IESO_REP_0658

REPORT

Power to Ontario.
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System Impact Assessment Report

Wolfe Island Shoals Wind Generation Station

CONNECTION ASSESSMENT & APPROVAL PROCESS

Final Report

CAA ID 2010-402

Applicant: Windstream Energy Inc.

Market Facilitation Department
Independent Electricity System Operator

November 8, 2010

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System Impact Assessment Report

Acknowledgement

The IESO wishes to acknowledge the assistance of Hydro One in completing this assessment.

<u>Disclaimers</u>

IESO

This report has been prepared solely for the purpose of assessing whether the connection applicant's proposed connection with the IESO-controlled grid would have an adverse impact on the reliability of the integrated power system and whether the IESO should issue a notice of approval or disapproval of the proposed connection under Chapter 4, section 6 of the Market Rules.

Conditional approval of the proposed connection is based on information provided to the IESO by the connection applicant and the transmitter(s) at the time the assessment was carried out. The IESO assumes no responsibility for the accuracy or completeness of such information, including the results of studies carried out by the transmitter(s) at the request of the IESO. Furthermore, the connection approval is subject to further consideration due to changes to this information, or to additional information that may become available after the approval has been granted.

If the connection applicant has engaged a consultant to perform connection assessment studies, the connection applicant acknowledges that the IESO will be relying on such studies in conducting its assessment and that the IESO assumes no responsibility for the accuracy or completeness of such studies including, without limitation, any changes to IESO base case models made by the consultant. The IESO reserves the right to repeat any or all connection studies performed by the consultant if necessary to meet IESO requirements.

Conditional approval of the proposed connection means that there are no significant reliability issues or concerns that would prevent connection of the proposed facility to the IESO-controlled grid. However, connection approval does not ensure that a project will meet all connection requirements. In addition, further issues or concerns may be identified by the transmitter(s) during the detailed design phase that may require changes to equipment characteristics and/or configuration to ensure compliance with physical or equipment limitations, or with the Transmission System Code, before connection can be made.

This report has not been prepared for any other purpose and should not be used or relied upon by any person for another purpose. This report has been prepared solely for use by the connection applicant and the IESO in accordance with Chapter 4, section 6 of the Market Rules. The IESO assumes no responsibility to any third party for any use, which it makes of this report. Any liability which the IESO may have to the connection applicant in respect of this report is governed by Chapter 1, section 13 of the Market Rules. In the event that the IESO provides a draft of this report to the connection applicant, you must be aware that the IESO may revise drafts of this report at any time in its sole discretion without notice to you. Although the IESO will use its best efforts to advise you of any such changes, it is the responsibility of the connection applicant to ensure that it is using the most recent version of this report.

HYDRO ONE

The results reported in this study are based on the information available to Hydro One, at the time of the study, suitable for a System Impact Assessment of a new generation or load connection proposal.

The short circuit and thermal loading levels have been computed based on the information available at the time of the study. These levels may be higher or lower if the connection information changes as a result of, but not limited to, subsequent design modifications or when more accurate test measurement data is available.

This study does not assess the short circuit or thermal loading impact of the proposed connection on facilities owned by other load and generation (including OPG) customers.

In this study, short circuit adequacy is assessed only for Hydro One breakers and does not include other Hydro One facilities. The short circuit results are only for the purpose of assessing the capabilities of existing Hydro One breakers and identifying upgrades required to incorporate the proposed connection. These results should not be used in the design and engineering of new facilities for the proposed connection. The necessary data will be provided by Hydro One and discussed with the connection proponent upon request.

The ampacity ratings of Hydro One facilities are established based on assumptions used in Hydro One for power system planning studies. The actual ampacity ratings during operations may be determined in real-time and are based on actual system conditions, including ambient temperature, wind speed and facility loading, and may be higher or lower than those stated in this study.

The additional facilities or upgrades which are required to incorporate the proposed connection have been identified to the extent permitted by a System Impact Assessment under the current IESO Connection Assessment and Approval process. Additional facility studies may be necessary to confirm constructability and the time required for construction. Further studies at more advanced stages of the project development may identify additional facilities that need to be provided or that require upgrading.

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Executive Summary

Description

Windstream Energy Inc. is developing a new 300 MW wind power generation farm, Wolfe Island Shoals (the Project) in Lake Ontario near Wolfe Island, Ontario. The project was awarded a contract under the government FIT program, and is expected to start commercial operation in 2014.

This assessment examined the impact of injecting 300 MW of wind power generation to the provincial grid Lennox 230 kV TS, on the reliability of the IESO-controlled grid.

Findings

The following conclusions are achieved based on this assessment:

(1) The proposed connection arrangement and equipment for the Project are acceptable to the IESO.

(2) The proposed project will not cause new violations of existing circuit breaker interrupting capabilities on the IESO-controlled grid.

(3) Protection adjustments to accommodate the Project have no adverse impact on the reliability of IESO-controlled grid.

(4) For now, it is not necessary for the Project to participate in any existing or new SPS.

(5) The reactive capability of the wind turbine generators along with the cable susceptances between the wind turbine generators and the IESO controlled grid results in a reactive power surplus at the connection point which has to be compensated with additional reactive power devices.

(6) The functions of the proposed wind farm control system meet the requirements in the Market Rules except that the inertia emulation control function is unavailable. The IESO reserves the right to ask the applicant to install this function in the future when the function is available for the proposed type of WTG.

(7) No thermal overloads were identified due to the connection of Wolfe Island Shoals on the IESO controlled grid. However, the wind farm 230 kV bus, circuit breakers and 240/34.5 kV transformer could potentially become overloaded at full output, after the loss of a companion transformer. This can be alleviated by operating the 34.5 kV section circuit breaker normally open, or transfer tripping the 34.5 kV section breaker following a fault, or reducing the output of the machines to within the rating of the remaining transformer, through the wind farm management system following a fault.

(8) For all contingency cases tested with the proposed Wolfe Island Shoals, all voltage declines are within the 10% pre and post-ULTC action limit. Thus, the voltage performance meets the voltage decline criteria.

(9) With the proposed project in service, none of the recognized contingencies causes any material adverse impact to the transient performance of the IESO-controlled grid.

(10) Based on the information provided by the applicant, the fault ride through capability of the wind turbines is adequate.

Recommendations

Since the Wind Farm Management System (WFMS) must coordinate the voltage control process, it is recommended that all Wind Turbine Generators (WTG)'s control the PCC voltage to a reference value, reactive power compensation devices are automatically controlled/switched to regulate the overall WTGs' reactive power generation to around zero output, while the WF main transformer ULTC is adjusted to regulate the collector bus voltage such that it is within normal range. Once the WFMS description document is provided to the IESO, we will assess if the voltage control philosophy is acceptable.

IESO's Requirements for Connection

Transmitter Requirements

The following requirements are applicable for Hydro One for the incorporation of Wolfe Island Shoals

(1) The transmitter changes the relay settings of Lennox terminal station to account for the effect of the wind farm. Modifications to protection relays after this SIA is finalized must be submitted to IESO as soon as possible or at least six (6) months before any modifications are to be implemented. If those modifications result in adverse impacts, the connection applicant and the transmitter must develop mitigation solutions.

Applicant Requirements

Specific Requirements: The following *specific* requirements are applicable to the applicant for the incorporation of Wolfe Island Shoals. Specific requirements pertain to the level of reactive compensation needed, operation restrictions, Special Protection System, upgrading of equipment and any project specific items not covered in the *general* requirements:

(1) The wind farm is required to have the capability to inject or withdraw reactive power continuously (i.e. dynamically) at a connection point up to 33% of its rated active power at all levels of active power output. Based on the equivalent parameters for the WF provided by the connection applicant, the IESO's simulations resulted in the following:

- Static compensation devices of -110 MVAr must be installed at the collector buses to compensate for surplus reactive power, generated by the collector and main 230 kV submarine feeder cables within the facility. The shunt reactors will need to be auto-switched via the Wind Farm Management Scheme. -50 MVArs of the -110 MVArs is required while the WTG's are operational and the remaining -60 MVArs is to be switched when the WTG's are outside their operating range and unable to absorb reactive power.
- The applicant must confirm that the thermal ratings of the equipment, will not restrict the reactive capability of the wind farm at full power output. This will require a review of the short term ratings of the equipment specified against the expected duration the plant will operate at full output.

The connection applicant has the obligation to ensure that that the WF has the capability to meet the MR requirement at the connection point and be able to confirm this capability during the commission tests.

(2) The applicant is required to provide a copy of the functionalities of the Wind Farm Management System (WFMS) to the IESO.

General Requirements: The proposed connection must comply with all the applicable requirements from the Transmission System Code (TSC), IESO Market Rules and standards and criteria. The most relevant requirements are summarized below and presented in more detail in Section 2 of this report.

(1) The new generator must satisfy the Generator Facility Requirements in Appendix 4.2 of the Market Rules.

(2) All 230 kV equipment must have a maximum continuous voltage rating and the ability to interrupt fault current at a voltage of at least 250 kV.

(3) Any revenue metering equipment that is installed must comply with Chapter 6 of the Market Rules.

(4) The new equipment must sustain the fault levels in the area where the due to future system enhancements. Should future system enhancements result in fault levels exceeding equipment capability, the applicant is required to replace equipment at its own expense with higher rated equipment, up to 63 kA as per the Transmission System Code for the 230 kV system.

(5) The 230 kV breakers must meet the required interrupting time of less than or equal to 3 cycles as per the Transmission System Code.

(6) The connection equipment must be designed such that adverse effects due to failure are mitigated on the IESO-controlled grid.

(7) The connection equipment must be designed for full operability in all reasonably foreseeable ambient temperature conditions.

(8) The facility must satisfy telemetry requirements as per Appendices 4.15 and 4.19 of the Market Rules. The determination of telemetry quantities and telemetry testing will be conducted during the IESO Facility Registration/Market entry process.

(9) Protection systems must satisfy requirements of the Transmission system code and specific requirements from the transmitter. New protection systems must be coordinated with existing protection systems.

(10) Protective relaying must be configured to ensure transmission equipment remains in service for voltages between 94% of minimum continuous and 105% of maximum continuous values as per Market Rules, Appendix 4.1.

(11) Although the SIA has found that a Special Protection Scheme (SPS) is not required for Wolfe Island Shoals, provisions must be made in the design of the protections and controls at the facility to allow for the installation of Special Protection Scheme equipment. Should a future SPS be installed to improve the transfer capability in the area or to accommodate transmission reinforcement projects, Wolfe Island Shoals will be required to participate in the SPS system and to install the necessary protection and control facilities to affect the required actions.

(12) Protection systems within the generation facility must only trip appropriate equipment required to isolate the fault. After the facility begins commercial operation, if an improper trip of the transmission facilities occurs due to events within the generation facility, the new facility may be required to be disconnected from the IESO-controlled grid until the problem is resolved.

(13) The autoreclosure of the new 230 kV breaker(s) at the connection point must be blocked. Upon its opening for a contingency, it must be closed only after the IESO approval is granted. The IESO will require reduction of power generation prior to the closure of the breaker(s) followed by gradual increase of power to avoid a power surge.

(14) The generation facility must operate in voltage control mode and shall regulate automatically voltage at a point whose impedance (based on rated apparent power and rated voltage) is not more than 13% from the highest voltage terminal based within ±0.5% of any set point within ±5% of rated voltage. If the AVR target voltage is a function of reactive output, the slope $\Delta V / \Delta Q_{max}$ shall be adjustable to 0.5%.

(15) A disturbance monitoring device must be installed. The applicant is required to provide disturbance data to the IESO upon request.

(16) Models and data, including any controls that would be operational, must be provided to the IESO through the IESO Facility Registration/Market Entry process at least seven months before energisation to the IESO-controlled grid.

(17) The registration of the new facilities will need to be completed through the IESO's Market Entry process before IESO final approval for connection is granted and any part of the facility can be placed in-service. If the data or assumptions supplied for the registration of the facilities materially differ from those that were used for the assessment, then some of the analysis might need to be repeated.

(18) As part of the IESO Facility Registration/Market Entry process, the connection applicant must provide evidence to the IESO confirming that the equipment installed meets the Market Rules requirements and matches or exceeds the performance predicted in this assessment. Until this evidence is provided and found acceptable to the IESO, the Facility Registration/Market Entry process will not be considered complete and the connection applicant must accept any restrictions the IESO may impose upon this project's participation in the IESO administered market or connection to the IESO-controlled grid. Failure to provide evidence may result in disconnection from the IESO-controlled grid.

(19) During the commissioning period, a set of IESO specified tests must be performed. The commissioning report must be submitted to the IESO within 30 days of the conclusion of commissioning. Field test results should be verifiable using the PSS/E models used for this SIA.

(20) The proposed facility must be compliant with applicable reliability standards set by the North American Electric Reliability Corporation (NERC) and the North East Power Coordinating Council (NPCC) prior to energisation to the IESO controlled grid.

(21) The applicant may need to meet the restoration participant criteria as per the NERC standard EOP-005. Further details can be found in section 3 of Market Manual 7.8 (Ontario Power System Restoration Plan).

Notification of Conditional Approval

From the information provided, our review concludes that the proposed connection of Wolfe Island Shoals, subject to the requirements specified in this report, will not result in a material adverse effect on the reliability of the IESO-controlled grid.

It is recommended that a *Notification of Conditional Approval for Connection* be issued for Wolfe Island Shoals subject to the requirements listed in this report being implemented.

– End of Section –

1. Project Description

Windstream Energy Inc. has proposed to develop a 300 MW wind farm located in Lake Ontario, near Wolfe Island, Ontario, known as Wolfe Island Shoals Wind Farm which has been awarded a Power Purchase Agreement for FIT program with Ontario Power Authority. It is expected that commercial operation will start 2014.

Wolfe Island Shoals Wind Farm will be connected to Hydro One's Lennox 230 kV substation. The new offshore substation will consist of two 34.5/240 kV transformers, two 230 kV circuit breakers and associated switchgears, two 34.5 kV buses, and 10 collector line breakers. Each 34.5 kV bus is connected to the step-up transformer via a disconnect switch.

The development will consist of a total of 100 Vestas V112 wind turbine generators with a rated power output of 3 MW each. A 0.65/34.5 kV transformer connects each generator to one of the ten 34.5 kV collector circuits C1 to C10. Each collector circuit will have following number of generators:

Vestas V112 (300 MVA, 100 x 3 MW each)											
Collector	1					2					Total
Circuit ID	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	10
Number of generators	10	10	10	10	10	10	10	10	10	10	100
Maximum MW	30	30	30	30	30	30	30	30	30	30	300

– End of Section –

2. General Requirements

Generators

The proposed facility must satisfy the Generation Facility requirements in Appendix 4.2 of Market Rules.

The generation facility requirements for a wind farm primarily include:

- the generation facility shall have the capability to operate continuously between 59.4Hz and 60.6Hz and for a limited period of time in the region above straight lines on a log-linear scale defined by the points (0.0s, 57.0Hz), (3.3s, 57.0Hz), and (300s, 59.0Hz);
- the generators shall respond to frequency increase by reducing the active power with an average droop based on maximum active power adjustable between 3% and 7% and set at 4%. Regulation deadband shall not be wider than ± 0.06%. A sustained 10% change of rated active power after 10 s in response to a constant rate of change of frequency of 0.1%/s during interconnected operation shall be achievable;
- the generation facility shall respond to frequency decline by temporary boosting their active power output for a limited time (i.e. 10s) by recovering energy from the rotating blades. It is not required for wind facilities to "spill" wind to provide a sustained response to frequency decline;
- the generators must be able to ride through routine switching events and design criteria contingencies assuming standard fault detection, auxiliary relaying, communication, and rated breaker interrupting times unless disconnected by configuration;
- the generation facility directly connecting to the IESO-controlled grid must have the minimum capability to supply continuously all levels of active power output for 5% deviations in terminal voltage. Rated active power is the smaller output at either rated ambient conditions (e.g. temperature, head, wind speed, solar radiation) or 90% of rated apparent power. To satisfy steady-state reactive power requirements, active power reductions to rated active power are permitted;
- the generation facility must have the capability to inject or withdraw reactive power continuously (i.e. dynamically) at a connection point up to 33% of its rated active power at all levels of active power output except where a lesser continually available capability is permitted by the IESO. If necessary, shunt capacitors must be installed to offset the reactive power losses within the facility in excess of the maximum allowable losses. If generators do not have dynamic reactive power capabilities as described above, dynamic reactive compensation devices must be installed to make up the deficient reactive power;
- the generation facility shall regulate automatically voltage at a point whose impedance (based on rated apparent power and rated voltage) is not more than 13% from the highest voltage terminal based within ±0.5% of any set point within ±5% of rated voltage. If the AVR target voltage is a function of reactive output, the slope $\Delta V / \Delta Q_{max}$ shall be adjustable to 0.5%. The equivalent time constants shall not be longer than 20 ms for voltage sensing and 10 ms for the forward path to the regulator output.

Connection Equipment (Breakers, Disconnects, Transformers, Buses)

Appendix 4.1, reference 2 of the Market Rules states that under normal conditions voltages are maintained within the range of 220 kV to 250 kV.

The IESO requires that the 230 kV equipment in Ontario must have a maximum continuous voltage rating of at least 250 kV.

Fault interrupting devices must be able to interrupt fault current at the maximum continuous voltage of 250 kV.

If revenue metering equipment is being installed as part of this project, please be aware that revenue metering installations must comply with Chapter 6 of the IESO Market Rules for the Ontario electricity market. For more details the applicant is encouraged to seek advice from their Metering Service Provider (MSP) or from the IESO metering group.

The Transmission System Code (TSC), Appendix 2 establishes maximum fault levels for the transmission system. For the 230 kV system, the maximum 3 phase symmetrical fault level is 63 kA and the single line to ground (SLG) symmetrical fault level is 80 kA (usually limited to 63 kA).

The TSC requires that new equipment be designed to sustain the fault levels in the area where the equipment is installed. If any future system enhancement results in an increased fault level higher than the equipment's capability, the connection applicant is required to replace the equipment at their own expense with higher rated equipment capable of sustaining the increased fault level, up to the TSC's maximum fault level of 63 kA for the 230 kV system.

The Transmission System Code (TSC), Appendix 2 states that the maximum rated interrupting time for 230 kV kV breakers must be ≤ 3 cycles. The connection applicant shall ensure that the new breakers meet the required interrupting time as specified in the TSC.

The connection equipment must be designed so that the adverse effects of failure on the IESO-controlled grid are mitigated. This includes ensuring that all circuit breakers fail in the open position.

The connection equipment must be designed so that it will be fully operational in all reasonably foreseeable ambient temperature conditions.

IESO Monitoring and Telemetry Data

In accordance with the telemetry requirements for a generation facility (see Appendices 4.15 and 4.19 of the Market Rules) the connection applicant must install equipment at this project with specific performance standards to provide telemetry data to the IESO. The data is to consist of certain equipment status and operating quantities which will be identified during the IESO Market Entry Process.

As part of the IESO Facility Registration/Market Entry process, the connection applicant must also complete end to end testing of all necessary telemetry points with the IESO to ensure that standards are met and that sign conventions are understood. All found anomalies must be corrected before IESO final approval to connect any phase of the project is granted.

Protection Systems

Protection systems must be designed to satisfy all the requirements of the Transmission System Code as specified in Schedules E, F and G of Appendix 1 (version B) and any additional requirements identified by the transmitter. New protection systems must be coordinated with existing protection systems.

Protective relaying must be set to ensure that transmission equipment remains in-service for voltages between 94% of the minimum continuous and 105% of the maximum continuous values in the Market Rules, Appendix 4.1.

The Applicant is required to have adequate provision in the design of protections and controls at the facility to allow for installation of Special Protection Scheme (SPS). Should a future SPS be installed to improve the transfer capability in the area or to accommodate transmission reinforcement projects, the applicant will be required to participate in the SPS system and to install the necessary protection and control facilities to affect the required actions.

Any modifications made to protection relays by the transmitter after this SIA is finalized must be submitted to the IESO as soon as possible or at least six (6) months before any modifications are to be implemented on the existing protection systems. If those modifications result in adverse impacts, the connection applicant and the transmitter must develop mitigation solutions.

Send documentation for protection modifications triggered by new or modified primary equipment (i.e. new or replacement relays) to connection.assessments@ieso.ca.

Protection systems within the generation facility must only trip the appropriate equipment required to isolate the fault. After the facility begins commercial operation, if an improper trip of the 230 kV equipment occurs due to events within the facility, the facility may be required to be disconnected from the IESO-controlled grid until the problem is resolved.

The autoreclosure of the new 230 kV breakers at the connection point must be blocked. Upon its opening for a contingency, it must be closed only after the IESO approval is granted. The IESO will require reduction of power generation prior to the closure of the breaker followed by gradual increase of power to avoid a power surge.

Miscellaneous

The generation facility must operate in voltage control mode and shall regulate automatically voltage at a point whose impedance (based on rated apparent power and rated voltage) is not more than 13% from the highest voltage terminal based within ±0.5% of any set point within ±5% of rated voltage. If the AVR target voltage is a function of reactive output, the slope $\Delta V / \Delta Q_{max}$ shall be adjustable to 0.5%.

Connection Applicant is required to install at the facility a disturbance recording device with clock synchronization that meets the technical specifications provided by Hydro One. The device will be used to monitor and record the response of the facility to disturbances on the 230 kV system in order to verify the dynamic response of generators. The quantities to be recorded, the sampling rate and the trigger settings will be provided by Hydro One.

Facility Registration/Market Entry Requirements

Models and data, including any controls that would be operational, must be provided to the IESO through the IESO Facility Registration/Market Entry process at least seven months before energization to the IESO-controlled grid.

Models and data, including any controls that would be operational, must be provided to the IESO through the IESO Facility Registration/Market Entry process at least seven months before energization to the IESO-controlled grid.

The registration of the new facilities will need to be completed through the IESO's Market Entry process before IESO final approval for connection is granted and any part of the facility can be placed in-service. If the data or assumptions supplied for the registration of the facilities materially differ from those that were used for the assessment, then some of the analysis might need to be repeated.

As part of the IESO Facility Registration/Market Entry process, the connection applicant must provide evidence to the IESO confirming that the equipment installed meets the Market Rules requirements and matches or exceeds the performance predicted in this assessment. Until this evidence is provided and found acceptable to the IESO, the Facility Registration/Market Entry process will not be considered complete and the connection applicant must accept any restrictions the IESO may impose upon this project's participation in the IESO administered market or connection to the IESO-controlled grid. Failure to provide evidence may result in disconnection from the IESO-controlled grid.

During the commissioning period, a set of IESO specified tests must be performed. The commissioning report must be submitted to the IESO within 30 days of the conclusion of commissioning. Field test results should be verifiable using the PSS/E models used for this SIA.

Reliability Standards

Prior to connecting to the IESO controlled grid, the proposed facility must be compliant with the applicable reliability standards set by the North American Electric Reliability Corporation (NERC) and the North East Power Coordinating Council (NPCC).

A list of applicable standards, based on the proponent's/connection applicant's market role/OEB license can be found here:

http://www.ieso.ca/imoweb/ircp/reliabilityStandards.asp

In support of the NERC standard EOP-005, the proponent/connection applicant may need to meet the restoration participant criteria. Please refer to section 3 of Market Manual 7.8 (Ontario Power System Restoration Plan) to determine its applicability to the proposed facility.

The IESO monitors and assesses market participant compliance with these standards as part of the IESO Reliability Compliance Program. To find out more about this program, visit the webpage referenced above or write to ircp@ieso.ca.

Also, to obtain a better understanding of the applicable reliability obligations and find out how to engage in the standards development process, we recommend that the proponent/ connection applicant join the IESO's Reliability Standards Standing Committee (RSSC) or at least subscribe to their mailing list at rssc@ieso.ca. The RSSC webpage is located at: http://www.ieso.ca/imoweb/consult/consult_rssc.asp.

– End of Section –

3. Data Verification

3.1 Review of Connection Arrangement

The proposed connection arrangement is shown in Figure 1 below and a more detailed SLD is included in Appendix A. The protection impact assessment in Appendix D contains some further detail, including protection, circuit breakers and disconnectors. Lennox 230 kV TS is considered the point of connection for the purposes of performance specifications and reactive requirements.

Figure 1 shows the -50 MVAr reactive plant required during normal operation, split evenly between the two collector buses.

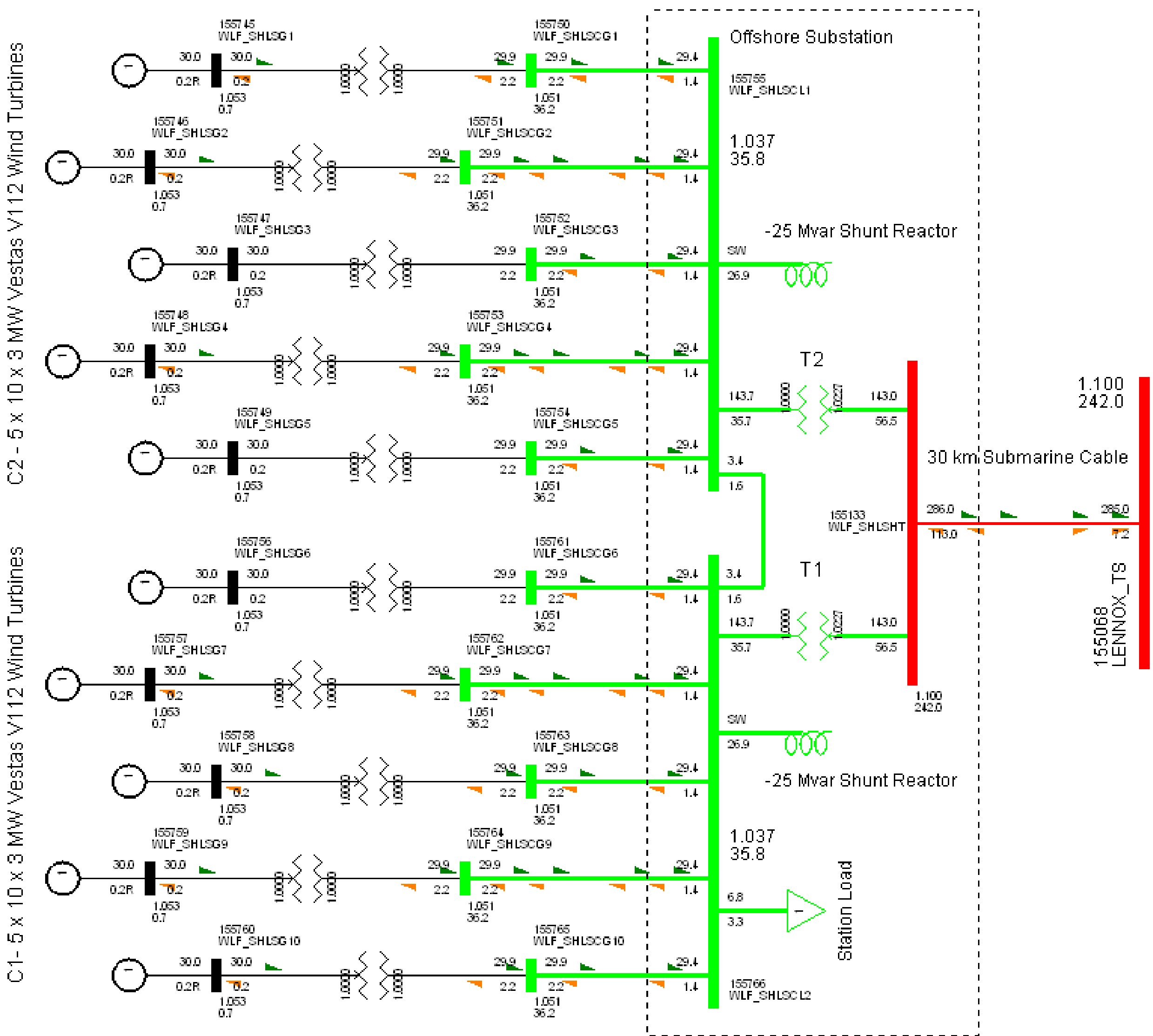


Figure 1: Proposed Connection Arrangement

The connection arrangement of the Project will not reduce the level of reliability of the integrated power system and is, therefore, acceptable to the IESO. Hydro One has indicated that two new 230 kV circuit breakers and one 230 kV disconnector will be installed at Lennox to create a new diameter and this work may be carried out by Hydro One, meeting requirements for connection to the IESO controlled grid.

3.2 Generator

The details of the generator data used in this assessment are given below and in Appendix A.

