analogs
      - ☐ RTUs
      - ☐ SCADA
  - ☐ Control Center EMS
    - ☐ Backup Control Center
  - ☐ Neighbors
- ☐ **Outages**
  - ☐ Forced
    - ☐ Generation ______________________
      - ☐ Limits ______________________
    - ☐ Transmission ______________________
    - ☐ Distribution ______________________
  - ☐ Scheduled ______________________
- ☐ **Capacity and energy adequacy conditions**
  - ☐ Contingency Reserves
    - ☐ Generation ordered on-line ______________________
    - ☐ Load with Hi-Set UFC relays (Loads acting as a resource) ______________________
    - ☐ Schedules ______________________
- ☐ **Reactive Reserves**
  - ☐ Dynamic ______________________
  - ☐ Static
    - ☐ Capacitors ______________________
    - ☐ Reactors ______________________
    - ☐ Other ______________________

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