Type	Rated Voltage	Rated MVA	Rated MW	Transformer			Q_{max} (MX)	Q_{min} (MX)	X_d”(1) (pu)	I_d”(2) (pu)
				MVA	R	X				
Vestas V112	650V	3.37*	3	3.35	0.006 pu	0.08 pu	1.53	-1.53	0.31	-

*based on 0.89 power factor converter operating mode

3.3 Transformer

Specifications for the two parallel 34.5/240 kV step-up transformers is listed below. Tap data is assumed.

Unit	Transformation	Rating (MVA) (ONAN/ONAF/ONAF)	Positive Sequence Impedance (pu) S_B= 165 MVA	Configuration(1)		Zero Sequence Impedance (pu) S_B= 165 MVA(2)	Taps (%) 17 Steps
				HV-Side	LV-Side		
T1	34.5/240 kV	95/125/165MVA	0.0025+j0.10	WYE-G	DELTA	0.0025+j0.10	+/- 10
T2	34.5/240 kV	95/125/165MVA	0.0025+j0.10	WYE-G	DELTA	0.0025+j0.10	+/- 10

3.4 Circuit Breakers and Switches

Specifications of the isolation devices provided by the connection applicant are listed below.

Breakers and switches	**HV**
Rated line-to-line voltage (kV)	250
Interrupting time (ms)	50*
Rated main feeder continuous current (A)	800
Rated bus continuous current (A)	400
Rated short circuit breaking current (kA)	63

*Required, not provided

3.5 Collector System and Tap Line

The 34.5 kV collector system equivalent circuit impedance provided by the connection applicant are listed as follows:

Feeder Number	Equivalent Impedance (Ohm)	Equivalent Impedance(pu)
1 – Collector System	R = 0.636 X = 0.838 B = 1.08E-03 MHO	R = 0.0536 X = 0.0704 B = 0.0129
1 - Equivalent WTG Transformer	X = 2.84	X = 0.236

Per unit data are based on 100 MVA & 34.5 kV. Data submitted for feeders 2 to 10 is the same as 1.

230 kV Tap Line	**Positive-Sequence Impedance (pu, S_B=100MVA)**			**Zero-Sequence Impedance (pu, S_B=100MVA)**		
	R	X	B	R	X	B
L1	0.0015	0.0081	1.04	0.0221	0.0121	

– End of Section –

4. Fault Level Assessment

Fault level studies were completed by Hydro One to examine the effects of Wolfe Island Shoals Wind Farm on fault levels at existing facilities in the area. Studies were performed to analyze the fault levels with and without Wolfe Island Shoals Wind Farm and other proposed wind farms in the surrounding area.

The short circuit study was carried out with the following facilities and system assumptions:

Generation Facilities In-Service

Niagara, South West, West Zones

- All hydraulic generation
- 6 Nanticoke
- 2 Lambton
- Brighton Beach (J20B/J1B)
- Greenfield Energy Centre (Lambton SS)
- St. Clair Energy Centre (L25N & L27N)
- East Windsor Cogen (E8F & E9F) + existing Ford generation
- TransAlta Sarnia (N6S/N7S)
- Imperial Oil (N6S/N7S)
- Thorold GS (Q10P)
- Kruger Port Alma (C24Z)

Central, East Zones

- All hydraulic generation
- 6 Pickering units
- 4 Darlington units
- 4 Lennox units
- GTAA (44 kV buses at Bramalea TS and Woodbridge TS)
- Sithe Goreway GS (V41H/V42H)
- Portlands GS (Hearn SS)
- Halton Hills GS
- Kingston Cogen
- TransAlta Douglas (44 kV buses at Bramalea TS)
- Wolf Island WGS

Northwest, Northeast Zones

- All hydraulic generation
- 1 Atikokan
- 2 Thunder Bay
- NP Iroquois Falls
- AP Iroquois Falls

- Kirkland Lake
- 1 West Coast (G2)
- Lake Superior Power
- Terrace Bay Pulp STG1 (embedded in Neenah paper)
- Prince I & II WGS

Bruce Zone

- 8 Bruce units
- 4 Bruce B Standby Generators
- Erie Shores WGS (WT1T)
- Kingsbridge WGS (embedded in Goderich TS)
- Amaranth WGS – Amaranth I (B4V) & Amaranth II (B5V)
- Ripley WGS (B22D/B23D)
- Underwood (B4V/B5V)
- Wolf Island (injecting into X4H)

New Generation Facilities:

Committed wind generation

- Byran Wind Farm (X21)
- Greenwich Wind Farm (M23L and M24L)
- Gosfield Wind Project (K2Z)
- Kruger Energy Chatham Wind Project (C24Z)
- Raleigh Wind Energy Centre (C23Z)
- Talbot Wind Farm (W45LC)

Other new generation additions or modifications:

- Bruce G1 and G2: 835 MW each
- Beck 1 G9: 68.5 MVA
- Greenfield South GS
- York Energy Centre
- Island Falls
- Oakville Generating Station
- Becker Cogeneration
- New Post Creek GS
- Mattagami Lake Dam
- Wawatay G4

Transmission System Configuration

Existing system with the following upgrades:

- Bruce x Orangeville 230 kV circuits up-rated
- Burlington TS: Rebuild 115 kV switchyards
- Leaside TS to Birch JCT: Build new 115 kV circuit. Birch to Bayfield: Replace 115 kV cables.
- Uprate circuits D9HS, D10S and Q11S

- Cherrywood TS to Claireville TS: Unbundle the two 500 kV super-circuits (C551VP & C550VP)
- Allanburg x Middleport 230 kV circuits (Q35M and Q26M) installed
- One 250 MVAr (@ 250 kV) shunt capacitor bank installed at Buchanan TS
- 1250 MW HVDC line ON-HQ in service
- Tilbury West DS second connection point for DESN arrangement using K2Z and K6Z
- Second 500kV Bruce-Milton double-circuit line in service.
- Windsor area transmission reinforcement (okay):
    - 230 kV transmission line from Sandwich JCT (C21J/C22J) to Lauzon TS
    - New 230/27.6 DESN, Leamington TS, that will connect C21J and C22J and supply part of the existing Kingsville TS load
    - Replace Keith 230/115 kV T11 and T12 transformers
    - 115 kV circuits J3E and J4E upgrades
- Woodstock Area transmission reinforcement:
    - Karn TS in service and connected to M31W & M32W at Ingersol TS
    - W7W/W12W terminated at LFarge CTS
    - Woodstock TS connected to Karn TS
- Nanticoke and Detweiler SVCs
- Series capacitors at Nobel SS in each of the 500 kV circuits X503 & X504E to provide 50% compensation for the line reactance
- Lakehead TS SVC
- Porcupine TS & Kirkland Lake TS SVC
- Porcupine TS: Install 2x125 MVAr shunt capacitors
- Essa TS : Install 250 MVAr shunt capacitor
- Hanmer TS: Install 149 MVAr shunt capacitor
- Pinard TS: Install 2x30 MVAr LV shunt capcitors
- Upper Mattagami expansion
- Fort Frances TS: Install 22 MVAr moveable shunt capacitor
- Dryden TS: Install shunt capacitors

System Assumptions

- Lambton TS 230 kV operated ***open***
- Claireville TS 230 kV operated ***open***
- Leaside TS 230 kV operated ***open***
- Leaside TS 115 kV operated ***open***
- Middleport TS 230 kV bus operated ***open***
- Hearn SS 115 kV bus operated ***open*** **–** as required in the Portlands SIA
- Napanee TS 230 kV operated ***open***
- Cherrywood TS North & South 230kV buses operated ***open***
- All capacitors in service
- All tie-lines in service and phase shifters on neutral taps
- Maximum voltages on the buses

Monitored Buses

Bowmanville 500 kV
Lennox 230 kV, 500 kV

Dobbin 230 kV, 115 kV
Belleville 230 kV
Havelock 230 kV
Hinchinbrooke 230 kV
St. Lawrence 230 kV, 115 kV
Hawthorne 500 kV, 230 kV, 115 kV
Riverdale 115 kV
Merivale 230 kV, 115 kV
Chatfalls 230 kV
Chenaux 230 kV, 115 kV
Sidney 115 kV
Frontenac 115 kV
Kingston Cogen 230 kV
Cataraqui 115 kV
Barrett Chute 115 kV
Stewartville 115 kV

The following tables summarize the symmetric and asymmetric fault levels near Wolfe Island Shoals Wind Farm and the corresponding breaker ratings.

Table 1: Eastern Transformer Station Symmetrical Breaker Ratings

Bus	Before FIT projects		After FIT projects (incl. Wolfe Island Shoals)		Breaker Ratings Symmetrical (kA) (1)
	Total Fault Current Symmetrical (kA)		Total Fault Current Symmetrical (kA)		
	3-phase fault	L-G	3-phase fault	L-G	
Barrett Chute 115 kV	9.391	10.087	9.396	10.091	10.33
Hawthorne 500 kV	11.452	12.451	11.494	12.485	40
Hawthorne 230 kV	20.988	26.502	21.041	26.558	50
Hawthorne 115 kV	27.674	35.452	27.718	35.500	39.3
Hinchinbrooke 230 kV	19.767	13.363	20.052	13.453	63
Lennox 500 kV	25.978	26.756	26.331	27.146	41
Lennox 230 kV	34.091	41.708	35.871	44.172	60
Riverdale 115 kV	20.428	17.452	20.528	17.501	19.3
Stewartville 115 kV	8.938	10.744	8.942	10.748	10.33
Sidney 115 kV	6.209	6.453	6.229	6.455	6.2
St. Lawrence 230 kV	26.148	27.606	26.181	27.630	40
St. Lawrence 115 kV	18.932	22.171	18.939	22.177	50

(1) Most Restrictive Breaker Rating at the Maximum Operating Voltage level

Table 2: Eastern Transformer Station Asymmetrical Breaker Ratings

Bus	Before FIT projects		After FIT projects (incl. Wolfe Island Shoals)		Breaker Ratings Asymmetrical (kA) (1)
	Total Fault Current Asymmetrical (kA)		Total Fault Current Asymmetrical (kA)		
	3-phase fault	L-G	3-phase fault	L-G	
Barrett Chute 115 kV	9.535	10.953	9.538	10.955	11.4
Hawthorne 500 kV	14.004	16.098	14.047	16.137	48
Hawthorne 230 kV	25.899	34.492	25.958	34.558	60
Hawthorne 115 kV	32.686	43.934	32.732	43.987	45.4
Hinchinbrooke 230 kV	23.178	15.367	23.462	15.453	75.2
Lennox 500 kV	35.958	38.791	36.431	39.321	53.3
Lennox 230 kV	49.011	62.343	51.419	65.76	66
Riverdale 115 kV	22.780	19.241	22.803	19.252	22.7
Stewartville 115 kV	9.374	12.106	9.375	12.108	11.4
Sidney 115 kV	6.721	6.991	6.723	6.992	6.8
St. Lawrence 230 kV	32.684	36.164	32.718	36.191	48
St. Lawrence 115 kV	24.430	29.434	24.439	29.441	60

(1) Most Restrictive Breaker Rating at the Maximum Operating Voltage level

By comparing the fault levels from initial studies to the most restrictive breaker ratings, further investigation of Riverdale 115kV, Stewartville 115kV and Sidney 115kV transformer stations was required. Hydro One stated that in these cases, the topology of these substations would ensure that breaker ratings will not be exceeded under fault conditions.

The Fault Level study was performed before and after adding FIT generation to the IESO-controlled grid. There is a small, but relatively insignificant increase in fault levels following the addition of FIT generation.

Therefore, it can be concluded that the increase in fault levels due to the Wolfe Island Shoals Wind Farm Project does not cause new violations of breaker fault level ratings.

– End of Section –

5. Protection Impact Assessment

A Protection Impact Assessment (PIA) was completed by Hydro One to examine the impact of the new generators on existing transmission system protections.

Wolfe Island Shoals will be connected to the Lennox 230kV Transformer Station via a new diameter, which will be formed by the addition of two new breakers adjacent to lines X21 and X22. The complete protection impact assessment is available in Appendix D.

The IESO has concluded that the proposed protection adjustments have no material adverse impact on the IESO-controlled grid.

– End of Section –

6. System Impact Studies

This connection assessment was carried out to identify the effect of the proposed facility on thermal loading of transmission interfaces in the vicinity, the system voltages for pre/post contingencies, the ability of the facility to control voltage and the transient performance of the system.

6.1 Existing System

Wolfe Island Shoals Wind Farm is proposed to connect to the existing Hydro One Lennox 230 kV substation. The graphs below display the MW flow from Lennox 230 kV and 500 kV TS. These are hourly average samples from Jan 1 to August 10, 2010 obtained from IESO real-time data. Positive values mean flow out of the station.

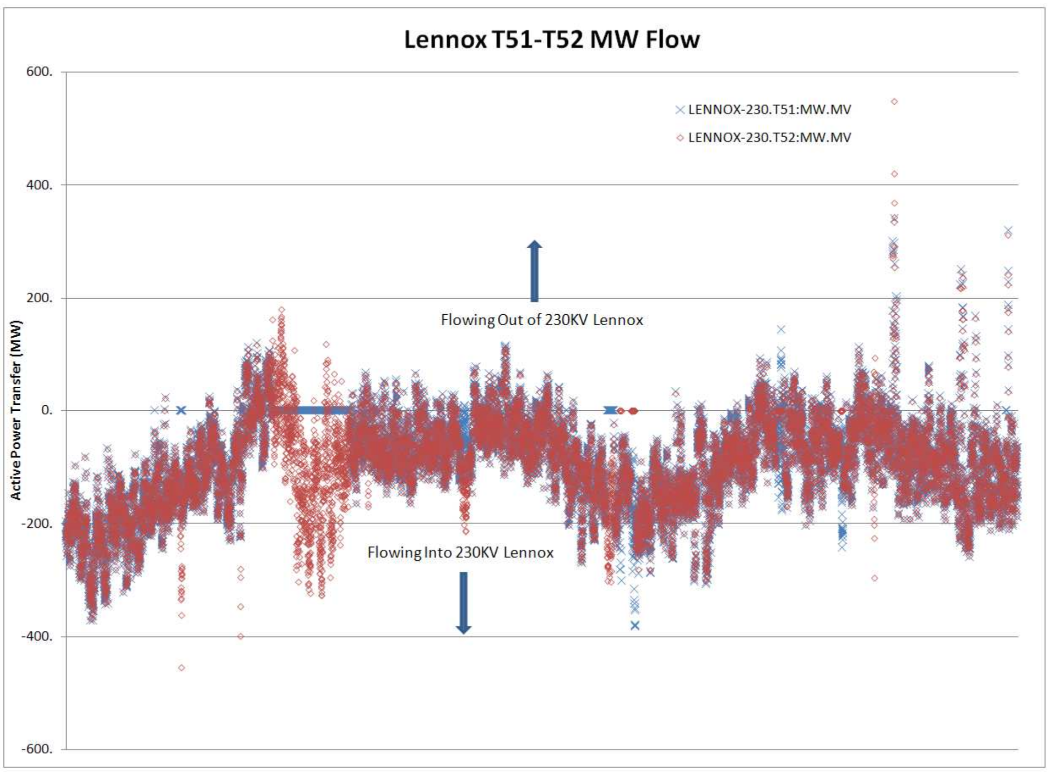


Figure 2: MW flow on 230/500 kV transformers at Lennox TS during 2009-2010

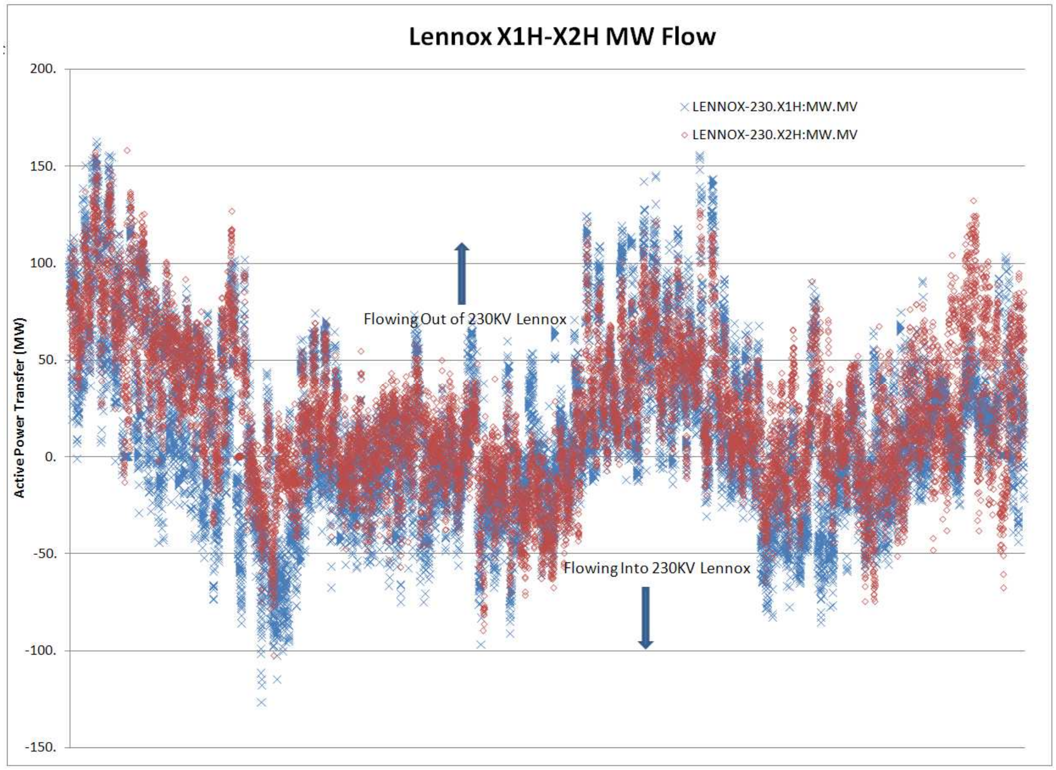


Figure 3: MW Flow on X1H-X2H 230KV Lennox-Hinchinbrooke Circuits during 2009-2010

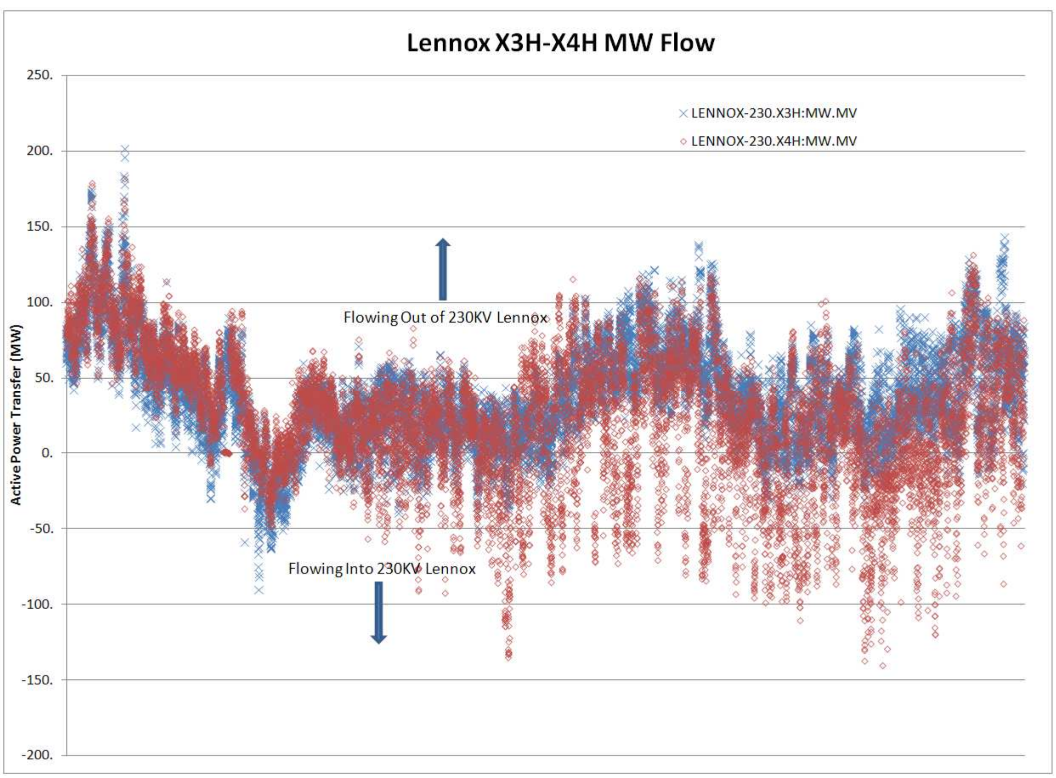


Figure 4: MW Flow on X3H-X4H 230KV Lennox-Hinchinbrooke Circuits during 2009-2010

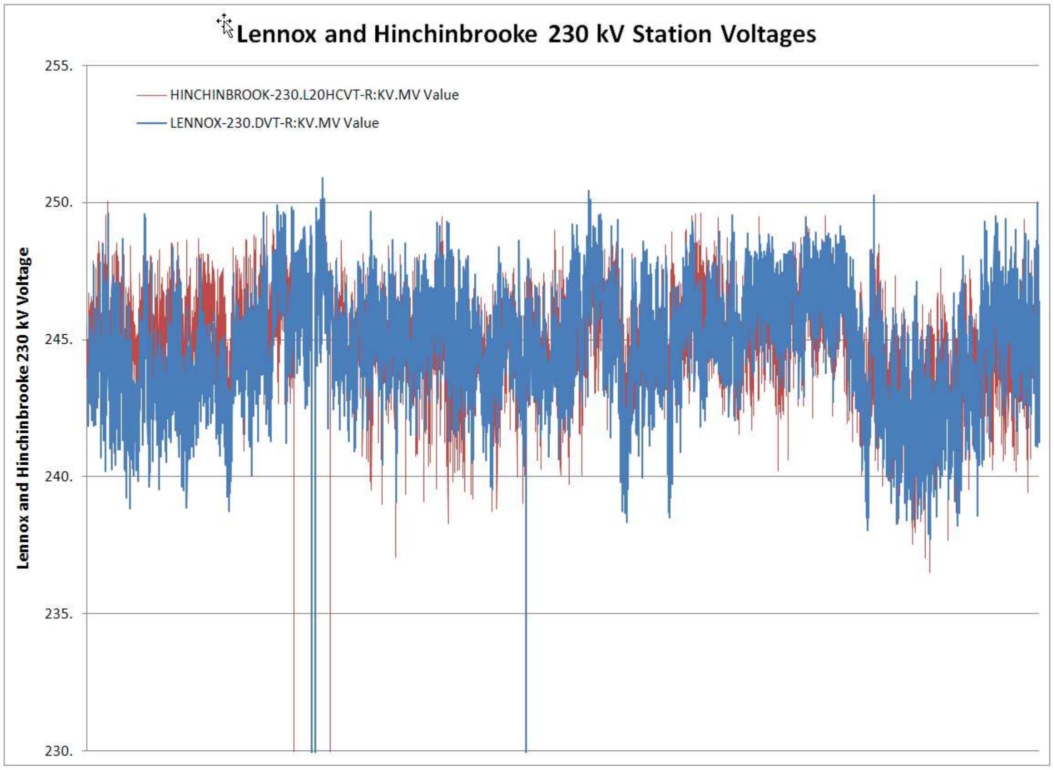


Figure 5: Voltages at Lennox and Hinchinbrooke Transformer Stations during 2009-2010

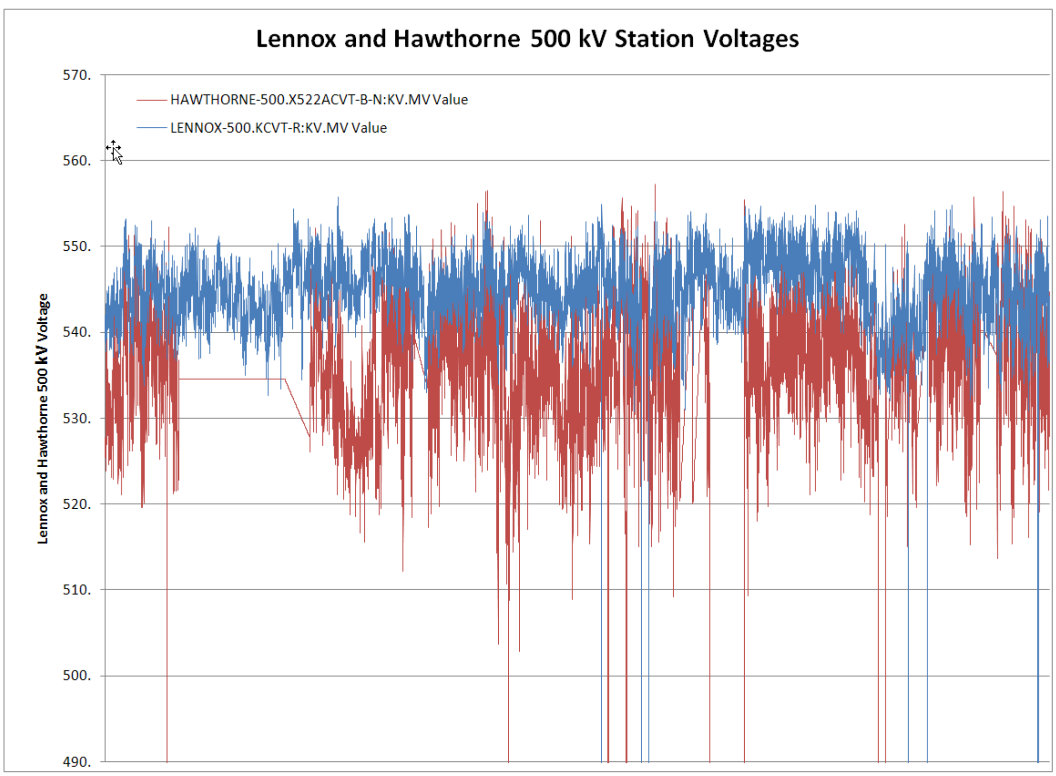


Figure 6: Voltages measured at Lennox and Hawthorne 500kV Transformer Stations during 2009-2010

The following average voltages and equipment loadings can be observed in the dataset used to produce the previous historical plots.

	Average Voltage (kV)
Lennox 230 TS	243
Hinchinbrooke 230 TS	236
Lennox 500 TS	541
Hawthorne 500 kV	511

	Average Loading (MW)
Lennox T51/T52	90
Lennox Hinchinbrooke X1H	12
Lennox-Hinchinbrooke X2H	21
Lennox-Hinchinbrooke X3H	36
Lennox-Hinchinbrooke X4H	24

Voltages at Lennox 500 kV TS are often close to continous operating limits of 550 kV. For this reason, the WTG plant shall not be allowed to contribute to any further voltage increases under normal operating conditions.

6.2 Study Assumptions

Summer 2013 peak load conditions were used for this study, along with the following assumptions:

System Conditions

All transmission system elements were in service.

Peak Primary demand is 25912 MW

	FABCW	**BLIP**	**EWTE**	**MFE**	**FN**	**FIO**	**FETT**	**QFW**	**CLAN**
S1	5396.5	-747.2	328.1	819	-1540	1568	4877.8	1301.9	-894

The interfaces are defined as follows:

Interface	**Definition**
FABCW	Flow away from Bruce Complex (West)
BLIP	Buchanan Longwood Input
EWTE	East West Transfer East
MFE	Mississagi Flow East
FN	Flow North
FIO	Flow Into Ottawa
FETT	Flow East towards Toronto
QFW	Queenston Flow West
CLAN	Claireville North

Lennox/Hawthorne Reactors status depended on voltage profile for each of the study scenarios. i.e. Voltages were maintained within ORTAC min/max voltage requirements for precontingency state.

Major Generating Stations Units Statuses are as follows:

Generating Station	Units In Service
Atikokan	1
Nanticoke	4
Thunder Bay	1
Lambton	0
Bruce	7
Pickering	4
Lennox	0
Darlington	4
Halton Hills	3
Thorold	2
York Energy Centre	2
Portlands	0
Sithe Goreway	0
West Coast	1
Total Wind	1045.5

Modeling Assumptions

- HVDC Intertie was simulated using a generator for either sinking or sourcing a maximum of 1250MW, for exporting or importing respectively
- Nanticoke station output reduced following addition of Wolfe Shoals Wind Farm (300MW)
- White Pines Wind farm assumed to be in-service injecting 60MW on X21, Picton to Napanee/Lennox 230 kV circuit near Picton TS.
- Bryan wind farm removed from basecase
- Voltage dependent load model used for Pre UTLC solution. Constant Power load model used for Post-ULTC solution, except where depressed voltages were observed Post-ULTC.
- Eastern Region embedded generators in-service and generating based on on-peak capacity factors.

Distribution Transformer Station	Total Nameplate Capacity (kW)	On-Peak Capacity Factor	On-Peak Distributed Generation (kW)	Off-Peak Capacity Factor	Off-Peak Distributed Generation (kW)
Almonte TS	20748	0.61	12598.2	0.21	4398.6
Belleville TS	31128	0.60	18826.2	0.21	6474.6
Brockville TS	29973	0.61	18163.2	0.21	6293.6
Crosby TS DESN 2	40000	0.60	24000	0.20	8000
Dobbin TS	20000	0.30	6000	0.85	17000
Fallowfield DS	1050	0.74	780	0.44	460

Distribution Transformer Station	Total Nameplate Capacity (kW)	On-Peak Capacity Factor	On-Peak Distributed Generation (kW)	Off-Peak Capacity Factor	Off-Peak Distributed Generation (kW)
Havelock TS	10299	0.89	9119.4	0.68	6959.8
Kingston Gardiner TS	50630	0.54	27486	0.33	16806
Longueiul TS	20949	0.61	12803.4	0.22	4579.8
Morrisburg TS	39528	0.37	14716.8	0.69	27405.6
Napanee TS	11750	0.60	7050	0.20	2350
Otonabee TS DESN 1	2000	0.90	1800	0.70	1400
Otonabee TS DESN 2	6213	0.33	2047.8	0.79	4882.6
Picton TS	24100	0.30	7260	0.85	20420
Port Hope TS DESN 1	17000	0.60	10200	0.20	3400
Sidney TS	10385	0.60	6231	0.20	2077
Smith Falls TS	65850	0.60	39660	0.20	13420
South March TS	6667	0.89	5920.2	0.68	4533.4
St. Isidore TS	4610	0.89	4116	0.69	3172
St. Lawrence TS	49333	0.60	29599.8	0.20	9866.6
Wilson TS DESN 2	235	0.60	141	0.20	47
Wilson TS DESN 2	11500	0.30	3450	0.85	9775
Grand Total	547745	0.53	288313.8	0.42	230491.15

Study Scenarios

Various generation Dispatch & Transfer Scenarios were examined for voltage decline exceeding IESO criteria and for current flows exceeding continuous equipment ratings.

1. Wolfe Island/White Pines Not Connected (Baseline)
   a. No HVDC Transfer, No Lennox Generation
2. Wolfe Island/White Pines Connected
   a. No HVDC Transfer, No Lennox Generation
   b. HVDC Exporting 1250MW, 2 Lennox Units on 230KV
   c. HVDC Exporting 1250MW, 2 Lennox Units on 500KV
   d. HVDC Exporting 1250MW, 2 Lennox Units on 500KV, 300MW export to NY via St. Lawrence
   e. No HVDC Transfer, Lennox Generation at Full Output (2200MW)
   f. HVDC Importing 1250MW, No Lennox Generation

Studies were repeated for all scenarios listed above for each of the outage elements listed below:

- X522A, Lennox to Hawthorne 500 kV
- Lennox 500/230 kV T51
- X1H, Lennox to Hinchinbrooke 230 kV

6.3 Thermal Analysis

The assessment examined the effect that the proposed facility would have on the thermal loadings of the Eastern region transmission elements.

The *Ontario Resource and Transmission Assessment Criteria* requires that all line and equipment loads be within their continuous ratings with all elements in service, and within their long-term emergency ratings with any element out of service. Lines and equipment may be loaded up to their short-term emergency ratings immediately following the contingencies to effect re-dispatch, perform switching, or implement control actions to reduce the loading to the long-term emergency ratings.

Thermal Analysis of the eastern transmission system was performed using the S1peak primary demand basecase. The Wolfe Island Shoals model was adjusted to full power output of 300MW to simulate the worst case thermal loadings. Lennox Generation was dispatched in different combinations which included: No Lennox Output, 2 Lennox Units on 230kV, 2 Lennox Units on 500kV and 4 Lennox Units at full power.

The tabulated results reported in this section are only a subset of the complete thermal studies performed. The results are for All-Elements-in-Service and for three notably severe contingencies in the vicinity. Five select scenarios are reported here in an effort to be concise:

- **Scenario 1:** Initial conditions - Wolfe Island Shoals generation not connected
- **Scenario 2:** Wolfe Island Shoals in service with S1 basecase flows
- **Scenario 3:** Wolfe Island Shoals in service with flows modified to include high export on HVDC interties; two 230kV Lennox units generating at full power (1100MW output)
- **Scenario 4:** Wolfe Island Shoals in service with flows modified to include high export on HVDC interties; four Lennox units generating at full power (2200MW output)
- **Scenario 5:** Wolfe Island Shoals in service with flows modified to include high import on HVDC interties

Hydro One has made available continuous and 15-min thermal ratings for summer conditions. 15-min Limited Time Ratings (LTR) were calculated based on 100% pre-flows, 4 km/h wind and 35˚C for summer ratings.

The reported thermal results are for the circuit sections with the higher current loadings relative to their continuous ratings.

In summary, the thermal analysis findings show that the transmission system is capable of carrying an additional 300MW from the new Wind-farm without violating the applicable equipment ratings. The flow pattern with the additional 300 MW, shows that a significant portion of the power flow pushes back onto the 500KV corridor through the Lennox T51/T52, 230/500 kV transformer pair. The remainder flows through the 230kV Lennox-Hinchinbrooke circuits. The individual Lennox (230/500KV) autotransformer loadings decrease by 7%-9%. However, the Lennox to Hinchinbrooke 230 kV, Hinchinbrooke to St. Lawrence 230 kV and St Lawrence to Hawthorne 230 kV circuit loadings increase by 5%-9%.

Snapshots of the system without and with the new generation are provided in Appendix B – Diagrams for Load Flow Results. Note that one of the more severe outage/contingency combinations is the loss of both Lennox 230/500kV autotransformers which results in significant loading increases on the 230KV circuits. Similarly, following an outage/contingency combination where three out of four 230kV Lennox to Hinchinbrooke circuits are lost, the loading on the Lennox autotransformers increases significantly. In either case, the current loadings are within the applicable ratings.

Note that under high export conditions, the St. Lawrence to Hawthorne, L24A line loading may violate the continuous line rating following a Lennox to Hawthorne 500 kV and Cherrywood to Merivale 230 kV, X522A+M29C contingency. However, as mentioned earlier, the line loading is permitted to be within the Limited Time Rating following the loss of any element, provided that flow can be reduced below the Long Term Emergency rating in 15 minutes.

The wind farm 230 kV bus, circuit breakers and 240/34.5 kV transformer could potentially become overloaded at full output, after a 240/34.5 kV transformer trip. This can be alleviated by operating the 34.5 kV section breaker normally open, transfer tripping the 34.5 kV section breaker following a fault or reducing the output of the machines to within the rating of the remaining transformer, through the wind farm management system following a fault.

Scenario 1: Initial Conditions

Table 3: Thermal Analysis Summary

Element	Section(s)		Summer Ratings (A or MVA)		Pre-contingency			Loss of X522A+M29C			Loss of X3H+X4H			Loss of T51		
					Flow	Loading (%)		Flow	Loading (%)		Flow	Loading (%)		Flow	Loading (%)	
	From	To	Cont	15-M	Amps	Cont	15-M	Amps	Cont	15-M	Amps	Cont	15-M	Amps	Cont	15-M
X1H	NPIF_Kingston JCT	Cataraqui TS	1060	1390	196.3	18.5	14.1	237.8	22.4	17.1	313.7	29.6	22.6	174.7	16.5	12.6
X2H	NPIF Kingston JCT	Westbrook JCT	1060	1400	218.5	20.6	15.6	253.7	23.9	18.1	241.9	22.8	17.3	199.7	18.8	14.3
X3H	Cataraqui TS	Lennox TS	1060	1400	161.2	15.2	11.5	200.6	18.9	14.3	0.0	0.0	0.0	139.0	13.1	9.9
X4H	Cataraqui TS	Hinchinbrooke SS	1060	1400	179.9	17.0	12.9	217.2	20.5	15.5	0.0	0.0	0.0	165.6	15.6	11.8
X21	Lennox TS	Gretna TS	1060	1400	190.9	18.0	13.6	194.3	18.3	13.9	191.1	18.0	13.7	192.5	18.2	13.8
X22	Long Reach W. JCT	Picton TS	840	1090	73.2	8.7	6.7	74.4	8.9	6.8	73.3	8.7	6.7	73.8	8.8	6.8
L20H	Easton JCT	St. Lawrence TS	770	770	153.6	19.9	19.9	121.8	15.8	15.8	165.4	21.5	21.5	167.9	21.8	21.8
L21H	Easton Yule JCT	St. Lawrence TS	770	770	156.3	20.3	20.3	122.2	15.9	15.9	167.5	21.8	21.8	170.1	22.1	22.1
L22H	Easton Yule JCT	Raisin River JCT	840	1020	165.6	19.7	16.2	135.7	16.2	13.3	176.4	21.0	17.3	178.7	21.3	17.5
L24A	St. Lawrence TS	Raisin River JCT	1370	1790	622.8	45.5	34.8	754.0	55.0	42.1	609.5	44.5	34.1	605.2	44.2	33.8
B31L	St. Lawrence TS	St. Lawrence B31L	1060	1350	404.2	38.1	29.9	466.3	44.0	34.5	397.9	37.5	29.5	395.9	37.3	29.3
X522A	Lennox TS	Hawthorne TS	2960	3660	513.8	17.4	14.0	0.0	0.0	0.0	520.7	17.6	14.2	520.7	17.6	14.2
X523A	Lennox TS	Hawthorne TS	2960	3660	513.8	17.4	14.0	895.5	30.3	24.5	520.7	17.6	14.2	520.7	17.6	14.2
X520B	Lennox TS	Bowmanville SS	2960	3620	312.2	10.6	8.6	301.4	10.2	8.3	306.9	10.4	8.5	306.4	10.4	8.5
X521B	Lennox TS	Bowmanville SS	2960	3620	312.3	10.6	8.6	301.6	10.2	8.3	307.0	10.4	8.5	306.5	10.4	8.5
X526B	Lennox TS	Bowmanville SS	2960	3660	312.6	10.6	8.5	301.9	10.2	8.3	307.3	10.4	8.4	306.9	10.4	8.4
X527B	Lennox TS	Bowmanville SS	2960	3660	312.9	10.6	8.6	302.1	10.2	8.3	307.6	10.4	8.4	307.1	10.4	8.4
Lennox T51	Winding 1-2	Winding 1-2	750	1397	135.8	18.1	9.7	167.2	22.3	12.0	118.6	15.9	8.4	0.0	0.0	0.0
Lennox T52	Winding 1-2	Winding 1-2	926	1542	132.1	14.3	8.6	162.8	17.6	10.6	115.3	12.5	7.5	232.5	25.1	15.1
Cataraqui T1	Winding 1-2	Winding 1-2	250	415	59.0	23.6	14.2	64.6	25.8	15.6	102.4	41.0	24.7	56.5	22.6	13.6
Cataraqui T2	Winding 1-2	Winding 1-2	250	415	53.2	21.3	12.8	58.9	23.6	14.2	0.0	0.0	0.0	50.7	20.3	12.2

Scenario 2: Wolfe Island Shoals In-Service with Basecase Flows

Table 4: Thermal Analysis Summary

Element	Section(s)		Summer Ratings (A or MVA)		Pre-contingency			Loss of X522A+M29C			Loss of X3H+X4H			Loss of T51		
					Flow	Loading (%)		Flow	Loading (%)		Flow	Loading (%)		Flow	Loading (%)	
	From	To	Cont	15-M	Amps	Cont	15-M	Amps	Cont	15-M	Amps	Cont	15-M	Amps	Cont	15-M
X1H	NPIF Kingston JCT	Cataraqui TS	1060	1390	189.5	17.9	13.6	229.0	21.6	16.5	303.2	28.6	21.8	198.0	18.7	14.2
X2H	NPIF Kingston JCT	Westbrook JCT	1060	1400	187.0	17.6	13.4	221.0	20.8	15.8	204.9	19.3	14.6	195.2	18.4	13.9
X3H	Cataraqui TS	Lennox TS	1060	1400	154.9	14.6	11.1	192.4	18.2	13.7	0.0	0.0	0.0	164.7	15.5	11.8
X4H	Cataraqui TS	Hinchinbrooke SS	1060	1400	181.3	17.1	13.0	215.7	20.3	15.4	0.0	0.0	0.0	185.5	17.5	13.3
X21	Gretna JCT	Longreach E. JCT	840	1090	101.2	12.0	9.3	103.0	12.3	9.4	101.4	12.1	9.3	100.1	11.9	9.2
X22	Longreach W. JCT	Picton TS	840	1090	57.0	6.8	5.2	57.7	6.9	5.3	57.1	6.8	5.2	56.5	6.7	5.2
L20H	Easton JCT	St. Lawrence TS	770	770	137.3	17.8	17.8	109.8	14.3	14.3	148.5	19.3	19.3	130.2	16.9	16.9
L21H	Easton Yule JCT	St. Lawrence TS	770	770	140.9	18.3	18.3	109.1	14.2	14.2	150.5	19.5	19.5	135.5	17.6	17.6
L22H	Easton Yule JCT	Raisin River JCT	840	1020	142.6	17.0	14.0	115.8	13.8	11.4	152.5	18.2	15.0	136.4	16.2	13.4
L24A	St. Lawrence TS	Raisin River JCT	1370	1790	738.6	53.9	41.3	859.6	62.7	48.0	727.5	53.1	40.6	744.4	54.3	41.6
B31L	St. Lawrence TS	St. Lawrence B31L	1060	1350	441.9	41.7	32.7	498.8	47.1	36.9	436.6	41.2	32.3	444.7	42.0	32.9
X522A	Lennox TS	Hawthorne TS	2960	3660	473.3	16.0	12.9	0.0	0.0	0.0	479.4	16.2	13.1	470.2	15.9	12.9
X523A	Lennox TS	Hawthorne TS	2960	3660	473.4	16.0	12.9	825.2	27.9	22.6	479.4	16.2	13.1	470.2	15.9	12.9
X520B	Lennox TS	Bowmanville SS	2960	3620	190.2	6.4	5.3	186.7	6.3	5.2	185.7	6.3	5.1	192.9	6.5	5.3
X521B	Lennox TS	Bowmanville SS	2960	3620	190.3	6.4	5.3	186.8	6.3	5.2	185.8	6.3	5.1	192.9	6.5	5.3
X526B	Lennox TS	Bowmanville SS	2960	3660	190.4	6.4	5.2	186.9	6.3	5.1	185.9	6.3	5.1	193.1	6.5	5.3
X527B	Lennox TS	Bowmanville SS	2960	3660	190.6	6.4	5.2	186.9	6.3	5.1	186.0	6.3	5.1	193.4	6.5	5.3
Lennox T51	Winding 1-2	Winding 1-2	750	1397	-64.7	8.6	4.6	-36.0	4.8	2.6	-80.1	10.7	5.7	0.0	0.0	0.0
Lennox T52	Winding 1-2	Winding 1-2	926	1542	-63.5	6.9	4.1	-35.4	3.8	2.3	-78.7	8.5	5.1	-112.6	12.2	7.3
Cataraqui T1	Winding 1-2	Winding 1-2	250	415	62.9	25.2	15.2	68.0	27.2	16.4	109.8	43.9	26.5	64.0	25.6	15.4
Cataraqui T2	Winding 1-2	Winding 1-2	250	415	57.1	22.8	13.8	62.2	24.9	15.0	0.0	0.0	0.0	58.2	23.3	14.0

Scenario 3: Wolfe Island Shoals In-Service with High Export Flows (Two 230 kV Lennox Units Generating 1100MW)

Table 5: Thermal Analysis Summary

Element	Section(s)		Summer Ratings (A or MVA)		Pre-contingency			Loss of X522A+M29C			Loss of X3H+X4H			Loss of T51		
					Flow	Loading (%)		Flow	Loading (%)		Flow	Loading (%)		Flow	Loading (%)	
	From	To	Cont	15-M	Amps	Cont	15-M	Amps	Cont	15-M	Amps	Cont	15-M	Amps	Cont	15-M
X1H	NPIF Kingston JCT	Cataraqui TS	1060	1390	377.3	35.6	27.1	463.4	43.7	33.3	619.4	58.4	44.6	454.4	42.9	32.7
X2H	NPIF Kingston JCT	Westbrook JCT	1060	1400	350.2	33.0	25.0	422.8	39.9	30.2	413.5	39.0	29.5	418.0	39.4	29.9
X3H	Cataraqui TS	Lennox TS	1060	1400	339.1	32.0	24.2	424.2	40.0	30.3	0.0	0.0	0.0	415.6	39.2	29.7
X4H	Cataraqui TS	Hinchinbrooke SS	1060	1400	343.6	32.4	24.5	412.3	38.9	29.5	0.0	0.0	0.0	406.4	38.3	29.0
X21	Gretna JCT	Longreach E. JCT	840	1090	103.1	12.3	9.5	104.3	12.4	9.6	103.5	12.3	9.5	102.2	12.2	9.4
X22	Longreach W. JCT	Picton TS	840	1090	57.8	6.9	5.3	58.5	7.0	5.4	57.9	6.9	5.3	57.4	6.8	5.3
L20H	Easton Yule JCT	Crosby JCT	770	770	81.1	10.5	10.5	165.1	21.4	21.4	54.1	7.0	7.0	128.6	16.7	16.7
L21H	Hinchinbrooke SS	Crosby JCT	870	870	107.7	12.4	12.4	180.4	20.7	20.7	94.0	10.8	10.8	146.0	16.8	16.8
L22H	Easton JCT	Hinchinbrooke SS	840	1020	87.4	10.4	8.6	165.6	19.7	16.2	61.9	7.4	6.1	132.0	15.7	12.9
L24A	St. Lawrence TS	Raisin River JCT	1370	1790	1083.4	79.1	60.5	1405.9	102.6	78.5	1048.9	76.6	58.6	1154.6	84.3	64.5
B31L	St. Lawrence TS	St. Lawrence B31L	1060	1350	606.1	57.2	44.9	758.8	71.6	56.2	589.7	55.6	43.7	633.5	59.8	46.9
X522A	Lennox TS	Hawthorne TS	2960	3660	1067.9	36.1	29.2	0.0	0.0	0.0	1084.1	36.6	29.6	1040.9	35.2	28.4
X523A	Lennox TS	Hawthorne TS	2960	3660	1067.9	36.1	29.2	1890.2	63.9	51.6	1084.1	36.6	29.6	1040.9	35.2	28.4
X520B	Lennox TS	Bowmanville SS	2960	3620	225.3	7.6	6.2	212.2	7.2	5.9	215.1	7.3	5.9	252.1	8.5	7.0
X521B	Lennox TS	Bowmanville SS	2960	3620	225.5	7.6	6.2	212.4	7.2	5.9	215.3	7.3	6.0	252.3	8.5	7.0
X526B	Lennox TS	Bowmanville SS	2960	3660	225.5	7.6	6.2	212.5	7.2	5.8	215.4	7.3	5.9	252.6	8.5	6.9
X527B	Lennox TS	Bowmanville SS	2960	3660	225.7	7.6	6.2	212.5	7.2	5.8	215.5	7.3	5.9	252.6	8.5	6.9
Lennox T51	Winding 1-2	Winding 1-2	750	1397	-468.0	62.4	33.5	-404.0	53.9	28.9	-507.0	67.6	36.3	0.0	0.0	0.0
Lennox T52	Winding 1-2	Winding 1-2	926	1542	-469.0	50.7	30.4	-393.0	42.4	25.5	-494.2	53.4	32.0	-797.0	86.1	51.7
Cataraqui T1	Winding 1-2	Winding 1-2	250	415	86.2	34.5	20.8	98.5	39.4	23.7	150.6	60.2	36.3	95.2	38.1	23.0
Cataraqui T2	Winding 1-2	Winding 1-2	250	415	80.7	32.3	19.5	93.1	37.2	22.4	0.0	0.0	0.0	89.9	36.0	21.7

Scenario 4: Wolfe Island Shoals In-Service with High Export Flows (Four Lennox Units Generating 2200MW)

Table 6: Thermal Analysis Summary

Element	Section(s)		Summer Ratings (A or MVA)		Pre-contingency			Loss of X522A+M29C			Loss of X3H+X4H			Loss of T51		
					Flow	Loading (%)		Flow	Loading (%)		Flow	Loading (%)		Flow	Loading (%)	
	From	To	Cont	15-M	Amps	Cont	15-M	Amps	Cont	15-M	Amps	Cont	15-M	Amps	Cont	15-M
X1H	NPIF Kingston JCT	Cataraqui TS	1060	1390	402.9	38.0	29.0	488.3	46.1	35.1	662.7	62.5	47.7	471.9	44.5	33.9
X2H	NPIF Kingston JCT	Westbrook JCT	1060	1400	373.0	35.2	26.6	443.7	41.9	31.7	455.8	43.0	32.6	433.6	40.9	31.0
X3H	Cataraqui TS	Lennox TS	1060	1400	364.9	34.4	26.1	449.4	42.4	32.1	0.0	0.0	0.0	433.8	40.9	31.0
X4H	Cataraqui TS	Hinchinbrooke SS	1060	1400	364.9	34.4	26.1	432.4	40.8	30.9	0.0	0.0	0.0	421.1	39.7	30.1
X21	Gretna JCT	Longreach E. JCT	840	1090	101.9	12.1	9.3	103.6	12.3	9.5	102.2	12.2	9.4	101.2	12.0	9.3
X22	Longreach W. JCT	Picton TS	840	1090	57.3	6.8	5.3	56.8	6.8	5.2	57.4	6.8	5.3	57.0	6.8	5.2
L20H	Easton JCT	Crosby JCT	770	770	75.0	9.7	9.7	160.2	20.8	20.8	44.8	5.8	5.8	117.5	15.3	15.3
L21H	Hinchinbrooke SS	Crosby JCT	870	870	99.3	11.4	11.4	171.4	19.7	19.7	85.2	9.8	9.8	133.9	15.4	15.4
L22H	Easton JCT	Hinchinbrooke SS	840	1020	81.5	9.7	8.0	160.1	19.1	15.7	54.1	6.4	5.3	120.9	14.4	11.9
L24A	St. Lawrence TS	Raisin River JCT	1370	1790	1067.3	77.9	59.6	1381.9	100.9	77.2	1028.6	75.1	57.5	1126.9	82.3	63.0
B31L	St. Lawrence TS	St. Lawrence B31L	1060	1350	598.2	56.4	44.3	746.3	70.4	55.3	579.8	54.7	42.9	626.4	59.1	46.4
X522A	Lennox TS	Hawthorne TS	2960	3660	1091.8	36.9	29.8	0.0	0.0	0.0	1109.1	37.5	30.3	1074.5	36.3	29.4
X523A	Lennox TS	Hawthorne TS	2960	3660	1091.9	36.9	29.8	1940.3	65.6	53.0	1109.1	37.5	30.3	1074.6	36.3	29.4
X520B	Lennox TS	Bowmanville SS	2960	3620	45.5	1.5	1.3	99.6	3.4	2.8	58.2	2.0	1.6	50.5	1.7	1.4
X521B	Lennox TS	Bowmanville SS	2960	3620	45.7	1.5	1.3	99.8	3.4	2.8	58.4	2.0	1.6	50.8	1.7	1.4
X526B	Lennox TS	Bowmanville SS	2960	3660	45.7	1.5	1.2	99.9	3.4	2.7	58.4	2.0	1.6	50.7	1.7	1.4
X527B	Lennox TS	Bowmanville SS	2960	3660	45.4	1.5	1.2	99.7	3.4	2.7	58.2	2.0	1.6	50.3	1.7	1.4
Lennox T51	Winding 1-2	Winding 1-2	750	1397	-430.1	57.3	30.8	-367.2	49.0	26.3	-473.0	63.1	33.9	0.0	0.0	0.0
Lennox T52	Winding 1-2	Winding 1-2	926	1542	-419.3	45.3	27.2	-357.8	38.6	38.6	-461.1	49.8	29.9	-737.3	79.6	47.8
Cataraqui T1	Winding 1-2	Winding 1-2	250	415	89.3	35.7	21.5	101.6	40.6	24.5	155.6	62.2	37.5	97.4	39.0	23.5
Cataraqui T2	Winding 1-2	Winding 1-2	250	415	83.8	33.5	20.2	96.3	38.5	23.2	0.0	0.0	0.0	92.2	36.9	22.2

Scenario 5: Wolfe Island Shoals In-Service with High Import Flows

Table 7: Thermal Analysis Summary

Element	Section(s)		Summer Ratings (A or MVA)		Pre-contingency			Loss of X522A+M29C			Loss of X3H+X4H			Loss of T51		
					Flow	Loading (%)		Flow	Loading (%)		Flow	Loading (%)		Flow	Loading (%)	
	From	To	Cont	15-M	Amps	Cont	15-M	Amps	Cont	15-M	Amps	Cont	15-M	Amps	Cont	15-M
X1H	NPIF Kingston JCT	Cataraqui TS	1060	1390	138.3	13.0	9.9	140.6	13.3	10.1	216.6	20.4	15.6	153.7	14.5	11.1
X2H	NPIF Kingston JCT	Westbrook JCT	1060	1400	142.7	13.5	10.2	146.2	13.8	10.4	167.5	15.8	12.0	156.9	14.8	11.2
X3H	Cataraqui TS	Lennox TS	1060	1400	103.6	9.8	7.4	104.2	9.8	7.4	0.0	0.0	0.0	119.8	11.3	8.6
X4H	Cataraqui TS	Hinchinbrooke SS	1060	1400	139.3	13.1	10.0	141.6	13.4	10.1	0.0	0.0	0.0	150.1	14.2	10.7
X21	Gretna JCT	Longreach E. JCT	840	1090	103.2	12.3	9.5	104.8	12.5	9.6	103.3	12.2	9.5	102.3	12.2	9.39
X22	Longreach E. JCT	Longreach W. JCT	840	1090	57.8	6.9	5.3	58.5	7.0	5.4	57.9	6.9	5.3	57.4	6.8	5.3
L20H	Easton JCT	St. Lawrence TS	770	770	251.8	32.7	32.7	264.3	34.3	34.3	256.8	33.4	33.4	240.7	31.3	31.3
L21H	Easton Yule JCT	St. Lawrence TS	770	770	256.5	33.3	33.3	268.3	34.8	34.8	260.7	33.9	33.9	245.9	31.9	31.9
L22H	Easton Yule JCT	Raisin River JCT	840	1020	248.6	29.6	24.4	260.0	31.0	25.5	253.0	30.1	24.8	238.4	28.4	23.4
L24A	Hawthorne TS	Raisin River JCT	1350	1760	516.1	38.2	29.3	506.1	37.5	28.8	511.9	37.9	29.1	528.1	39.1	30.0
B31L	St. Lawrence TS	St. Lawrence B31L	1060	1350	336.4	31.7	24.9	309.8	29.2	22.9	333.9	31.5	24.7	346.6	32.7	25.7
X522A	Lennox TS	Hawthorne TS	2960	3660	248.7	8.4	6.8	0.0	0.0	0.0	248.1	8.4	6.8	260.3	8.8	7.1
X523A	Lennox TS	Hawthorne TS	2960	3660	248.7	8.4	6.8	392.7	13.3	10.7	248.1	8.4	6.8	260.4	8.8	7.1
X520B	Lennox TS	Bowmanville SS	2960	3620	77.9	2.6	2.2	119.8	4.1	3.3	81.9	2.8	2.3	57.5	1.9	1.6
X521B	Lennox TS	Bowmanville SS	2960	3620	78.1	2.6	2.2	120.0	4.1	3.3	82.1	2.8	2.3	57.6	2.0	1.6
X526B	Lennox TS	Bowmanville SS	2960	3660	78.2	2.6	2.1	120.1	4.1	3.3	82.1	2.8	2.2	57.7	2.0	1.6
X527B	Lennox TS	Bowmanville SS	2960	3660	78.0	2.6	2.1	119.9	4.1	3.3	82.0	2.8	2.2	57.6	2.0	1.6
Lennox T51	Winding 1-2	Winding 1-2	750	1397	-105.3	14.0	7.5	-107.2	14.3	7.7	-116.5	15.5	8.3	0.0	0.0	0.0
Lennox T52	Winding 1-2	Winding 1-2	926	1542	-103.4	11.1	6.7	-105.1	11.3	6.8	-114.2	12.3	7.4	-184.1	19.9	11.9
Cataraqui T1	Winding 1-2	Winding 1-2	250	415	56.2	22.5	13.5	53.6	21.4	12.9	96.4	38.6	23.2	58.5	23.4	14.1
Cataraqui T2	Winding 1-2	Winding 1-2	250	415	50.2	20.1	12.1	47.7	19.1	11.5	0.0	0.0	0.0	52.6	21.0	12.7

6.4 Voltage Analysis

The assessment of the voltage performance in the Eastern area was done in accordance with the IESO's *Ontario Resource and Transmission Assessment Criteria.* The criteria states that with all facilities in service pre-contingency, 115 kV, 230 kV and 500KV system voltage changes following a contingency shall be limited to 10% both before and after transformer tap changer action.

The Lennox area is designated as 'NPCC impactive' and therefore requires testing of double circuit contingencies and breaker failures. A complete list of contingencies tested under both All-Elements-in-service and Single-element-out-of-service conditions are as follows:

Element(s)	Description	Type
X522A + M31A	Lennox to Hawthorne 500 kV + Hawthorne to Merivale 230 kV	500/230kV Double Circuit
X523A + M30A	Lennox to Hawthorne 500 kV + Hawthorne to Merivale 230 kV	500/230kV Double Circuit
X522A + M29C	Lennox to Hawthorne 500 kV + Cherrywood to Merivale 230 kV	500/230kV Double Circuits
X522A	Lennox to Hawthorne 500 kV	500kV Single Circuit
X21/X22	Picton to Napanee/Lennox 230 kV	230kV Single Radial Circuit
X1H/X2H/X3H/X4H	Lennox to Hinchinbrooke 230 kV	230kV Single Circuit
X1H + X2H	Lennox to Hinchinbrooke 230 kV	230kV Double Circuit
X3H + X4H	Lennox to Hinchinbrooke 230 kV	230kV Double Circuit
Lennox T51/T52	Lennox 230 kV to Lennox 500 kV	500/230kV Autotransformer
X520B + X521B	Lennox to Bowmanville (Darlington) 500 kV	Double Circuit
X21 + X22	Picton to Napanee/Lennox 230 kV	230KV Radial Double Circuit
L20H + L21H	Hinchinbrooke to St. Lawrence 230 kV	230kV Double Circuit
L20H + L22H	Hinchinbrooke to St. Lawrence 230 kV	230kV Double Circuit
L24A + B31L	St. Lawrence to Hawthorne 230 kV and St. Lawrence to Beauharnios 230 kV	230kV Double Circuit
L24A + L22H	St. Lawrence to Hawthorne 230 kV and Hinchinbrooke to St. Lawrence 230 kV	230kV Double Circuit
Q3K	Cataraqui to Frontenac 115 kV	Single Circuit
Q6S	Cataraqui to Sidney 115 kV	Single Circuit
B5QK	Cataraqui to Frontenac 115 kV	Single Circuit
B1S	Sidney to Barrett Chute 115 kV	Single Circuit

The pre-contingency voltage profile in the PSSE basecase, specifically for the area of interest, was maintained within the voltage limits provided in *Ontario Resource and Transmission Assessment Criteria*.

The voltage dependent load model was used to simulate contingencies during the pre-tap changer stage. For most cases, the constant power model was used during the post-tap changer stage. There were some severe contingencies which required the use of voltage dependent load model due to a depressed post-contingency voltage profile. Note that the only way to simulate XxH outage/contingency combinations, which results in a loss Cataraqui T1 & T2, is to arm the Frontenac load rejection SPS. The L/R SPS is utilized to mitigate voltage collapse in the Frontenac 115kV area.

The study results summarized in the following tables indicate both declines for pre-ULTC and post-ULTC to be within IESO's criteria of 10%. In most cases, there is insignificant impact to voltage performance in the area. A notable improvement is observed on Lennox 230kV post-contingency voltage profile following the loss of both 500/230kV autotransformers.

Scenario 1: Initial Conditions – Wolfe Island Shoals not installed

Table 8: Post-Contingency Voltage Change Results

Outage Element	Con-tingency	Period	Wolf Shoals B3	% Chng	Wolf Shoals B1	% Chng	Wolfe Shoals B2	% Chng	Lennox 500	% Chng	Lennox 230	% Chng	Hinchin-brooke 230	% Chng	Cata-raqui 115	% Chng
X522A[1]	X523A & M30A	Pre-Cont	-	-	-	-	-	-	538.20		246.23		245.25		124.75	
		Pre-ULTC	-	-	-	-	-	-	540.75	-0.47	246.62	-0.16	244.38	0.36	124.56	0.15
		Post-ULTC	-	-	-	-	-	-	538.92	-0.13	245.38	0.35	242.50	1.12	123.53	0.98
None	X522A & M29C	Pre-Cont	-	-	-	-	-	-	546.87		247.42		246.10		125.15	
		Pre-ULTC	-	-	-	-	-	-	540.35	1.19	245.02	0.97	244.09	0.82	124.18	0.78
		Post-ULTC	-	-	-	-	-	-	537.78	1.66	243.93	1.41	243.08	1.23	123.64	1.21
X1H[2]	X3H & X4H	Pre-Cont	-	-	-	-	-	-	546.62		247.31		245.61		124.04	
		Pre-ULTC	-	-	-	-	-	-	548.35	-0.32	248.87	-0.63	246.04	-0.18	128.91	-3.93
		Post-ULTC	-	-	-	-	-	-	547.72	-0.20	248.16	-0.34	245.18	0.18	128.05	-3.23
X522A	L24A & B31L	Pre-Cont	-	-	-	-	-	-	538.20		246.23		245.25		124.75	
		Pre-ULTC	-	-	-	-	-	-	533.32	0.91	243.96	0.92	243.07	0.89	123.85	0.72
		Post-ULTC	-	-	-	-	-	-	530.37	1.46	242.66	1.45	241.91	1.36	123.24	1.21
None	L21H & L22H	Pre-Cont	-	-	-	-	-	-	546.87		247.42		246.10		125.15	
		Pre-ULTC	-	-	-	-	-	-	546.44	0.08	246.87	0.22	244.92	0.48	124.73	0.34
		Post-ULTC	-	-	-	-	-	-	546.23	0.12	246.75	0.27	244.77	0.54	124.64	0.40
None	X522A	Pre-Cont	-	-	-	-	-	-	546.87		247.42		246.10		125.15	
		Pre-ULTC	-	-	-	-	-	-	540.71	1.13	245.23	0.88	244.43	0.68	124.31	0.67
		Post-ULTC	-	-	-	-	-	-	538.34	1.56	244.23	1.29	243.52	1.05	123.82	1.06
None	X1H	Pre-Cont	-	-	-	-	-	-	546.87		247.42		246.10		125.15	
		Pre-ULTC	-	-	-	-	-	-	546.78	0.02	247.42	0.00	245.70	0.16	124.14	0.81
		Post-ULTC	-	-	-	-	-	-	546.67	0.04	247.36	0.02	245.63	0.19	124.06	0.87
Lennox T51	Lennox T52	Pre-Cont	-	-	-	-	-	-	547.45		245.82		245.02		124.52	
		Pre-ULTC	-	-	-	-	-	-	551.26	-0.70	238.21	3.09	239.94	2.07	121.57	2.36
		Post-ULTC	-	-	-	-	-	-	551.33	-0.71	236.40	3.83	238.48	2.67	120.74	3.03
None	X22	Pre-Cont	-	-	-	-	-	-	546.87		247.42		246.10		125.15	
		Pre-ULTC	-	-	-	-	-	-	546.42	0.08	246.92	0.20	245.76	0.14	124.97	0.15
		Post-ULTC	-	-	-	-	-	-	546.20	0.12	246.77	0.26	245.63	0.19	124.89	0.21

[1] Voltage Dependent Load Model used due to depressed voltages at Hawthorne 500kV station bus following tap-changer movement for specified contingency

[2] Frontenac Load Rejection Scheme was armed during simulation because X1H outage includes Cataraqui T1 outage – Voltage collapse occurs in Kingston 115KV area if L/R is not used during loss of Cataraqui T2 (i.e. during X3H contingency)

Scenario 2: Wolfe Island Shoals In-Service with Basecase Flows

Table 9: Post-Contingency Voltage Change Results

Outage Element	Con-tingency	Period	Wolf Shoals B3	% Chng	Wolf Shoals B1	% Chng	Wolfe Shoals B2	% Chng	Lennox 500	% Chng	Lennox 230	% Chng	Hinchin-brooke 230	% Chng	Cata-raqui 115	% Chng
X522A[3]	X523A & M30A	Pre-Cont	245.97		35.97		35.94		542.04		246.32		245.53		124.93	
		Pre-ULTC	246.18	-0.09	35.98	-0.03	35.95	-0.03	543.77	-0.32	246.53	-0.09	244.55	0.40	124.69	0.20
		Post-ULTC	245.39	0.24	35.94	0.08	35.90	0.11	542.42	-0.07	245.63	0.28	243.03	1.02	123.92	0.81
None	X522A & M29C	Pre-Cont	245.96		34.74		34.70		546.53		244.40		244.10		124.12	
		Pre-ULTC	243.85	0.86	34.62	0.35	34.59	0.32	539.88	1.22	242.14	0.93	242.11	0.82	123.17	0.77
		Post-ULTC	243.03	1.19	34.58	0.46	34.54	0.46	537.74	1.61	241.26	1.29	241.20	1.19	122.69	1.15
X1H[4]	X3H & X4H	Pre-Cont	245.71		34.73		34.69		546.19		244.14		243.67		123.11	
		Pre-ULTC	246.38	-0.27	34.76	-0.09	34.73	-0.12	547.06	-0.16	244.86	-0.29	244.57	-0.37	129.27	-5.01
		Post-ULTC	245.88	-0.07	34.73	0.00	34.70	-0.03	546.55	-0.06	244.32	-0.08	243.82	-0.06	128.29	-4.21
X522A	L24A & B31L	Pre-Cont	245.97		35.97		35.94		541.95		246.29		245.50		124.92	
		Pre-ULTC	243.53	0.99	35.83	0.39	35.79	0.42	536.58	0.99	243.62	1.08	242.57	1.19	123.75	0.93
		Post-ULTC	242.59	1.37	35.77	0.56	35.73	0.58	534.09	1.45	242.60	1.50	241.56	1.61	123.21	1.37
None	L21H & L22H	Pre-Cont	245.96		34.74		34.70		546.53		244.40		244.10		124.12	
		Pre-ULTC	245.11	0.35	34.69	0.14	34.66	0.12	545.65	0.16	243.49	0.37	242.04	0.85	123.40	0.58
		Post-ULTC	244.83	0.46	34.68	0.17	34.64	0.17	545.14	0.26	243.19	0.50	241.58	1.03	123.18	0.76
None	X522A	Pre-Cont	245.96		34.74		34.70		546.53		244.40		244.10		124.12	
		Pre-ULTC	244.05	0.78	34.63	0.32	34.60	0.29	540.26	1.15	242.35	0.84	242.46	0.67	123.31	0.65
		Post-ULTC	243.34	1.07	34.59	0.43	34.56	0.40	538.36	1.50	241.58	1.15	241.70	0.98	122.89	0.99
None	X1H	Pre-Cont	245.96		34.74		34.70		546.53		244.40		244.10		124.12	
		Pre-ULTC	245.76	0.08	34.73	0.03	34.69	0.03	546.26	0.05	244.18	0.09	243.71	0.16	123.20	0.74
		Post-ULTC	245.68	0.11	34.72	0.06	34.69	0.03	546.13	0.07	244.11	0.12	243.61	0.20	123.09	0.83
Lennox T51	Lennox T52	Pre-Cont	246.89		34.63		34.59		546.01		245.17		244.62		124.39	
		Pre-ULTC	250.45	-1.44	34.82	-0.55	34.79	-0.58	549.02	-0.55	248.99	-1.56	247.18	-1.05	125.83	-1.16
		Post-ULTC	251.84	-2.00	34.73	-0.29	34.70	-0.32	549.56	-0.65	250.26	-2.07	248.22	-1.47	126.41	-1.62
None	X22	Pre-Cont	245.96		34.74		34.70		546.53		244.40		244.10		124.12	
		Pre-ULTC	245.58	0.15	34.72	0.06	34.68	0.06	546.16	0.07	243.99	0.17	243.81	0.12	123.96	0.12
		Post-ULTC	245.47	0.20	34.71	0.09	34.68	0.06	545.99	0.10	243.88	0.22	243.71	0.16	123.90	0.17

[3] Voltage Dependent Load Model used due to depressed voltages at Hawthorne 500kV station bus following tap-changer movement for specified contingency

[4] Frontenac Load Rejection Scheme was armed during simulation because X1H outage includes Cataraqui T1 outage – Voltage collapse occurs in Kingston 115KV area if L/R is not used during loss of Cataraqui T2 (i.e. during X3H contingency)

Scenario 3: Wolfe Island Shoals In-Service with High Export Flows

Table 10: Post-Contingency Voltage Change Results

Outage Element	Con-tingency	Period	Wolf Shoals B3	% Chng	Wolf Shoals B1	% Chng	Wolfe Shoals B2	% Chng	Lennox 500	% Chng	Lennox 230	% Chng	Hinchin-brooke 230	% Chng	Cata-raqui 115	% Chng
X522A[5]	X523A & M30A	Pre-Cont	-		-		-		-	-	-	-	-	-	-	-
		Pre-ULTC	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Post-ULTC	-	-	-	-	-	-	-	-	-	-	-	-	-	-
None	X522A & M29C	Pre-Cont	246.59		34.61		34.58		538.45		244.85		243.94		124.27	
		Pre-ULTC	245.27	0.54	34.54	0.20	34.50	0.20	533.79	0.87	243.44	0.58	241.77	0.89	123.31	0.77
		Post-ULTC	244.15	0.99	34.64	-0.09	34.60	-0.09	531.31	1.33	242.46	0.98	240.75	1.31	122.80	1.18
X1H[6]	X3H & X4H	Pre-Cont	246.38		34.60		34.56		538.11		244.63		243.41		123.35	
		Pre-ULTC	246.28	0.04	34.59	0.03	34.56	0.03	537.65	0.09	244.52	0.04	243.38	0.02	129.35	-4.86
		Post-ULTC	245.92	0.19	34.57	0.09	34.54	0.09	537.29	0.15	244.14	0.20	242.65	0.32	128.50	-4.18
X522A[5]	L24A & B31L	Pre-Cont	-		-		-		-	-	-	-	-	-	-	-
		Pre-ULTC	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Post-ULTC	-	-	-	-	-	-	-	-	-	-	-	-	-	-
None	L21H & L22H	Pre-Cont	246.59		34.61		34.58		538.45		244.85		243.94		124.27	
		Pre-ULTC	245.89	0.28	34.57	0.12	34.54	0.12	537.67	0.14	244.11	0.31	242.08	0.76	123.66	0.49
		Post-ULTC	245.68	0.37	34.56	0.14	34.53	0.14	537.21	0.23	243.88	0.40	241.67	0.93	123.49	0.63
None	X522A	Pre-Cont	246.59		34.61		34.58		538.45		244.85		243.94		124.27	
		Pre-ULTC	245.49	0.45	34.55	0.17	34.52	0.17	534.50	0.73	243.68	0.48	242.17	0.73	123.46	0.65
		Post-ULTC	244.92	0.68	34.52	0.26	34.48	0.26	532.59	1.09	243.06	0.73	241.48	1.01	123.13	0.92
None	X1H	Pre-Cont	246.59		34.61		34.58		538.45		244.85		243.94		124.27	
		Pre-ULTC	246.40	0.08	34.60	0.03	34.57	0.03	538.15	0.06	244.65	0.08	243.45	0.20	123.40	0.70
		Post-ULTC	246.34	0.10	34.60	0.03	34.56	0.03	538.01	0.08	244.59	0.11	243.36	0.24	123.32	0.76
Lennox T51	Lennox T52	Pre-Cont	246.59		34.61		34.58		538.45		244.85		243.94		124.27	
		Pre-ULTC	248.29	-0.69	34.70	-0.26	34.67	-0.26	534.75	0.69	246.67	-0.74	244.72	-0.32	124.80	-0.43
		Post-ULTC	248.11	-0.62	34.69	-0.23	34.66	-0.23	533.76	0.87	246.49	-0.67	244.52	-0.24	124.72	-0.36
None	X22	Pre-Cont	246.59		34.61		34.58		538.45		244.85		243.94		124.27	
		Pre-ULTC	246.31	0.11	34.59	0.06	34.56	0.06	538.17	0.05	244.56	0.12	243.73	0.09	124.15	0.09
		Post-ULTC	246.23	0.15	34.59	0.06	34.56	0.06	538.02	0.08	244.47	0.15	243.65	0.12	124.11	0.13

[5] Test not performed: Established operating limit prevents High Export during X522A outage.

[6] Frontenac Load Rejection Scheme was armed during simulation because X1H outage includes Cataraqui T1 outage – Voltage collapse occurs in Kingston 115KV area if L/R is not used during loss of Cataraqui T2 (i.e. during X3H contingency)

Scenario 4: Wolfe Island Shoals In-Service with High Import Flows

Table 11: Post-Contingency Voltage Change Results

Outage Element	Con-tingency	Period	Wolf Shoals B3	% Chng	Wolf Shoals B1	% Chng	Wolfe Shoals B2	% Chng	Lennox 500	% Chng	Lennox 230	% Chng	Hinchin-brooke 230	% Chng	Cata-raqui 115	% Chng
X522A	X523A & M30A	Pre-Cont	248.89		34.73		34.70		540.16		247.32		245.64		124.92	
		Pre-ULTC	247.78	0.45	34.67	0.17	34.64	0.17	537.97	0.41	246.14	0.48	244.11	0.62	124.15	0.62
		Post-ULTC	247.68	0.49	34.67	0.17	34.64	0.17	537.74	0.45	246.02	0.52	243.87	0.72	124.09	0.67
None	X522A & M29C	Pre-Cont	246.29		34.76		34.72		543.68		244.75		243.81		123.91	
		Pre-ULTC	244.26	0.82	34.65	0.32	34.61	0.32	537.84	1.07	242.58	0.89	241.75	0.84	122.87	0.84
		Post-ULTC	244.05	0.91	34.63	0.37	34.60	0.35	537.26	1.18	242.35	0.98	241.49	0.95	122.76	0.93
X1H[7]	X3H & X4H	Pre-Cont	246.16		34.75		34.72		543.57		244.62		243.34		122.79	
		Pre-ULTC	247.12	-0.39	34.80	-0.14	34.77	-0.14	544.66	-0.20	245.65	-0.42	243.85	-0.21	128.17	-4.38
		Post-ULTC	246.62	-0.19	34.78	-0.09	34.74	-0.06	544.13	-0.10	245.11	-0.20	243.09	0.10	127.30	-3.67
X522A	L24A & B31L	Pre-Cont	247.09		34.80		34.77		535.84		245.62		244.40		124.24	
		Pre-ULTC	245.92	0.47	34.74	0.17	34.70	0.20	534.55	0.24	244.36	0.51	242.41	0.82	123.63	0.50
		Post-ULTC	245.65	0.58	34.72	0.23	34.69	0.23	534.00	0.34	244.07	0.63	242.05	0.96	123.45	0.64
None	L21H & L22H	Pre-Cont	246.29		34.76		34.72		543.68		244.75		243.81		123.91	
		Pre-ULTC	245.41	0.36	34.71	0.14	34.67	0.14	542.43	0.23	243.82	0.38	241.76	0.84	123.15	0.61
		Post-ULTC	245.28	0.41	34.70	0.17	34.67	0.14	542.27	0.26	243.67	0.44	241.46	0.96	123.05	0.70
None	X522A	Pre-Cont	246.29		34.76		34.72		543.68		244.75		243.81		123.91	
		Pre-ULTC	244.53	0.71	34.66	0.29	34.63	0.26	538.30	0.99	242.86	0.77	242.22	0.65	123.08	0.67
		Post-ULTC	244.38	0.78	34.65	0.32	34.62	0.29	537.88	1.07	242.71	0.84	242.07	0.71	123.02	0.72
None	X1H	Pre-Cont	246.29		34.76		34.72		543.68		244.75		243.81		123.91	
		Pre-ULTC	246.18	0.04	34.75	0.03	34.72	0.00	543.55	0.02	244.64	0.04	243.36	0.18	122.85	0.85
		Post-ULTC	246.18	0.04	34.75	0.03	34.72	0.00	543.55	0.02	244.64	0.04	243.36	0.18	122.85	0.85
Lennox T51	Lennox T52	Pre-Cont	248.41		34.71		34.67		549.34		246.81		245.31		124.75	
		Pre-ULTC	249.57	-0.47	34.77	-0.17	34.74	-0.20	553.86	-0.82	248.05	-0.50	245.99	-0.28	125.26	-0.41
		Post-ULTC	249.79	-0.56	34.78	-0.20	34.75	-0.23	554.38	-0.92	248.29	-0.60	246.23	-0.38	125.40	-0.52
None	X22	Pre-Cont	248.41		34.71		34.67		549.34		246.81		245.31		124.75	
		Pre-ULTC	247.89	0.21	34.68	0.09	34.65	0.06	549.01	0.06	246.25	0.23	244.91	0.16	124.54	0.17
		Post-ULTC	247.77	0.26	34.67	0.12	34.64	0.09	548.86	0.09	246.12	0.28	244.79	0.21	124.47	0.22

[7] Frontenac Load Rejection Scheme was armed during simulation because X1H outage includes Cataraqui T1 outage – Voltage collapse occurs in Kingston 115KV area if L/R is not used during loss of Cataraqui T2 (i.e. during X3H contingency)

6.5 Reactive Power Compensation

Market Rules require that generators inject or withdraw reactive power continuously (i.e. dynamically) at a connection point up to 33% of its rated active power at all levels of active power output except where a lesser continually available capability is permitted by the IESO.

The Market Rules accepts that a generating unit with a power factor range of 0.90 lagging and 0.95 leading at rated active power connected via a main output transformer impedance not greater than 13% based on generator rated apparent power provides the required range of dynamic power at the connection point.

Typically, the impedance between the WTG and the connection point is larger than 13%. However, provided the WTG has the capability to provide a reactive power range of 0.90 lagging power factor and 0.95 leading power factor at rated active power, the IESO accepts the WF to compensate for the full reactive power requirement range at the connection point with switchable shunt admittances (e.g. capacitors and reactors). Where the WTG technology has no capability to supply the full dynamic reactive power range at its terminal, the shortfall has to be compensated with dynamic reactive power devices (e.g. SVC).

This section of the SIA indicates how the wind farm can meet the Market Rules requirements regarding reactive power capability, but the Connection Applicant is free to deploy any other solutions which result in its compliance with the Market Rules.

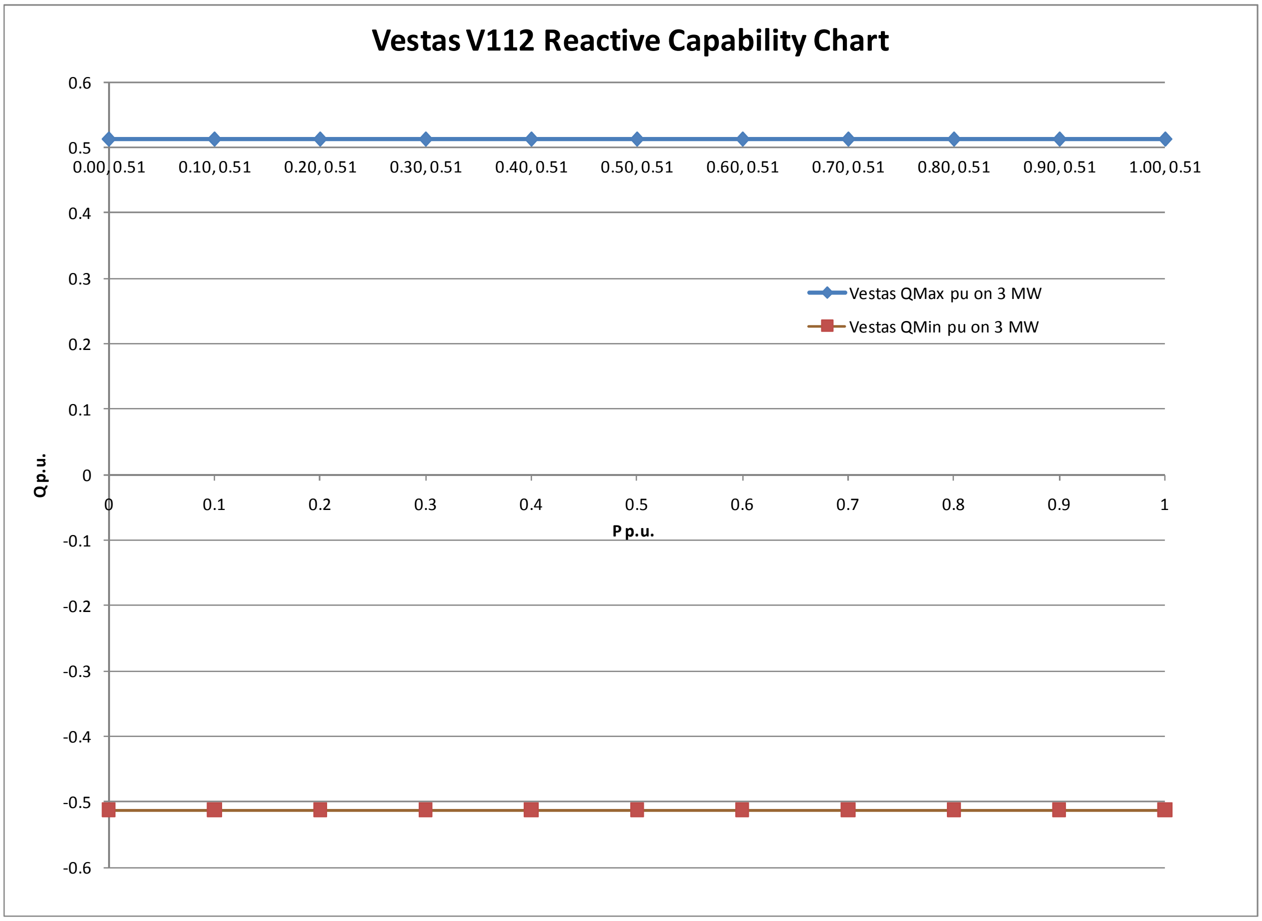
It is the Connection Applicant's responsibility to ensure that the wind farm has the capability to meet the Market Rules requirement at the connection point and be able to confirm this capability during the commission tests.

6.5.1 Dynamic Reactive Power Compensation

The following summarizes the IESO adequate level of dynamic reactive power from each generator and the available capability of Vestas V112 wind turbines.

	Terminal Voltage	Active Power	Reactive Power Capability/Turbine
IESO Required at generator terminals	1.0 pu	1.0 pu	$Q_{gen} = 3 \times \tan [\cos^{-1} (0.9)] = 1.45$ Mvar
			$Q_{abs} = 3 \times \tan [\cos^{-1} (0.95)] = 0.98$ Mvar
Vestas V112 Capability	1.0 pu	1.0 pu	$Q_{gen} = 3 \times \tan [\cos^{-1} (0.89)] = 1.53$ Mvar
			$Q_{abs} = 3 \times \tan [\cos^{-1} (0.89)] = 1.53$ Mvar

The Vestas V112 can deliver IESO required dynamic reactive power to the generator terminal at rated power and at rated voltage. Thus, the IESO has determined that there is no need to install any additional dynamic reactive power compensation device.



6.5.2 Static Reactive Power Compensation

In addition to the dynamic reactive power requirement identified above, Wolfe Island Shoals Wind Farm has to compensate for the reactive power losses and generation within the facility, to ensure that it has the capability to inject or withdraw reactive power up to 33% of its rated active power at the connection point. As mentioned above, the IESO accepts this compensation to be made with switchable shunt devices.

As such, Wolfe Island Shoals Wind Farm must have a minimum capability of supplying approximately **+99 MVAr** (capacitive) to **-99 MVAr** (inductive) at the connection point for at least one constant 230 kV system voltage at all active power outputs.

Preliminary calculations indicated that a shunt reactor of between -50 MVAr and -60 MVAr would be required at the 34.5 kV collector bus, to ensure that the plant could meet the market rules requirement to absorb 0.33 pu, or -99 MVAr of reactive power, at the point of connection. The long 230 kV cable connecting the plant to the IESO controlled grid behaves like a large capacitor and this gives rise to excess reactive power at the point of connection. The shunt reactors specified, bring the plant back to unity power factor at the point of connection when the machines are operating at unity power factor.

Further reactive compensation will also be required to ensure that while the WTG's are outside their operating range and cannot absorb reactive power, existing reactors at Lennox are not cancelled out in any way due to excessive MVAr generation from the cable. Another operational solution would have been to open the 230 kV breakers at Lennox but this would reduce the availability of the WTG capacity.

Load flow studies were performed to calculate the static reactive compensation based on the equivalent parameters provided by the connection applicant for the wind farm. Besides the conditions described in Chapter 4, additional simulation conditions for these load flow studies conclude that:

- The 230-kV voltages at Lennox and Hinchinbrooke are about 242 kV;
- The terminal voltages of the WTGs vary between 0.95 pu and 1.05 pu. For some combinations of active and reactive power, the terminal voltages can go from 0.9 up to 1.1 pu but this is considered acceptable because these machines are rated for continuous operation at this voltage level and there is action which can be taken over extended periods to adjust the collector voltage it if desired;
- The 230 kV tap of the step-up transformer at the interconnection substation is set to the position of 242 kV;
- The reactive capability of the generation facility was assessed with the WTG's operating at full active power output, and again at levels closer to average seasonal expectations which vary between 11% and 50% of full output. With the specified -50 MVAr of shunt reactors installed at the 34.5 kV collector bus, the generation facility can generate and absorb reactive power of +/**-99 MVAr** at the 230 kV connection point, as required by the market rules;
- The Vestas V112 WTG's will disconnect their capability to absorb reactive power under conditions of low or high wind. An additional -60 MVAr of reactors must be installed to ensure that the existing reactive plant at Lennox TS, installed to mitigate existing high voltages, is not cancelled out in any way by reactive power generated by the 230 kV submarine cable and the collector cables during these periods.
- The applicant must confirm that the thermal ratings of their equipment will not restrict the reactive capability of the wind farm at full power output. This will require a review of the short term ratings of the equipment specified against the expected duration the plant will operate at full output.

Two -25 MVAr shunt reactor banks were studied instead of one to ensure equal load sharing between transformers when the section breaker is open and this may be necessary to alleviate overloading. However, one -50 MVAr reactor would provide the required capability and causes no voltage violations during switching. The additional -60 MVAr required to be switched in during times of 0 MW generation would not result in any overloading and could be added in 2 x -30 MVAr blocks to the 2 x -25 existing banks.

The IESO's reactive power calculation used the equivalent electrical model for the WTG and collector feeders as provided by the connection applicant. It is very important that the WF has a proper internal design to ensure that the WTG are not limited in their capability to produce active and reactive power due to terminal voltage limits or other facility's internal limitations. For example, it is expected that the transformation ratio of the WTG step up transformers will be set in such a way that it will offset the voltage profile along the collector, and all the WTG would be able to contribute to the reactive power production of the WF in a shared amount.

A switching study was carried out to investigate the effect of the new LV shunt reactor banks on the voltage changes.

Following summarizes the change in voltage due to;

- removal of the WTG's from service,
- switching of a single reactor of -60 MVAr at the collector bus,
- removal of the entire -110 MVAr of reactive compensation by disconnection of the 34.5 kV collectors buses
- Switching of the 230 kV submarine cable with and without the reactors

All generators are out of service to prevent their dynamic reactive power capability from changing bus voltages, so that the ΔV is only due to switching. The transformers ULTCs have been locked.

	34.5 kV Collector			**Lennox 230 kV**			**Lennox 500 kV**			**Comments**
	PRE	**POST**	**%**	**PRE**	**POST**	**%**	**PRE**	**POST**	**%**	
From 300 MW, -50 MVAr to 0 MW, + 72 MVAr	34.6	36.7	6	244	247.2	1.31	537.8	539.9	0.39	Machines were absorbing reactive power from the system and then removed leaving the collector cables, submarine cable and -50 MVAr reactor connected
Switch in additional -60 MVAr	36.7	35.2	4.1	247.2	245.5	0.69	539.9	538.1	0.33	Above 4% change at collector bus. Recommend 2 x -30 MVAr additional banks
Loss of 34.5 kV system	N/A	N/A	N/A	245.5	248.5	1.22	538.1	541.3	0.59	No issues except increase in MVAr generation
Switch out 230 kV submarine cable	N/A	N/A	N/A	248.5	245.1	1.37	541.3	537.7	0.66	Increase of approx 3 kV on 500 kV system due to submarine cable
Switch in 230 kV submarine cable with reactors	N/A	35.2	N/A	245.1	245.5	0.16	537.7	538.1	0.07	Reactors specified cancel collector and submarine cable MVAr generation to approx. 0 MVAr

The IESO allows ΔV on a single reactor switching to be no more than 4 %. The results show switching of a single reactor of – 60 MVAr produces more than 4 % voltage increase at the 34.5 collector bus and it is therefore recommended that banks of -2 x 30 MVAr are added to the proposed -2 x 25 MVAr banks

Studies were completed covering a range of probable operating conditions and the initial runs attempted to meet the IESO requirements using no reactive compensation, testing the system at various voltages, and tap settings. The IESO also then calculated a nominal reactor size using the data provided then repeated the studies to find an operating point where the proposed arrangement would meet requirements at a typical system voltage of 242 kV and be capable providing zero reactive power at the point of connection at unity power factor. Several iterations were performed but only the key results are documented in this report.

The following figures 7 to 23 show examples of studies which demonstrate the performance of the proposed configuration with and without the reactors in service, at a range of active and reactive power outputs, for the recommended reactor size. The equipment loading is shown with MW above the element and MVAr below.

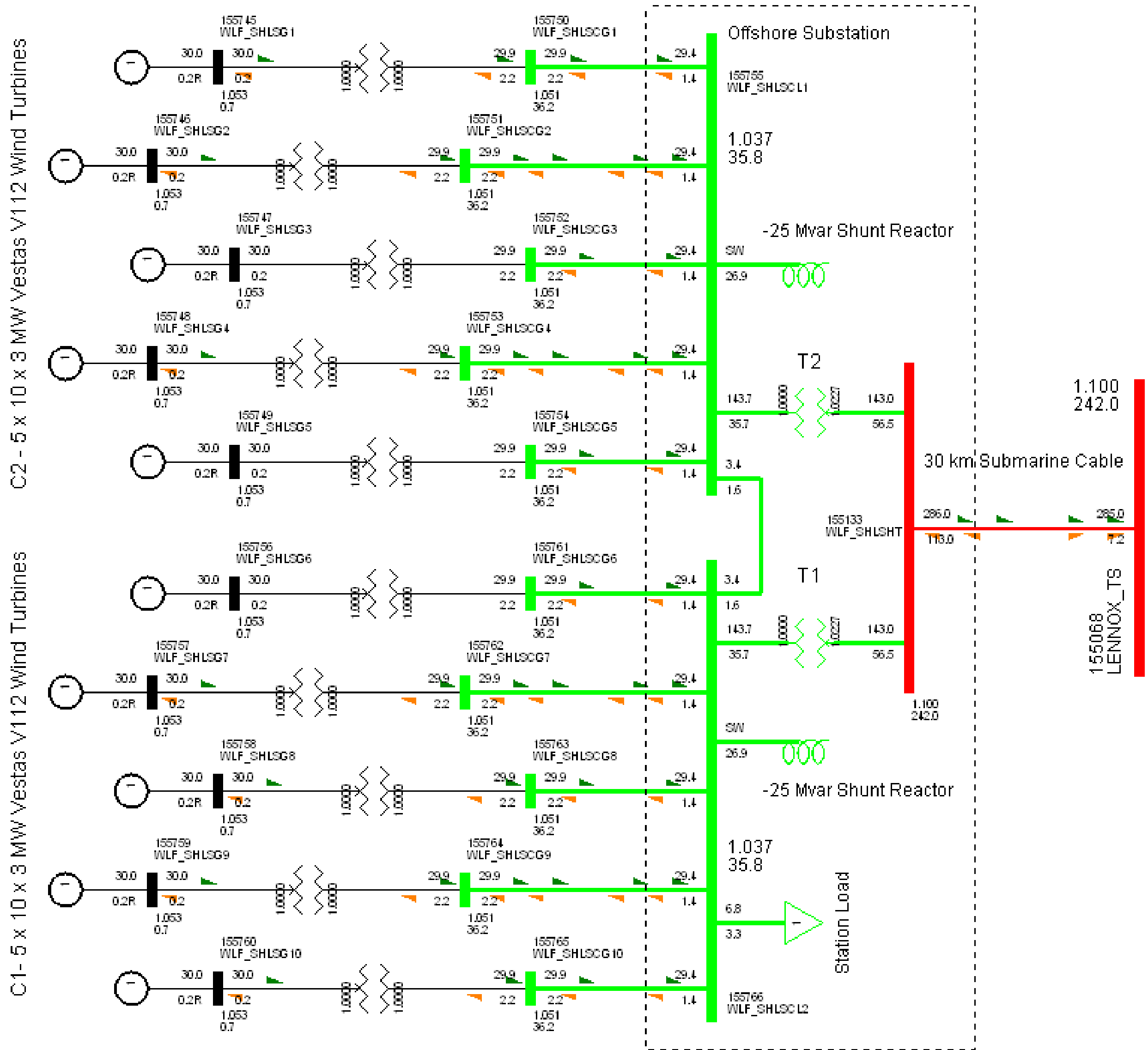


Figure 7: Approximately Unity Power Factor at Machines Terminals and Point of Connection

Figure 7 shows a condition where the machines are at unity power factor and the output from the facility at the point of connection, Lennox 230 kV TS, is also approximately equal to unity power factor. The machine voltages can be taken down from 1.05 pu to 1 pu if the WTG transformer is tapped at 1.025 pu on the HV side but this results in unacceptable machine terminal voltages of around 0.85 pu when absorbing maximum reactive power.

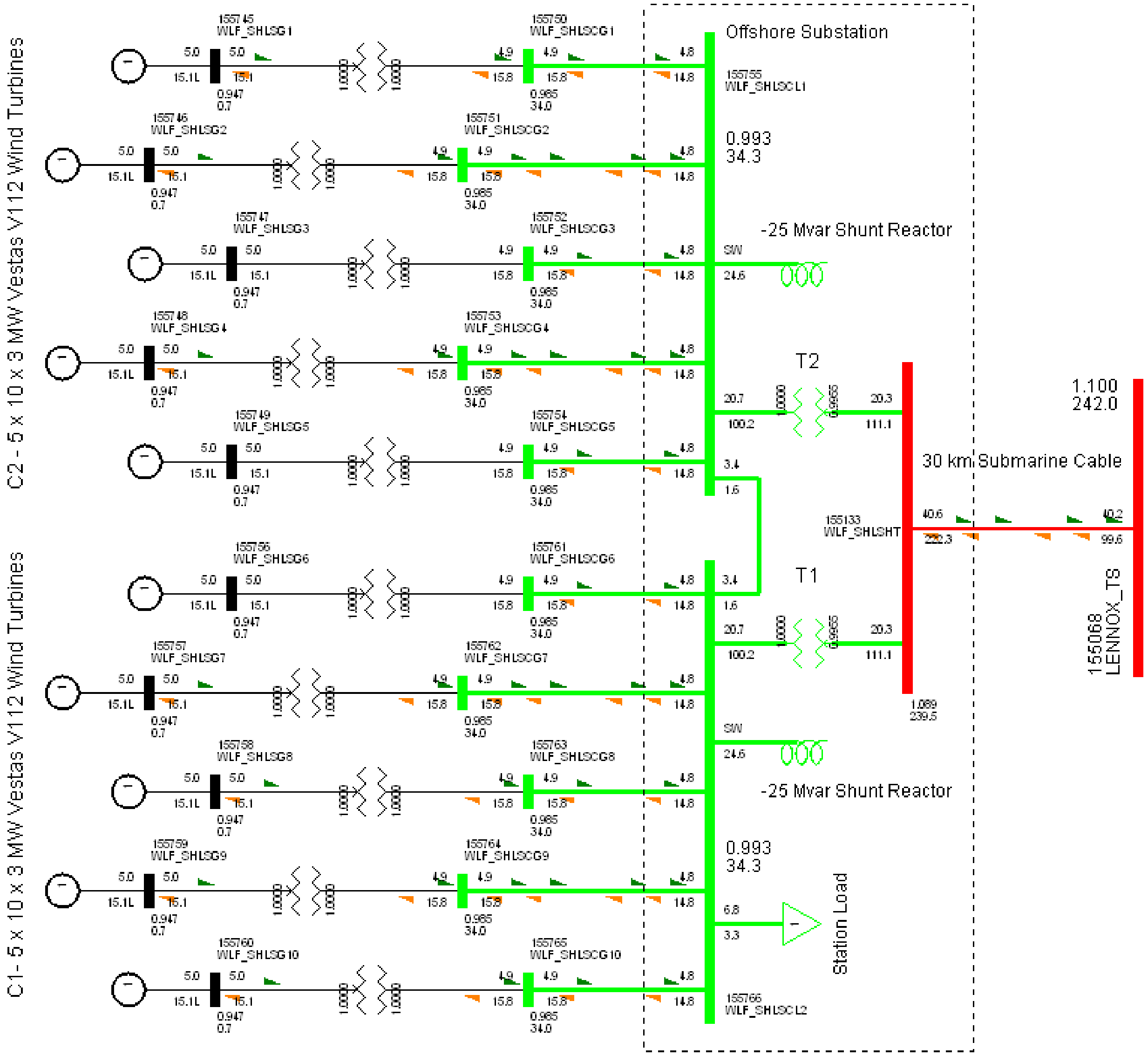


Figure 8: Absorbing 0.33 pu Reactive Power at Low Power Output

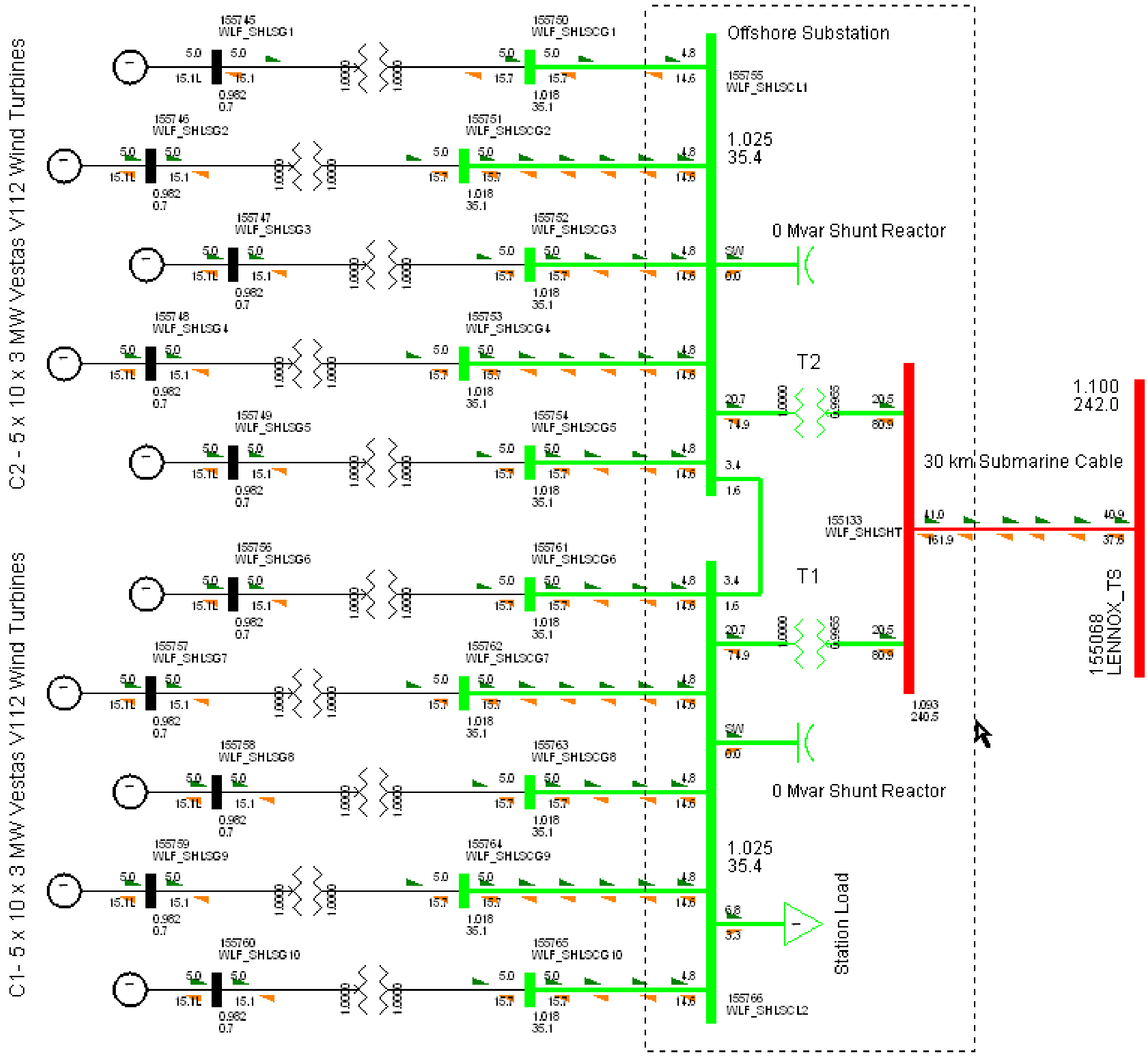


Figure 9: Absorbing 0.125 pu Reactive Power at Low Power Output Without Reactive Compensation.

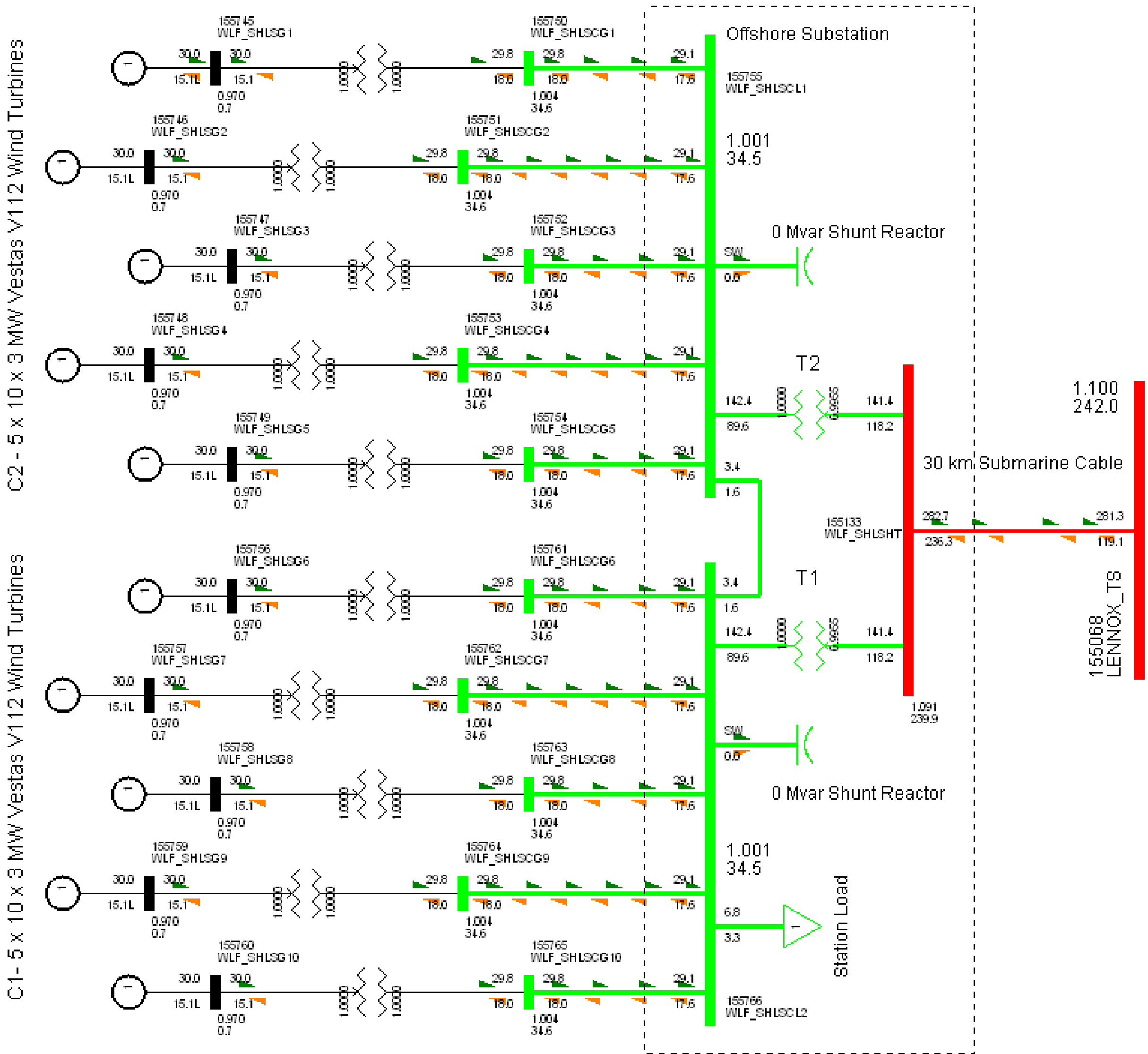


Figure 10: Absorbing 0.397 pu Reactive Power at Max Power Output Without Reactive Compensation

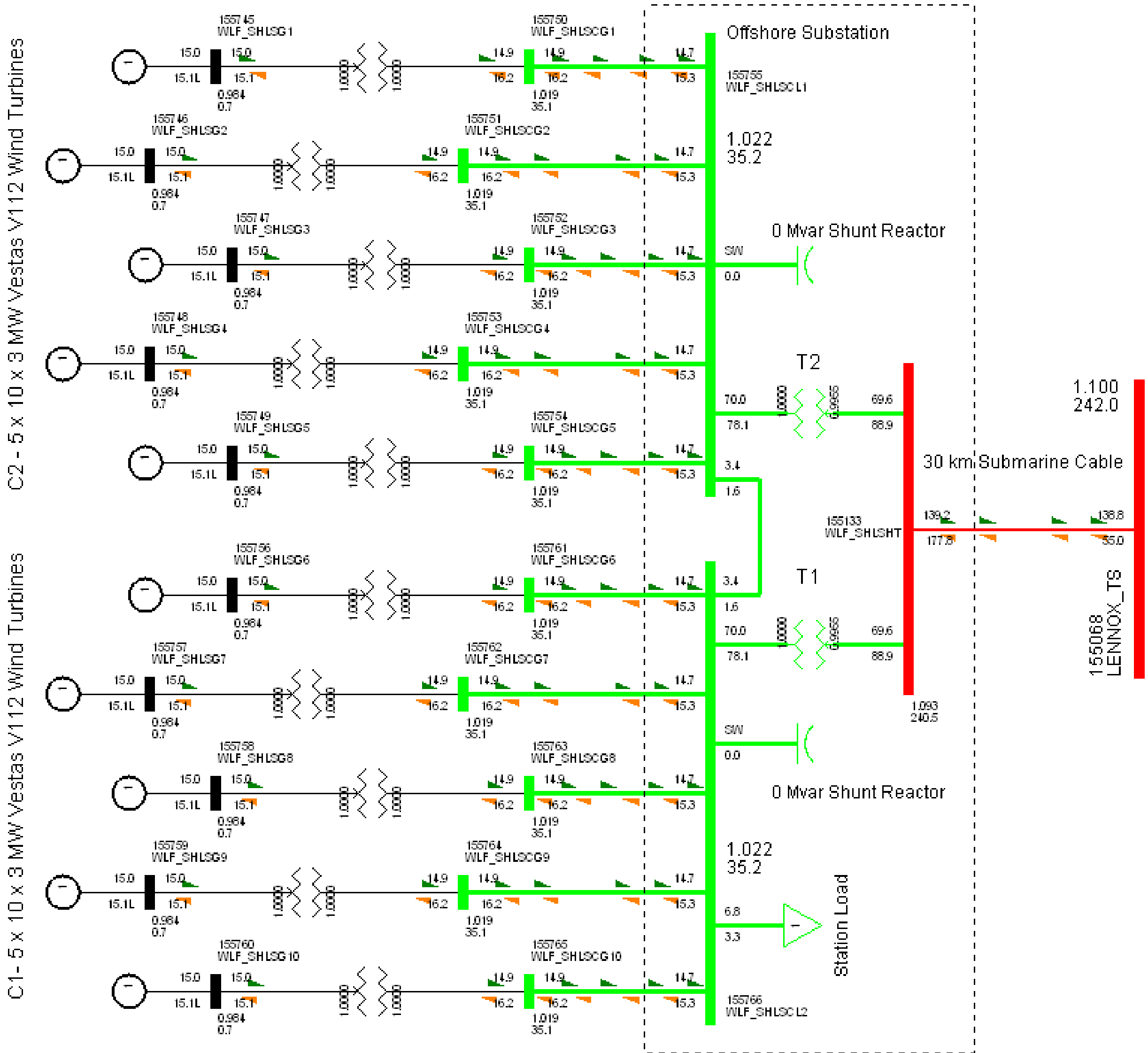


Figure 11: Absorbing 0.18 pu Reactive Power at Half Power Output Without Reactive Compensation

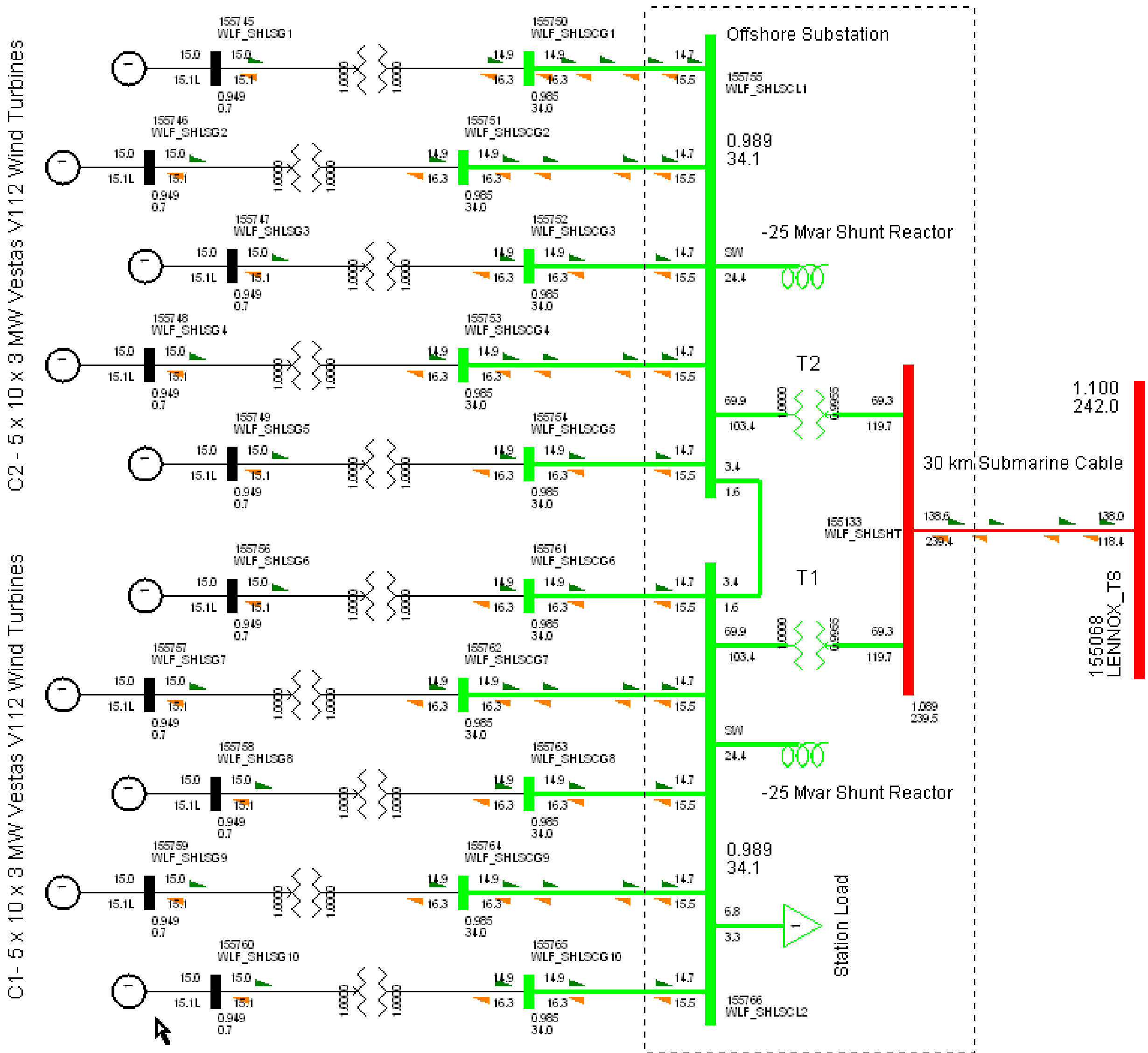


Figure 12: Absorbing 0.393 pu Reactive Power at Half Power Output With Reactive Compensation

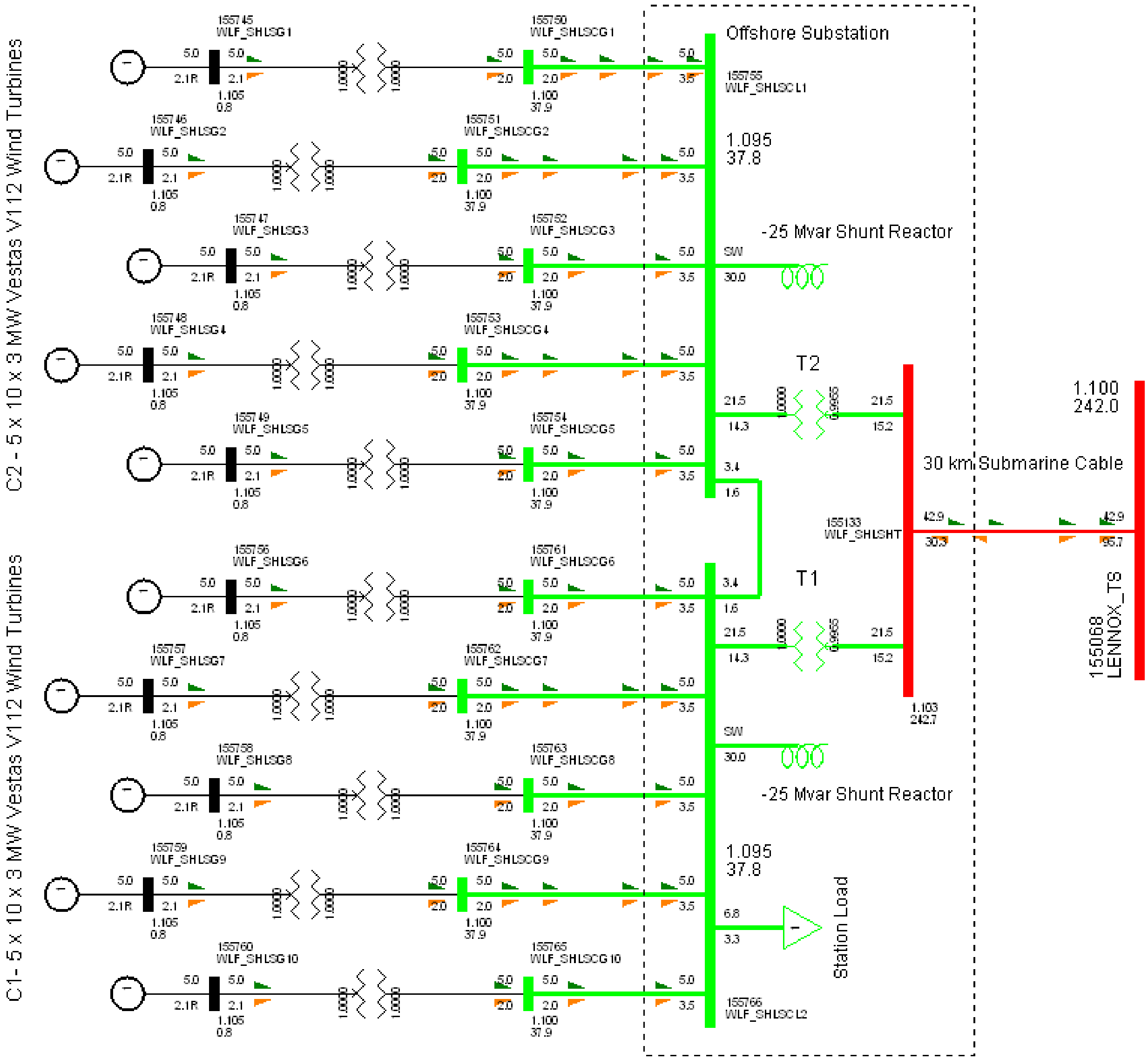


Figure 13: Generating 0.32 pu Reactive Power at 13% Power Output With Reactive Compensation

This example demonstrates that at the selected system voltage, 0.33 pu is achievable but collector bus voltages are at the continuous limits of the WTG plant. ULTC operation would be required at higher 230 kV system voltages to ensure the collector and WTG voltages were not above ratings.

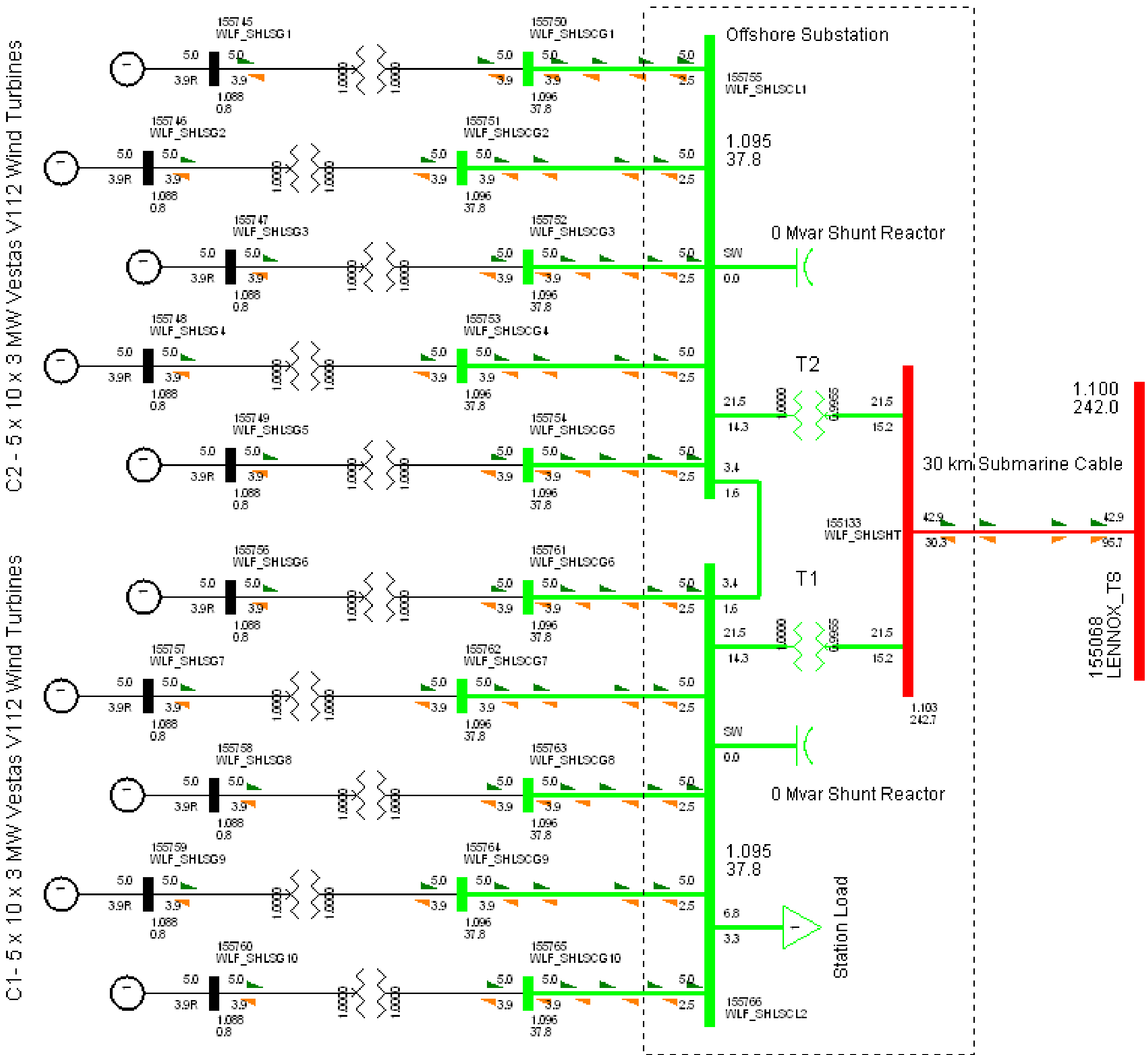


Figure 14: Generating 0.32 pu Reactive Power at Low Power Output Without Reactive Compensation

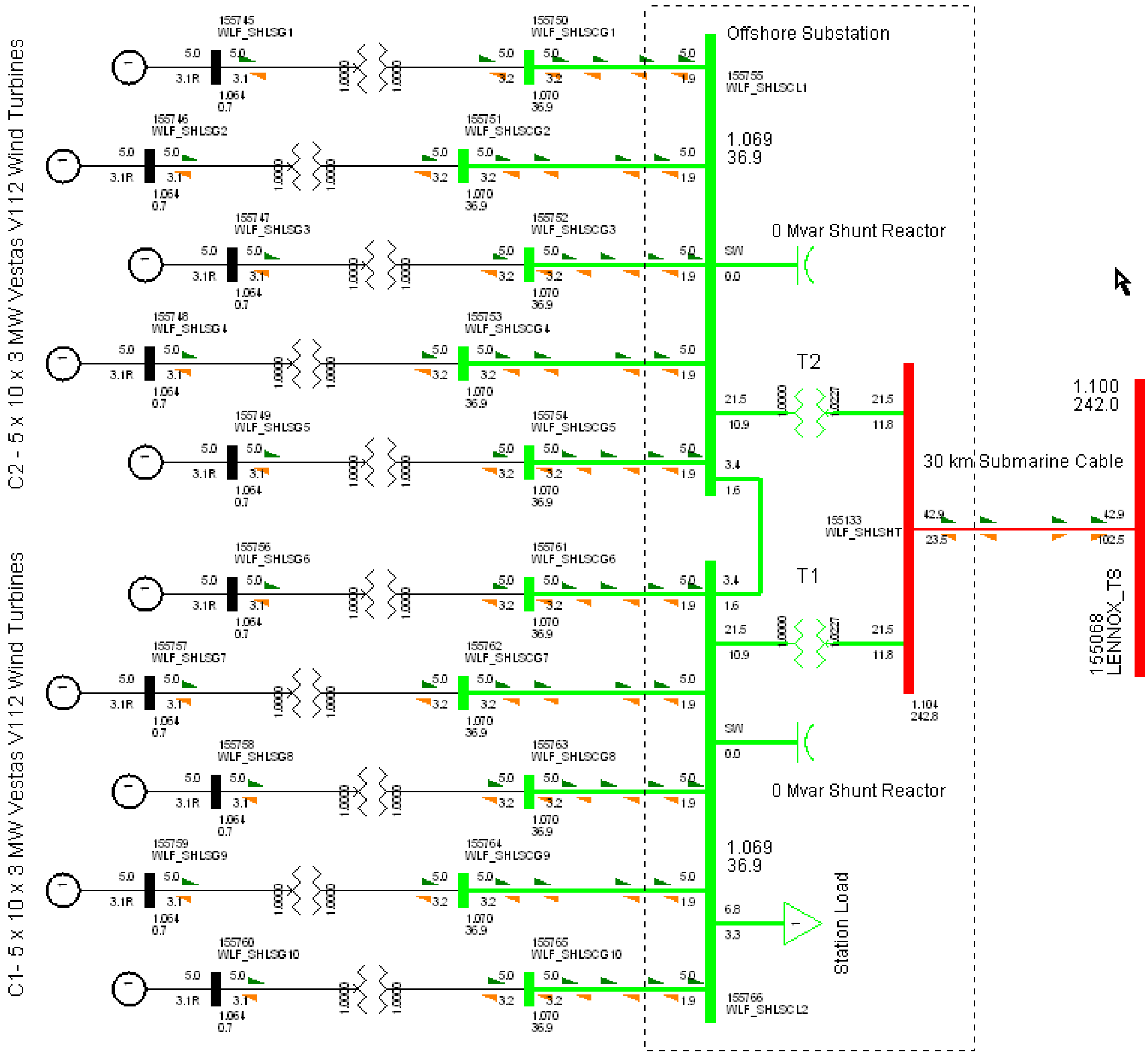


Figure 15: Generating 0.34 pu Reactive Power at 13% Power Output Without Reactive Compensation

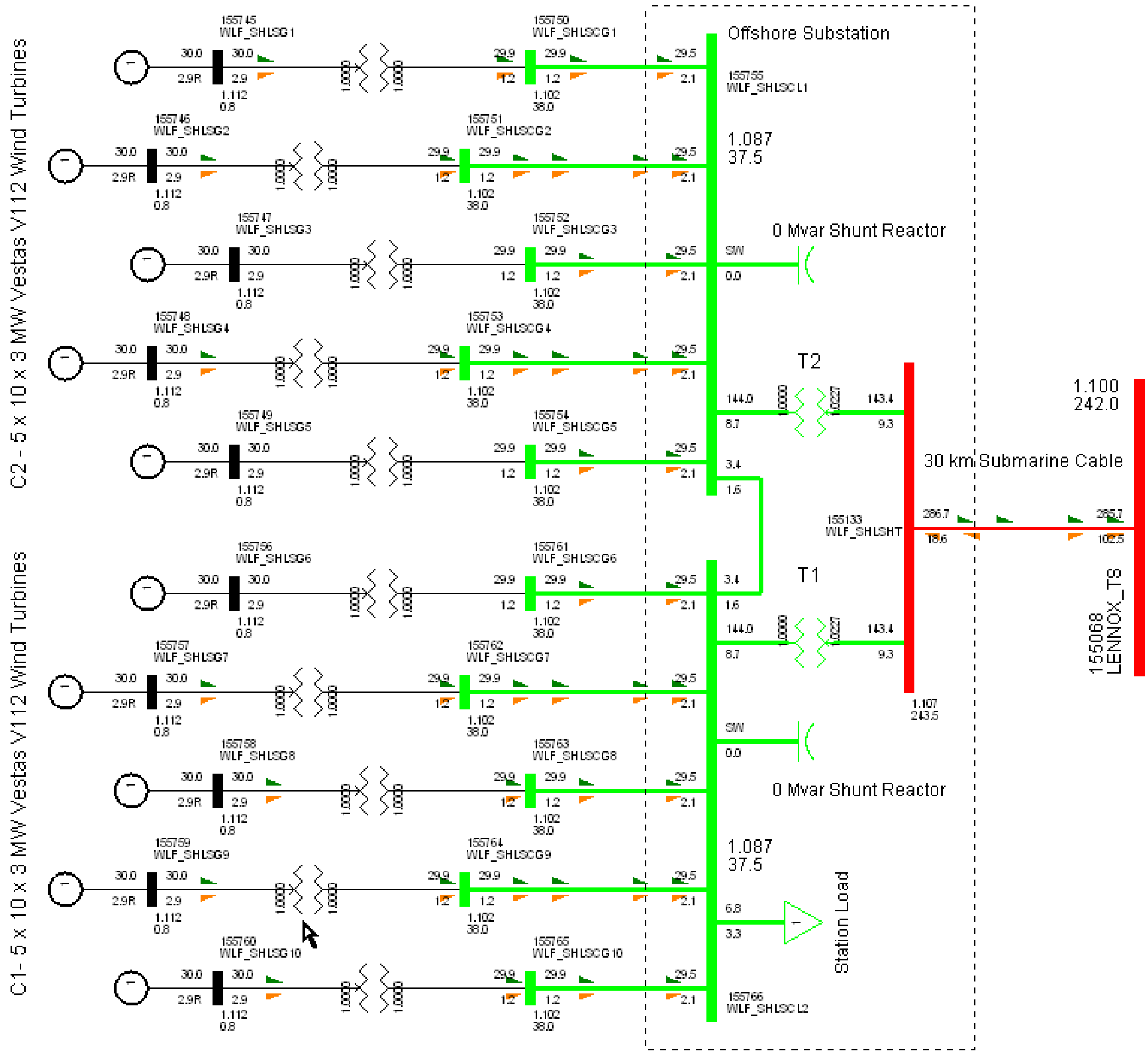


Figure 16: Generating 0.34 pu Reactive Power at Full Power Output Without Reactive Compensation

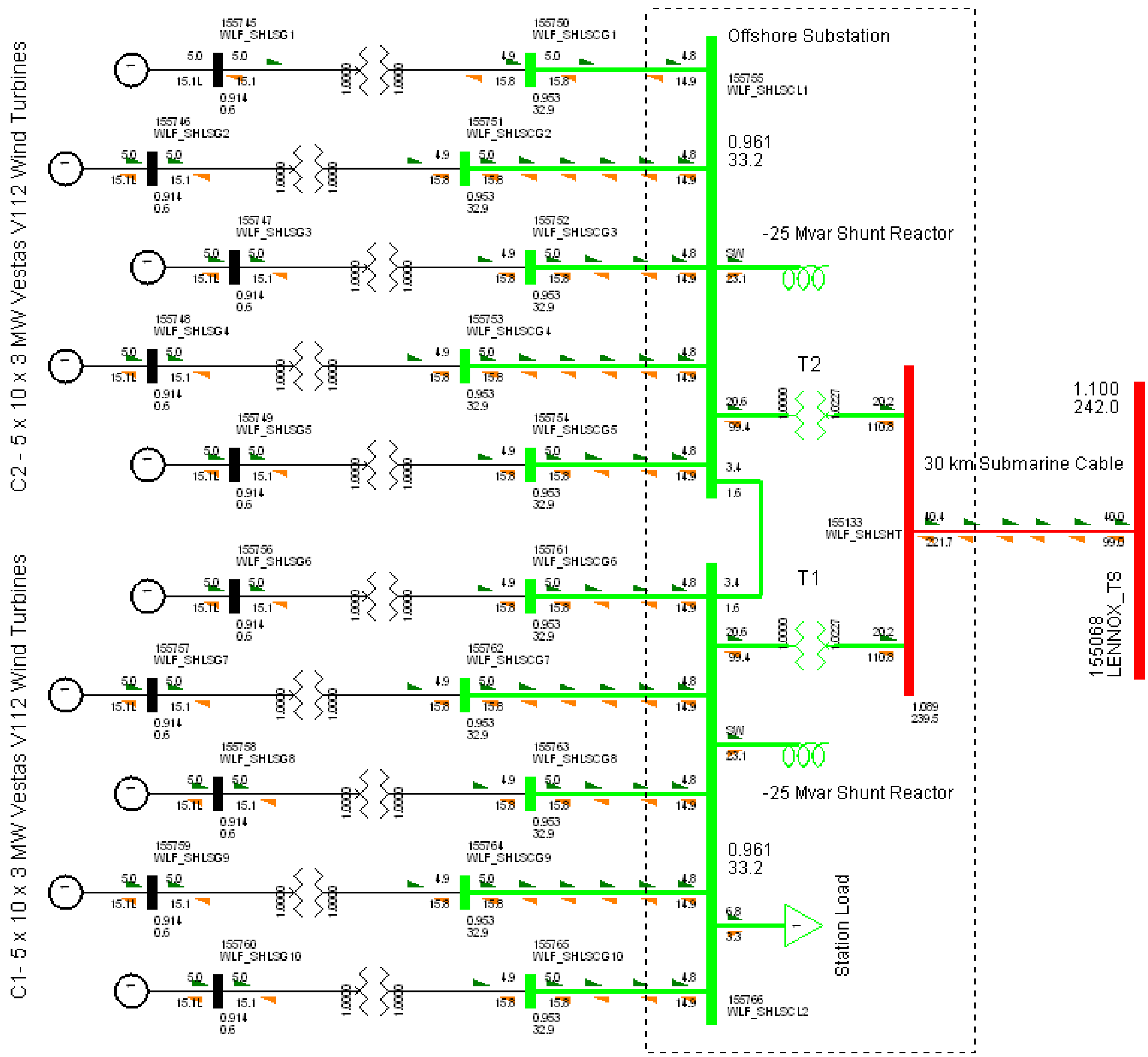


Figure 17: Absorbing 0.33 pu Reactive Power at Low Power Output (alternate tap setting)

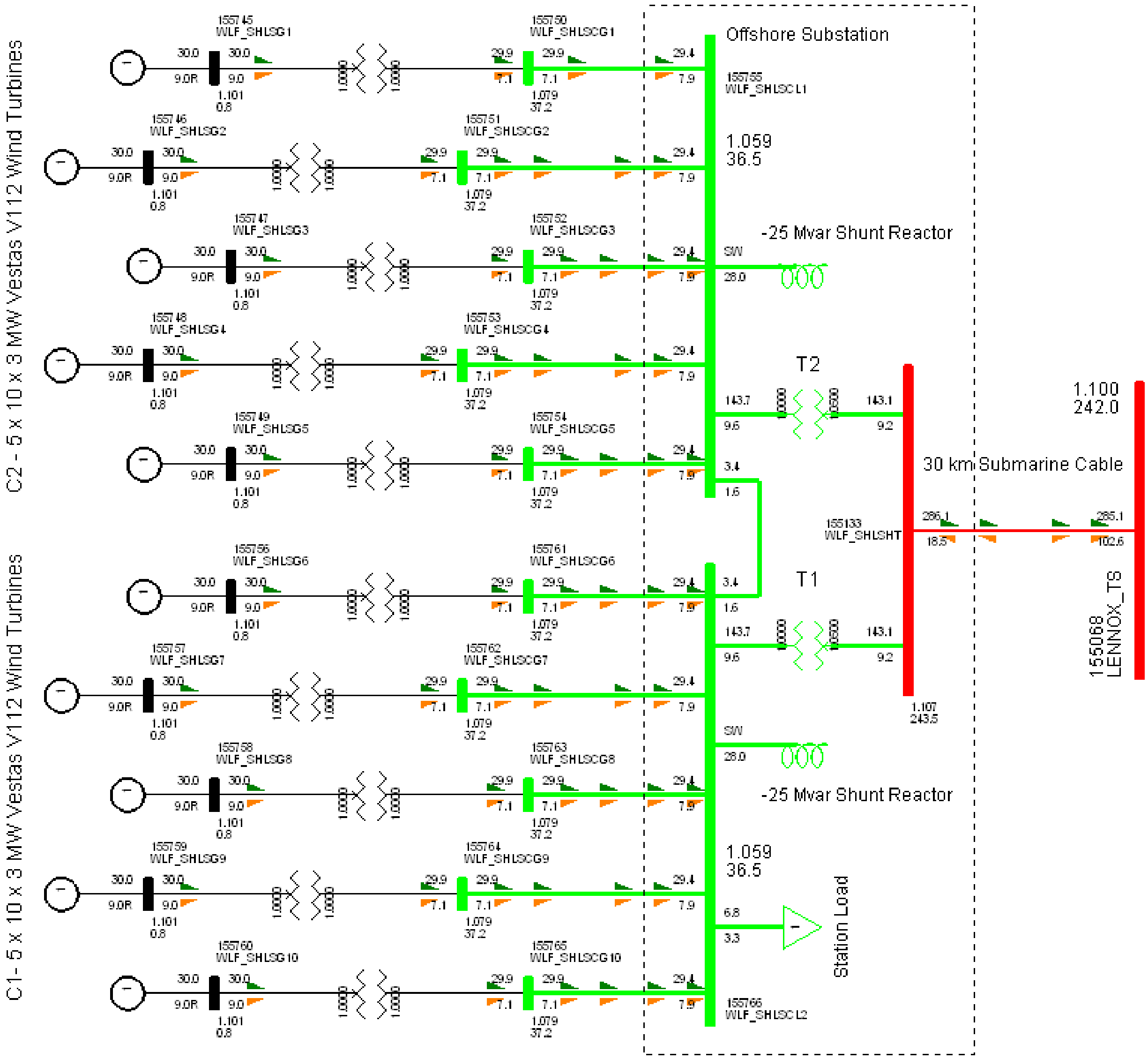


Figure 18: Generating 0.33 pu Reactive Power at Full Power Output With Reactive Compensation

Figure 18 is a full output version of the scenario in Figure 13. This example also demonstrates that at the selected system voltage, 0.33 pu reactive power output at the PCC is achievable but WTG voltages are at the continuous limits of the WTG plant. ULTC operation would be required at higher 230 kV system voltages to ensure the collector and WTG voltages were not above ratings.

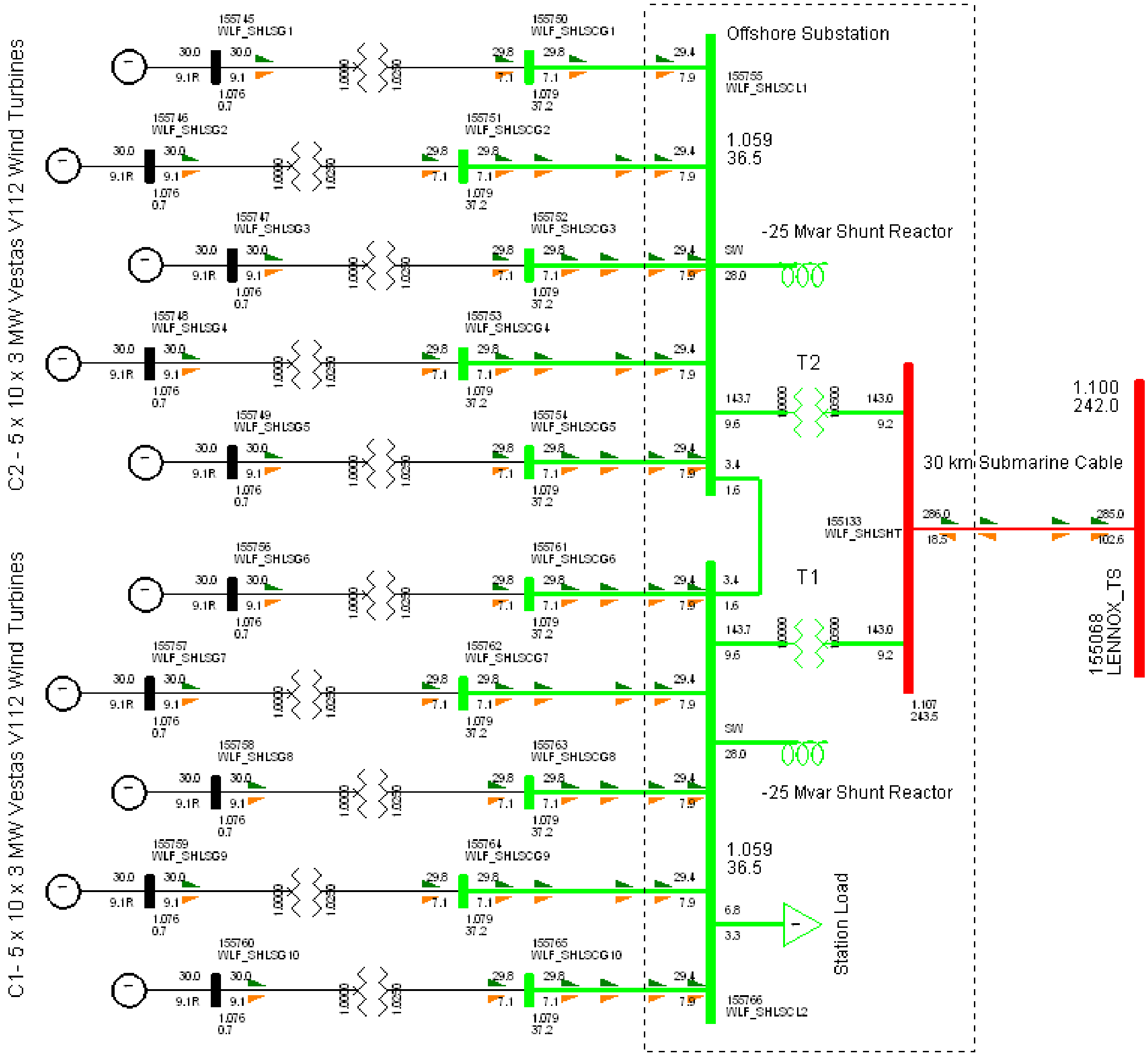


Figure 19: Generating 0.33 pu Reactive Power at Full Power Output With Reactive Compensation at 1.025 pu tap setting

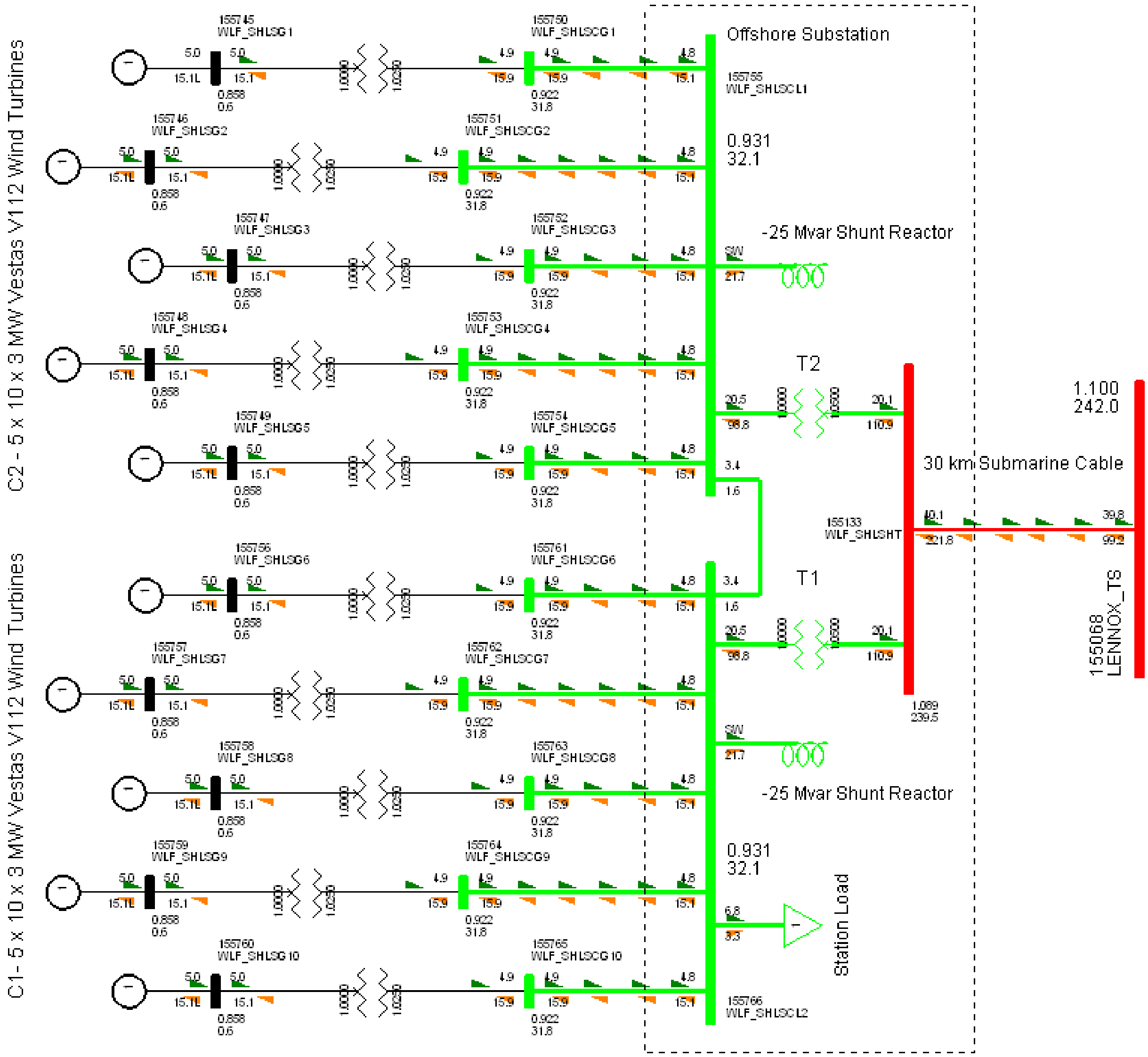


Figure 20: Absorbing 0.33 pu Reactive Power at 13% Power Output With Reactive Compensation and 1.025 pu WTG transformer tap setting

There was some investigation into setting the WTG taps to lower the terminal voltage so that the machine voltage is close to 1 pu, while at unity pf. However, Figure 20 shows that under some conditions, the terminal voltage would be as low as 0.85 pu and this is not acceptable for the Vestas V112 machines.

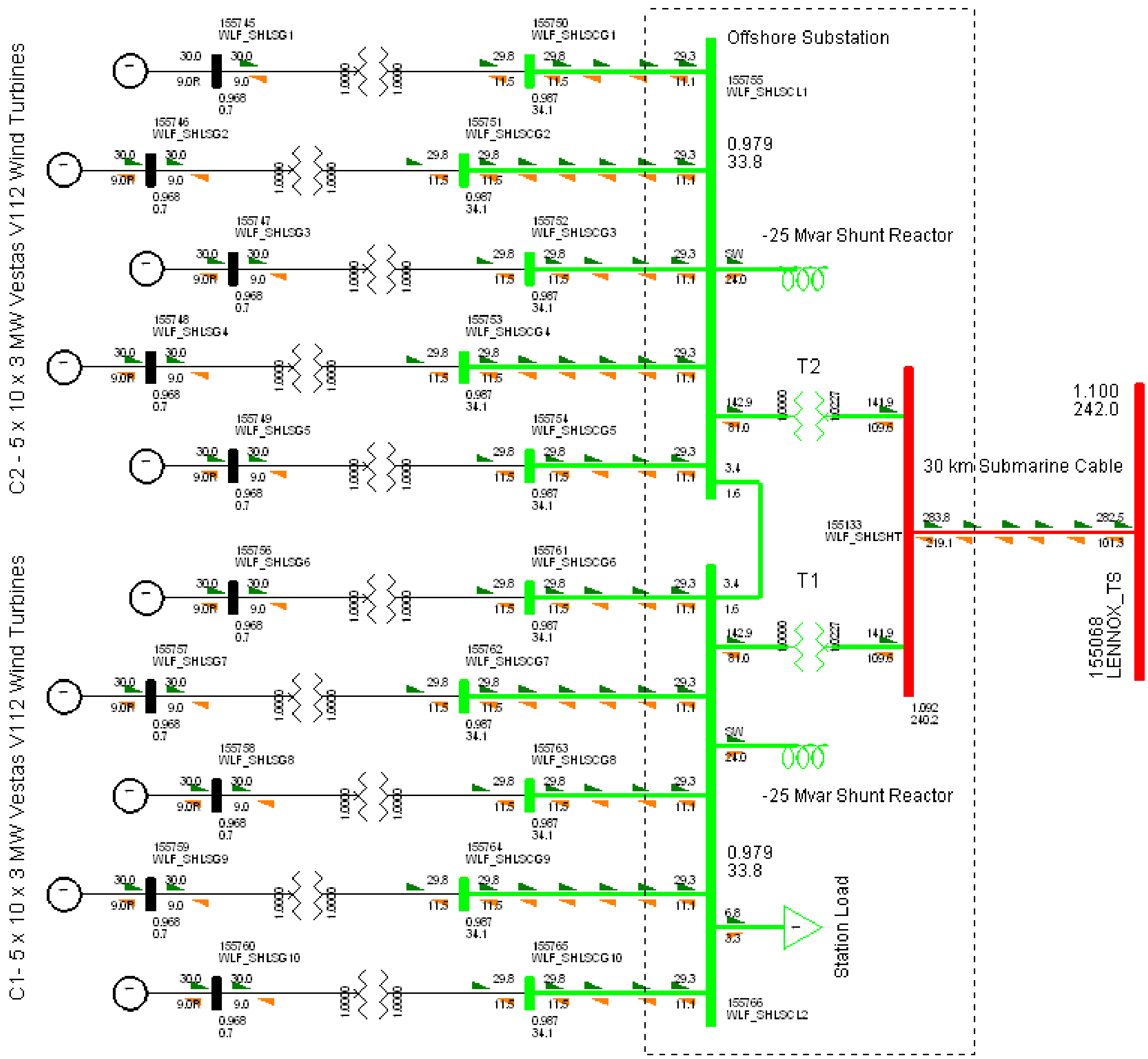


Figure 21: Absorbing 0.33 pu Reactive Power at Full Power Output.

This study was done to demonstrate that while absorbing the required amount of reactive power at rated plant output, the continuous equipment ratings provided will be exceeded due to the charging current of the 230 kV cable. The cable is carrying 234 MW and 219 MVAr, which is 363 MVA. At 240 kV, the load will be 870 Amps and the equipment is rated at 800 Amps. The 230 kV buses and equipment are rated at 400 Amps and they will carry 430 Amps under these conditions. The transformers are rated for the higher ONAF rating of 165 MVA and they would carry 178 MVA under these conditions.

The following options are available to the plant owner:

- Confirm the reactive capability of the plant at full power output would not be limited because the duration of the circumstances described, would result in short term overload ratings being utilised
- Increase the thermal capacity of the equipment
- Curtail active power output to avoid overloading

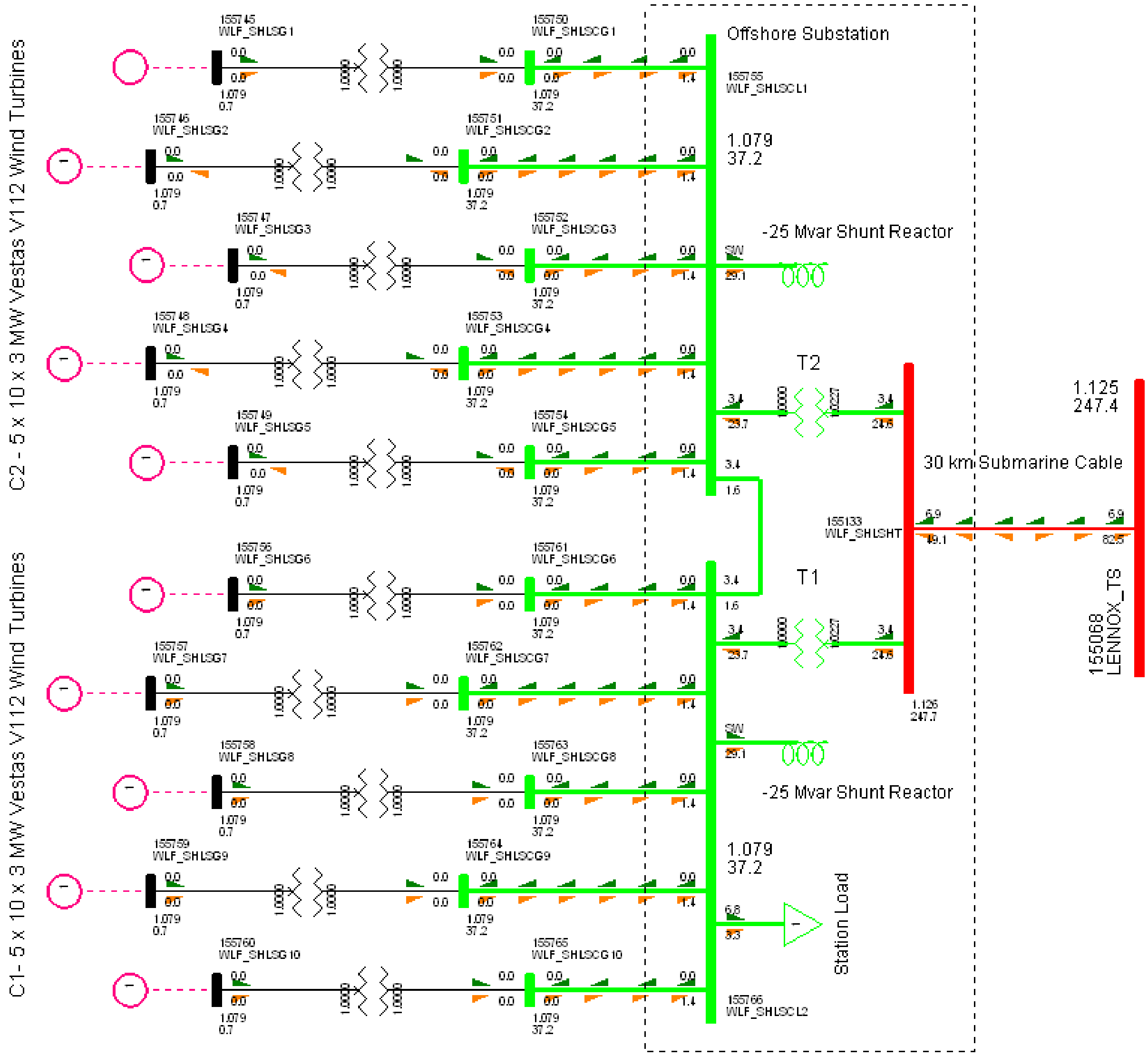


Figure 22: MVAr injection to IESO controlled grid at PCC with wind turbine reactive capability disconnected and 230 kV submarine cable in service.

Figure 22 shows that with the –50 MVAr of reactor banks in service, at conditions which leave the WTG plant unable to absorb reactive power, surplus MVAr is generated at the point of connection. This subtracts from the output of existing reactors placed at Lennox TS and is not permissible at this part of the network, where high voltages are an issue.

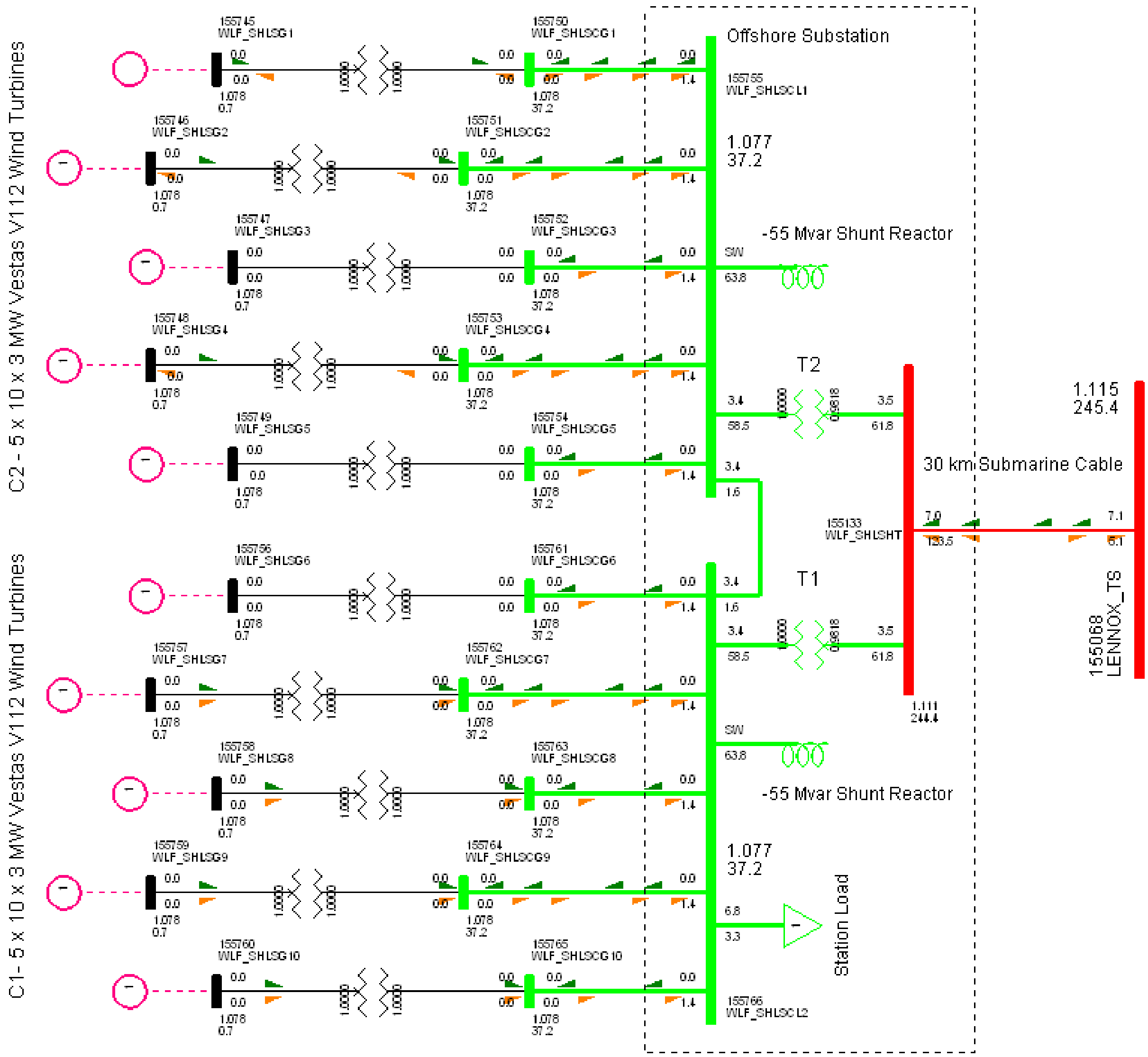


Figure 23: Additional shunt reactor requirement with wind turbine reactive capability disconnected and 230 kV submarine cable in service.

Addition of a further -60 MVAr of reactor banks provides an acceptable solution to the issues which arise from WTG's and their reactive capability disconnected from the system.

6.6 Wind Farm Management System

The Wind Farm Management System (WFMS) must coordinate the voltage control process.

The IESO requires that all generation facilities connected to the IESO-controlled grid control voltages in the system. It is expected that the wind farm controls the voltage at a point as close as possible to the connection point to values specified by the IESO. This requires that wind farms possess the ability to supply sufficient dynamic reactive power to the high voltage system during voltage declines.

The generation facility shall regulate automatically voltage at a point whose impedance (based on rated apparent power and rated voltage) is not more than 13% from the highest voltage terminal based within ±0.5% of any set point within ±5% of rated voltage. If the AVR target voltage is a function of reactive output, the slope $\Delta V / \Delta Q_{max}$ shall be adjustable to 0.5%.

The Wind Farm Management System (WFMS) must coordinate the voltage control process. The IESO recommend the following two voltage control schemes:

Recommendation #1

(1) All WTGs control the PCC voltage to a reference value. A control slope is applied for reactive power sharing among the WTGs as well as with adjacent generators.

(2) Reactors are automatically switched in/out to regulate the overall WTGs' reactive generation to around zero output.

(3) WF main transformer ULTC is adjusted to regulate the collector bus voltage (LT bus voltage) such that it is within normal range;

Recommendation #2

(1) The reactors are automatically switched in/out according to the WF active power output.

(2) All WTGs control the PCC voltage to a reference value. A control slope is applied for reactive power sharing among the WTGs as well as with adjacent generators.

(3) WF main transformer ULTC is adjusted to regulate the collector bus voltage (LT bus voltage) such that it is within normal range;

The proponent must submit a description of the functionalities of the WFMS, including the coordination between the automatic reactor switching and generator reactive power production to control the voltage at a desired point. This document also must contain the settings of the automatic reactor switching scheme. If the WFMS is unavailable, the IESO requires each generator controls its own terminal voltage.

6.7 Transient Analysis

Transient Stability Analysis was performed considering faults in the Eastern Area with the proposed Wolfe Island Wind Farm in-service. The following 3phase/LG double faults were simulated with the Vestas V112 model integrated into the basecase dynamics model.

Table 12: List of Faults for dynamic performance testing

Contingency	Voltage (kV)	Location	Fault Level (MVA)	Fault Clearing Time (ms)	
				Local	Remote
Normally Cleared Simultaneous LG Faults on different phases of circuits X522A + M29C	500kV/ 230kV	Hawthorne/ Merivale	162.8-j4774.8 1160.3-j3436.9	66 (X522A) 83 (M29C)	107 (X522A) 115 (M29C)
Normally Cleared Simultaneous LG Faults different phases of circuits X522A + M31A	500kV/ 230kV	Hawthorne	1907.3-j34851.6 2890.3-j33941.8	75(X522A) 66(M31A)	90(X522A) 107(M31A)
Normally Cleared Simultaneous LG Faults on different phases of circuits X3H + X4H	230kV	Lennox	-3055-j18180.6 4975.3-j17655.8	66	107
Normally Cleared 3-phase Lennox T52 fault	500kV	Lennox	-	74	-
3-Phase fault on X3H near Lennox followed by H51L1 Breaker Failure and Backup Clearing	230kV	Lennox	-	156 (incl. breaker failure and backup clearing)	173

Appendix C shows the time-based plots following application of each of the faults noted above. The internal machine angles of all Darlington and Lennox generating units have been plotted. For the Vestas V112 machines at Wolfe Island Shoals, the Active Power, Reactive Power, Machine Terminal Voltages, and Collector Bus Voltages are plotted. None of the simulated faults produced transient instability or under-damped oscillations.

6.8 Low-voltage ride through capability

The Vestas V112 Under-Voltage-Relay-Trip settings are noted below. These settings were provided in the *Vestas Generic PSS/E Model for Vestas Wind Turbines (Version 7.3)* as part of the Vestas GridStreamer™ Model.

Table 13: LVRT Settings for Vestas GridStreamer™ Model

Voltage Limit	Setting (pu)	Timeout	Setting (ms)
$U_{LVRT}1$	0.00	$t_{LVRT}1$	450
$U_{LVRT}2$	0.70	$t_{LVRT}2$	2.65
$U_{LVRT}3$	0.85	$t_{LVRT}3$	11
$U_{LVRT}4$	0.90	$t_{LVRT}4$	60

For Low-Voltage ride through capability testing, the closest fault which does not disconnect the windfarm by configuration was simulated. Specifically, a 3-phase fault on X3H at Lennox, followed by a H51L1 breaker failure and backup clearing was tested. The clearing time for this fault is 173ms.

The resultant terminal voltages have been plotted against the manufacturer provided LVRT voltage-time settings.

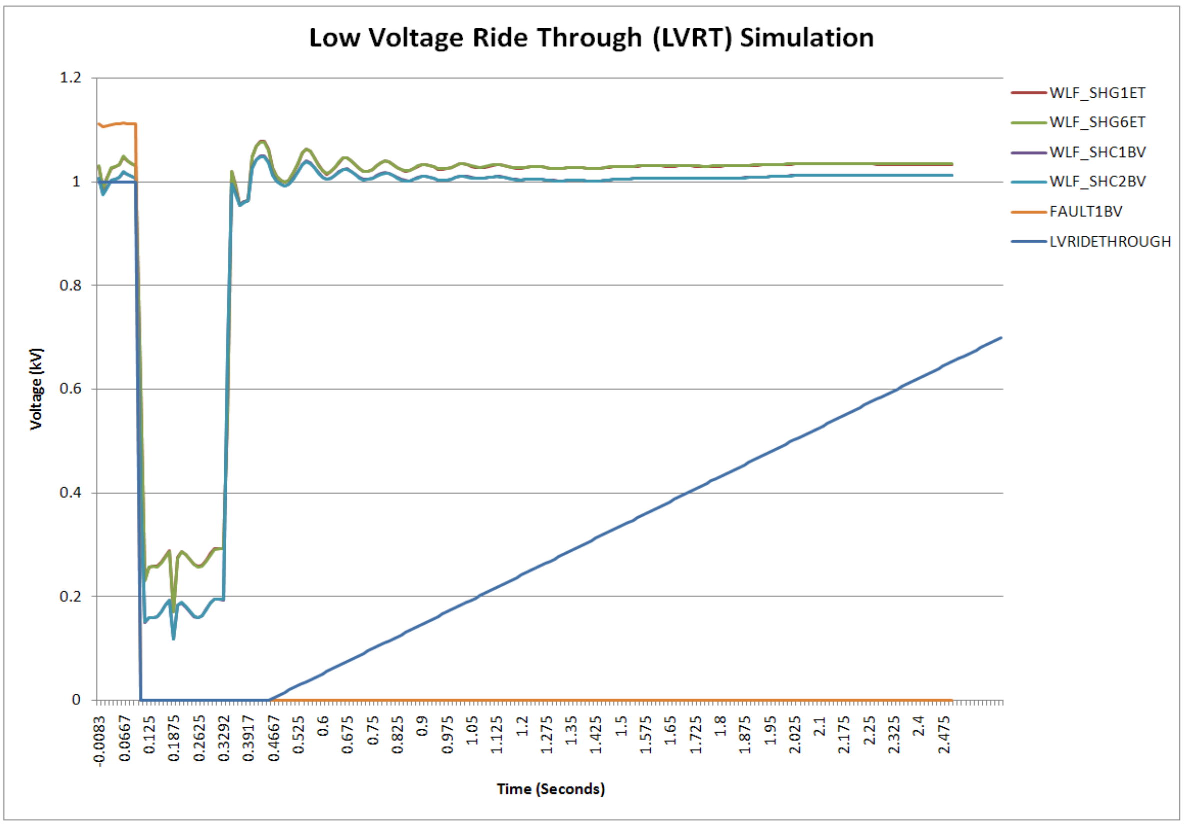
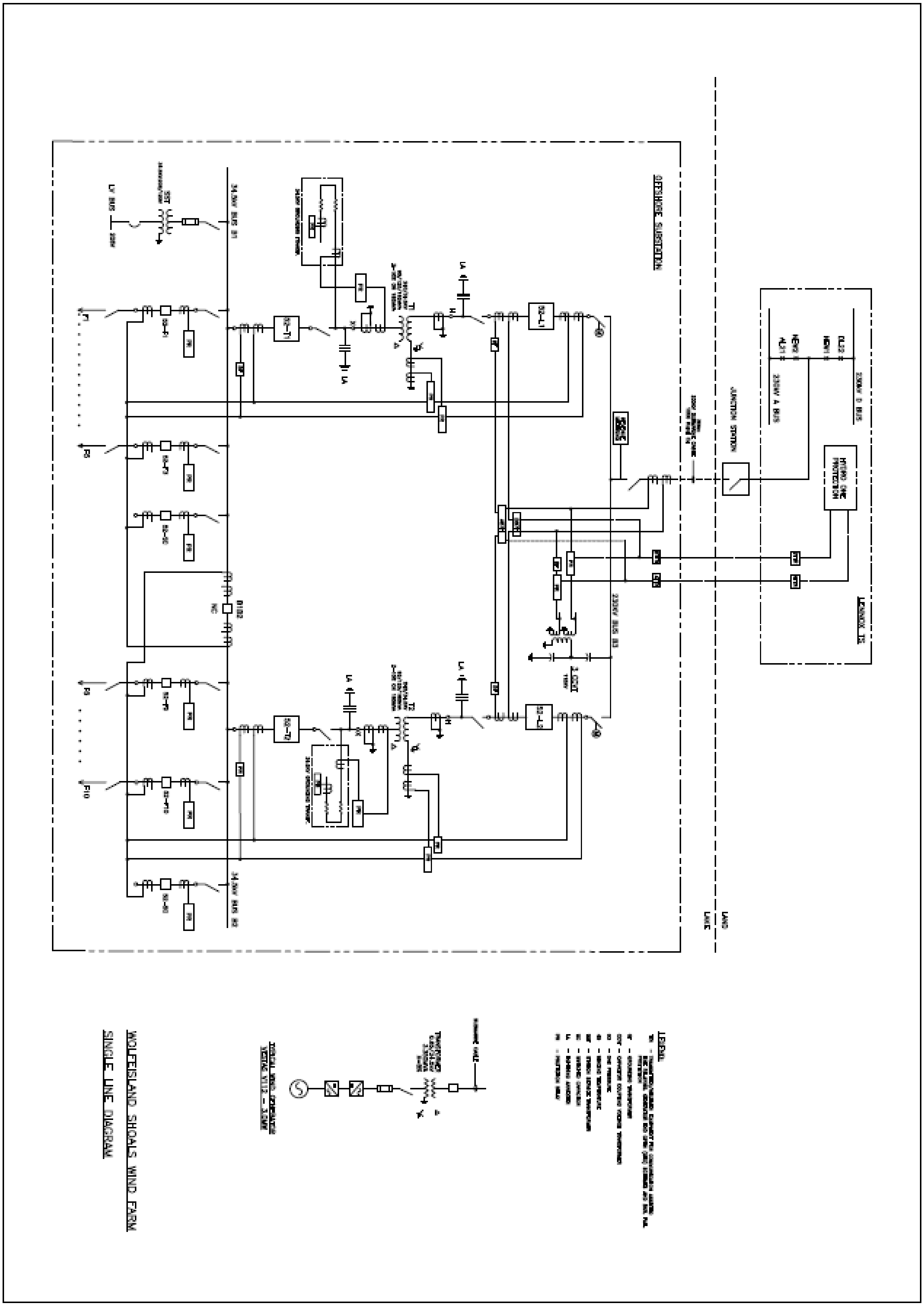


Figure 24: Low Voltage Ride Through Capability Test

– End of Report –

Appendix A: Single Line Diagram


WOLFEISLAND SHOALS WIND FARM
SINGLE LINE DIAGRAM
OFFSHORE SUBSTATION
34.5kV BUS B1
34.5kV BUS B2
230kV BUS B3
JUNCTION STATION
HYDRO ONE PROTECTION
LEGEND
LAKE
LAND

Appendix B: Diagrams for Load Flow Results

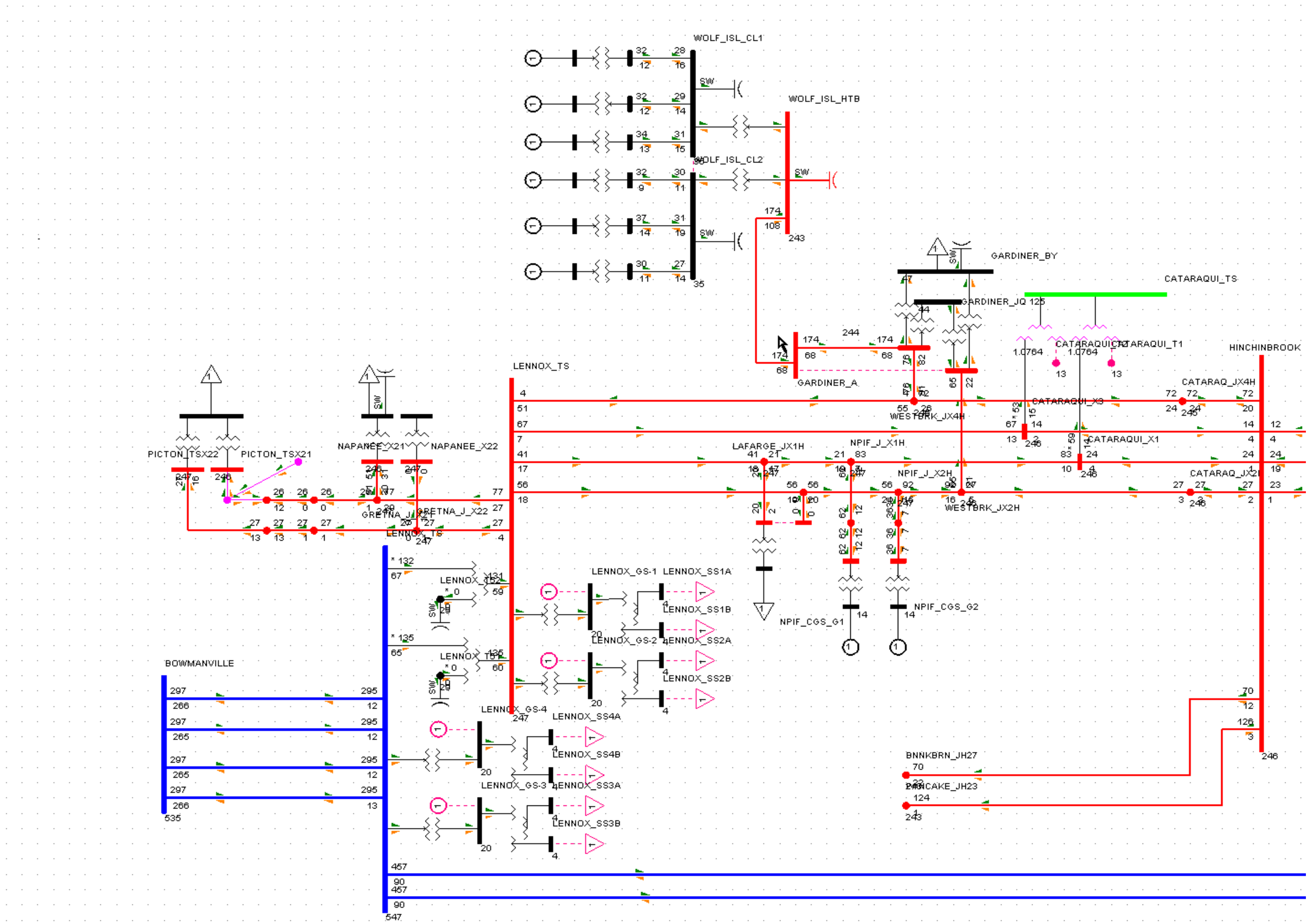


Figure 25: Eastern Transmission System without Wolfe Wind Farm Shoals

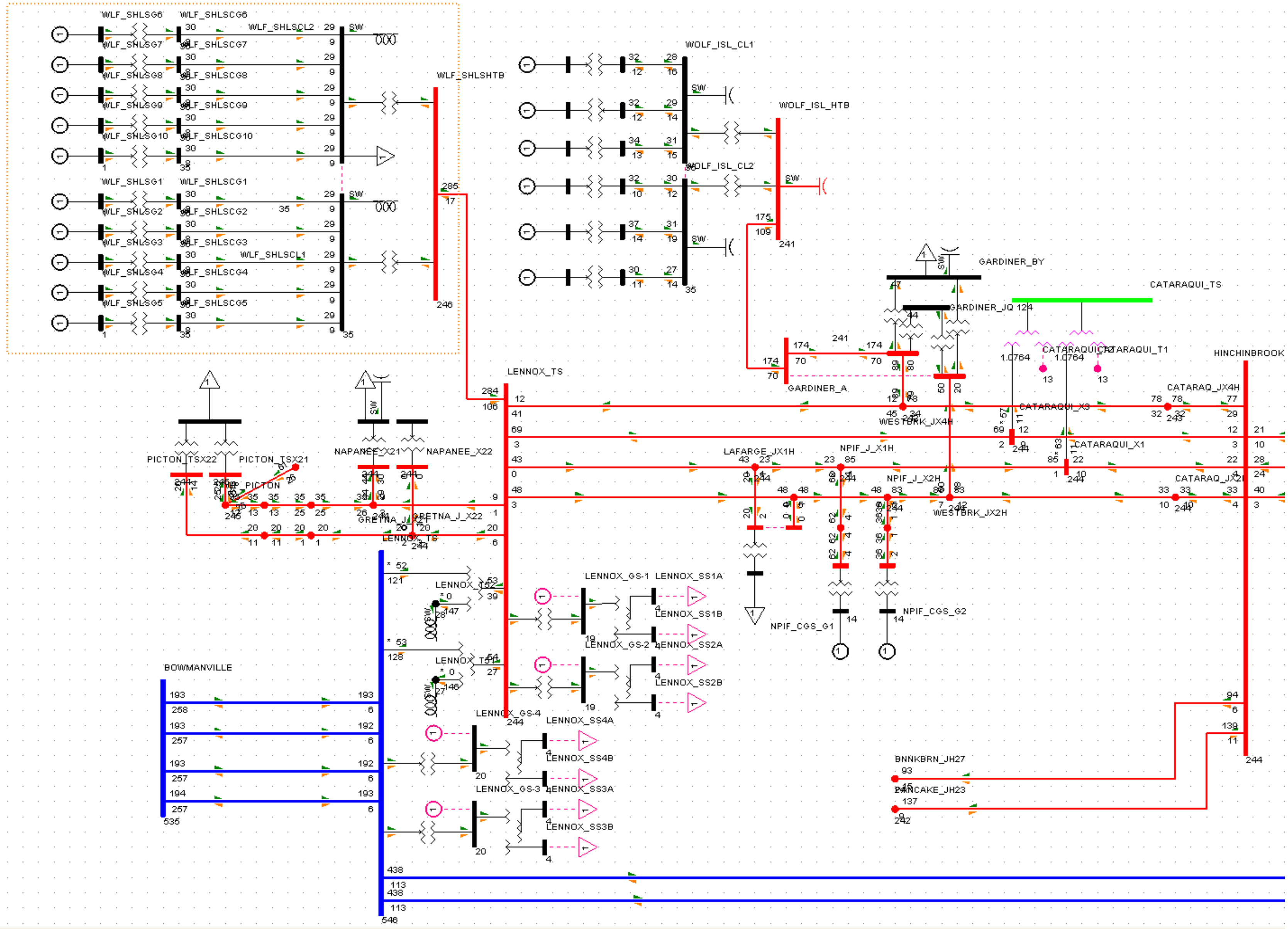


Figure 26: Eastern Transmission System with Wolfe Island Shoals Generating 300MW

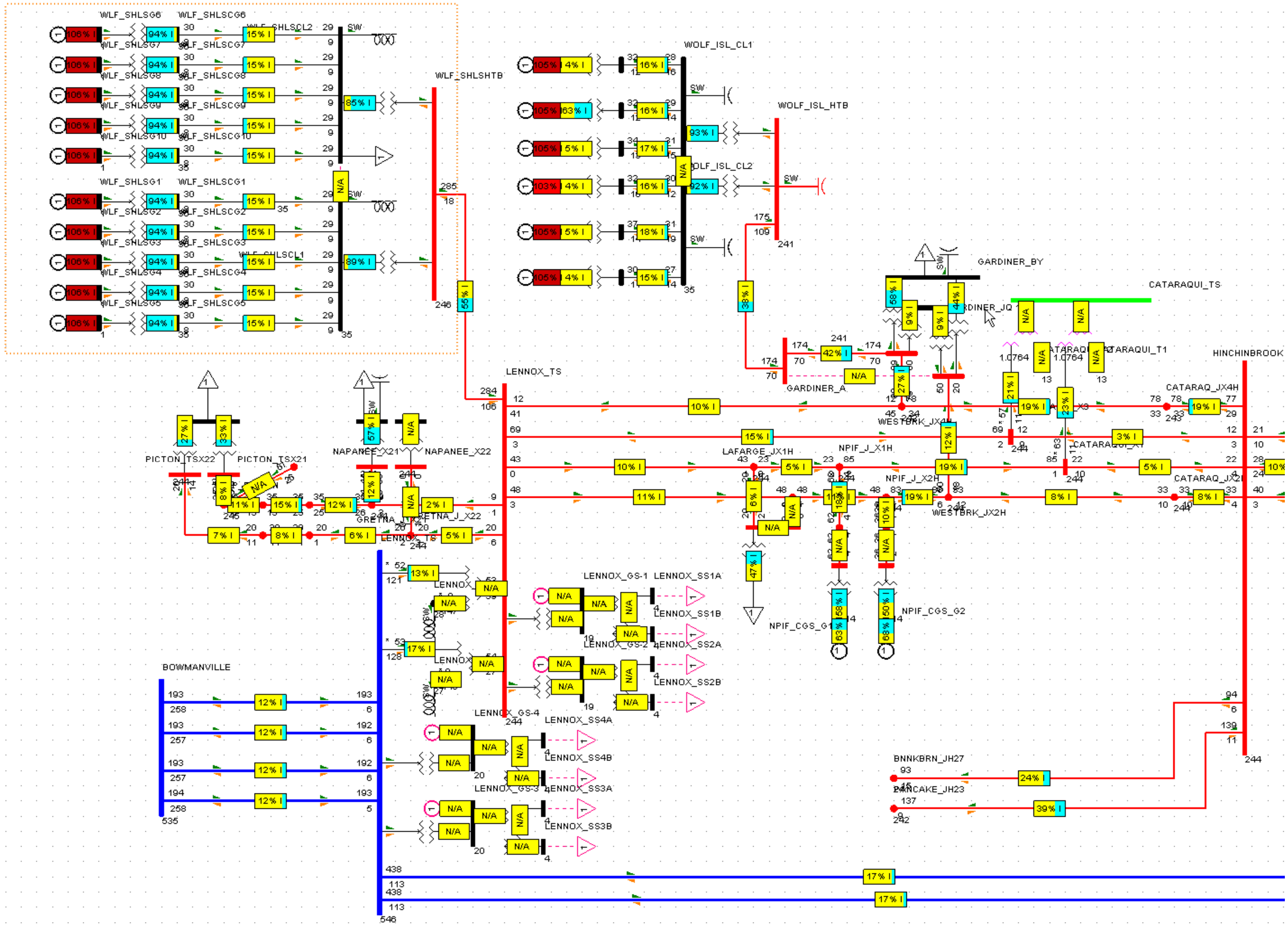


Figure 27: Eastern Transmission System Loadings with Wolfe Island Shoals Generating 300MW. Percentage loading is based on continuous current ratings available in PSSE basecase

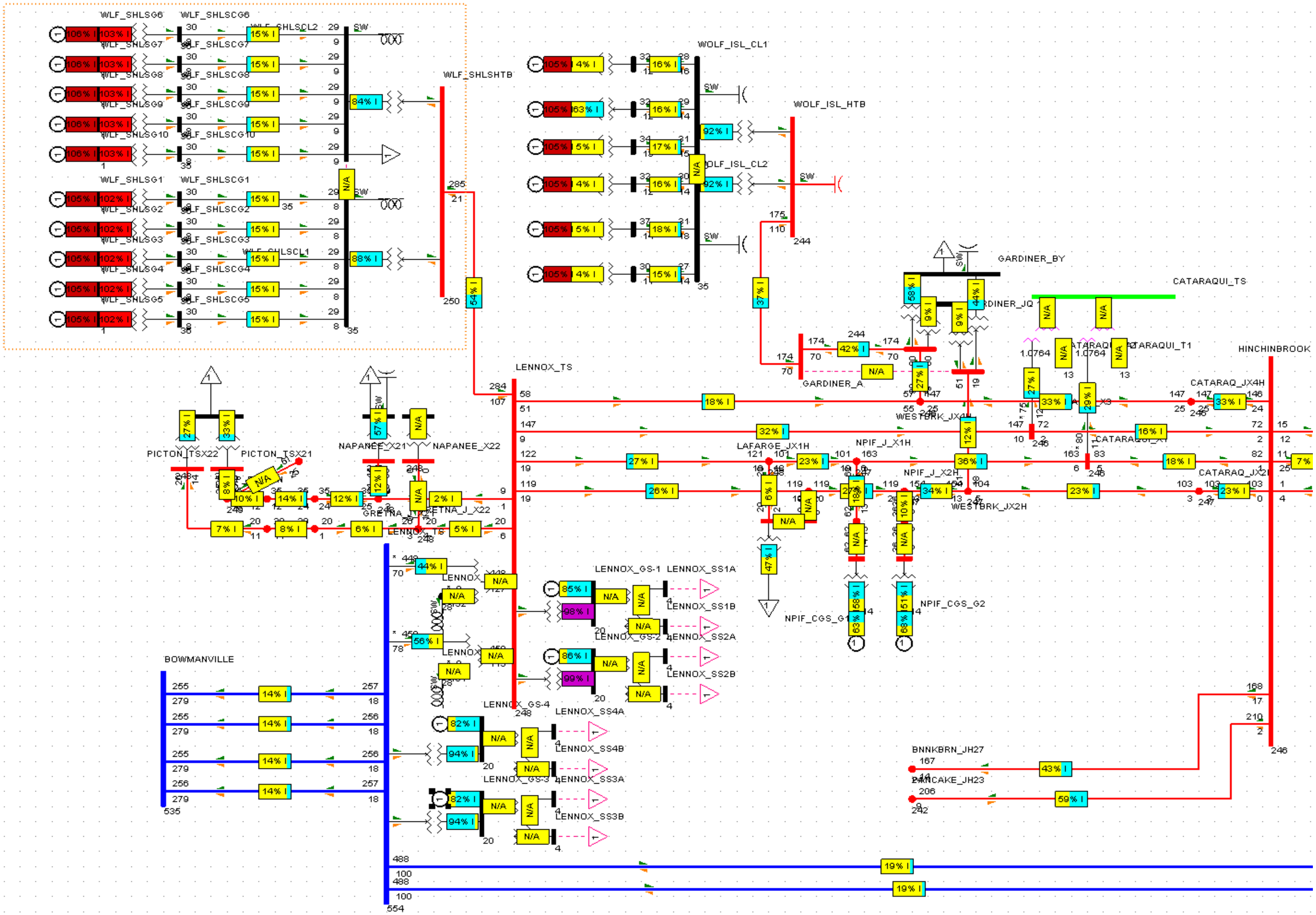


Figure 28: Eastern Transmission System with Wolfe Island Generating 300MW and Lennox GS all units in service generating 2200MW. Percentage loading is based on continuous current ratings available in PSSE basecase

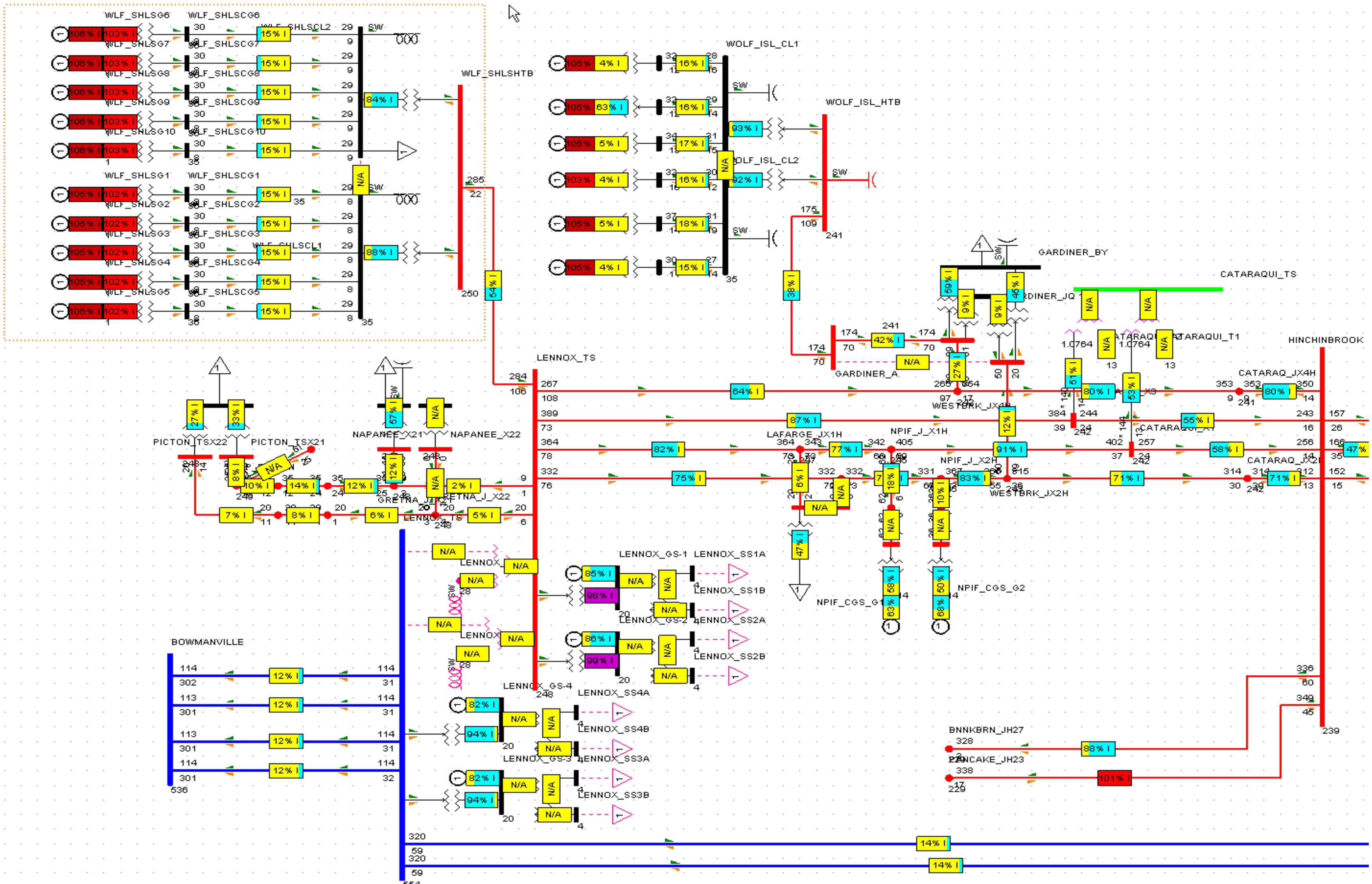


Figure 29: Eastern Transmission System with Wolfe Island Shoals Generating 300MW and Lennox GS generating 2200MW. Note that Lennox T51 auto-transformer is out-of-service and is followed by a Lennox T52 contingency. Percentage loading is based on continuous current ratings available in PSSE basecase. Under these conditions, short term emergency ratings are acceptable during system re-preparation.

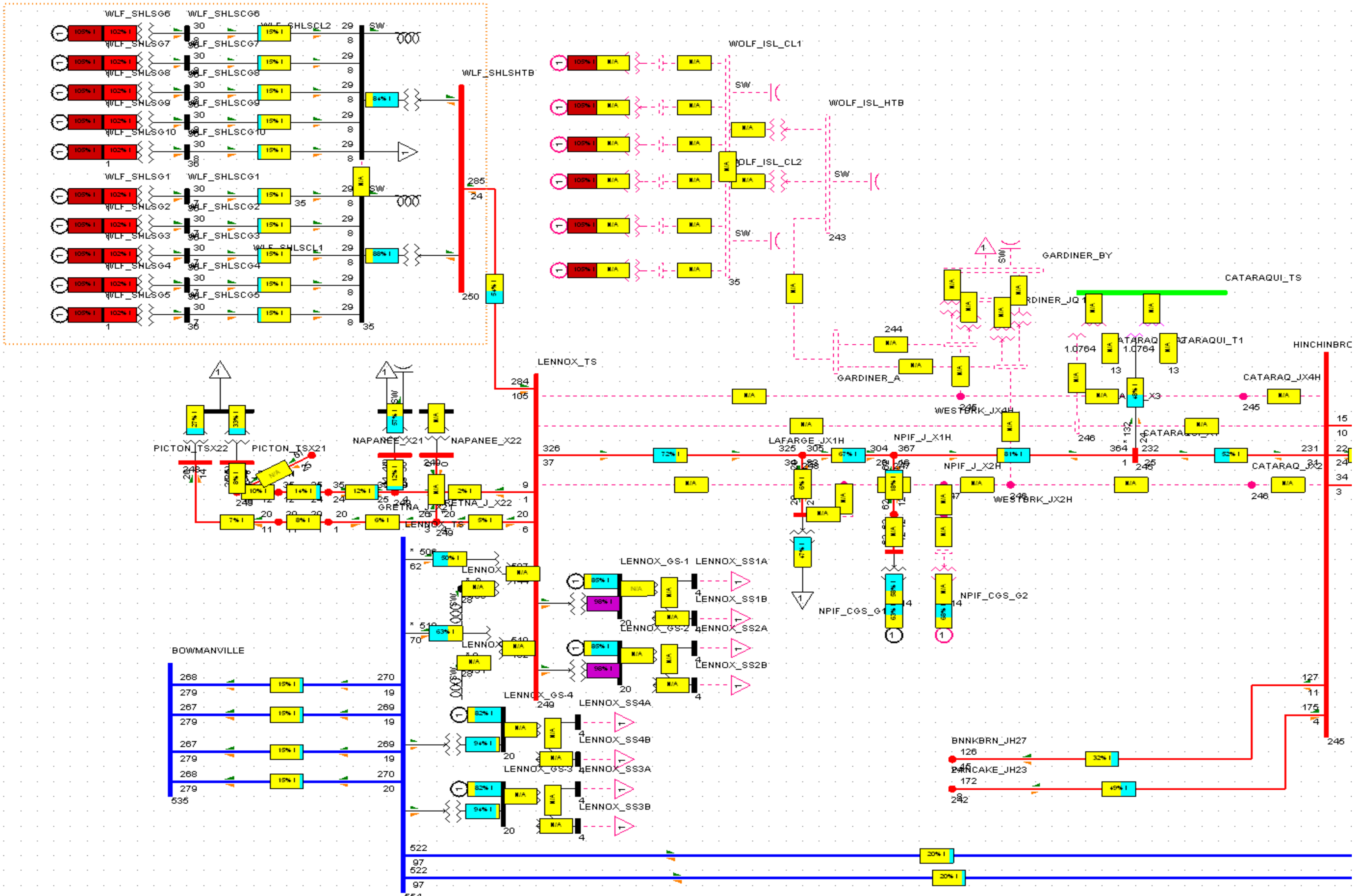


Figure 30: Eastern Transmission System with Wolfe Island Shoals Generating 300MW. The figure is a post-contingency snapshot following the loss of X3H + X4H during an X2H planned outage. Percentage loading is based on continuous current ratings available in PSSE basecase. Under these conditions, short term emergency ratings are acceptable during system re-preparation.

Appendix C: Diagrams for Transient Simulation Results

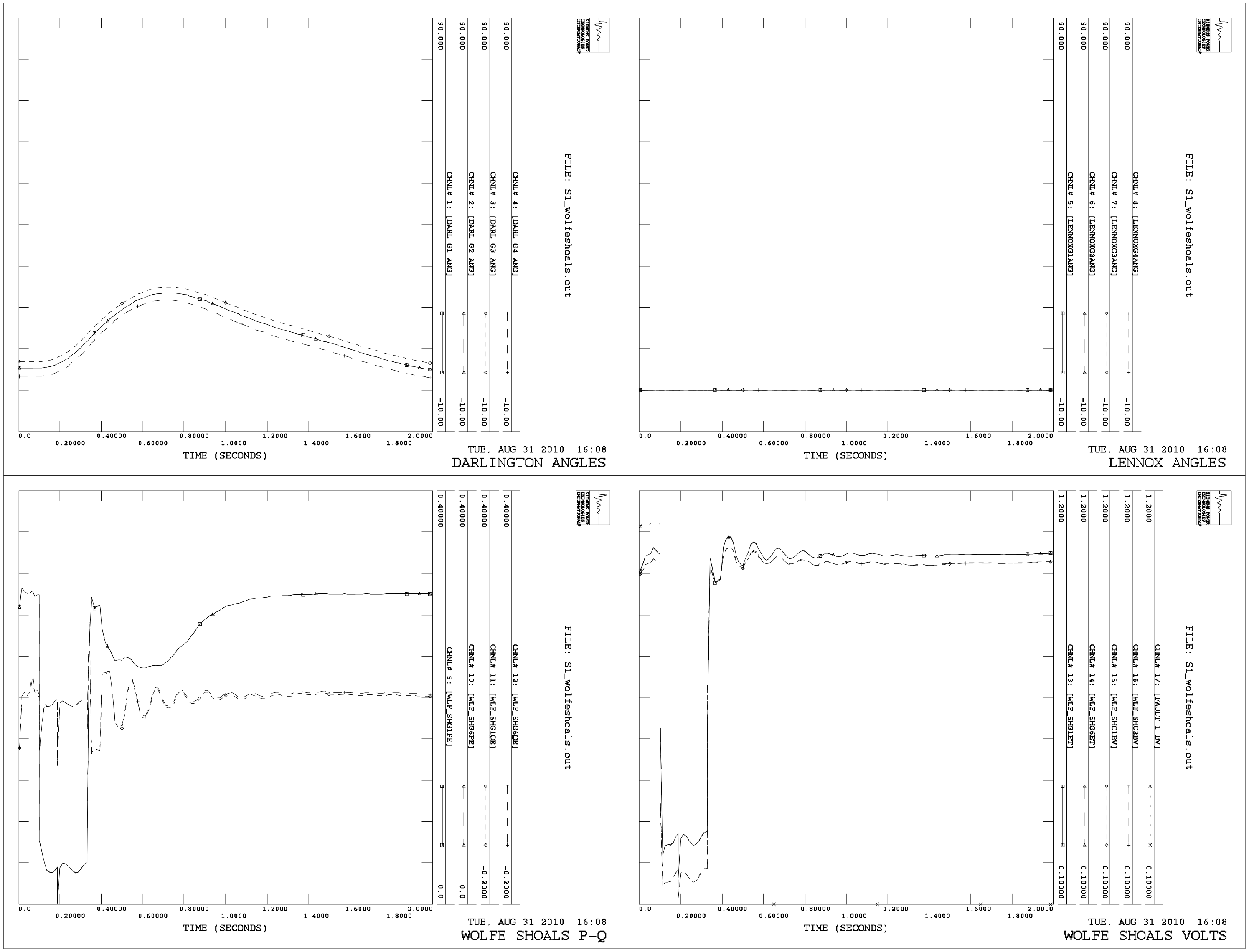


Figure 31: A two seconds simulation showing a 3-phase fault applied to X3H with H51L1 breaker failure followed by delayed clearing with backup breakers. This fault is used to assess LVRT capability of the wind turbine as it is electrically close to the wind farm and does not disconnect it by configuration.

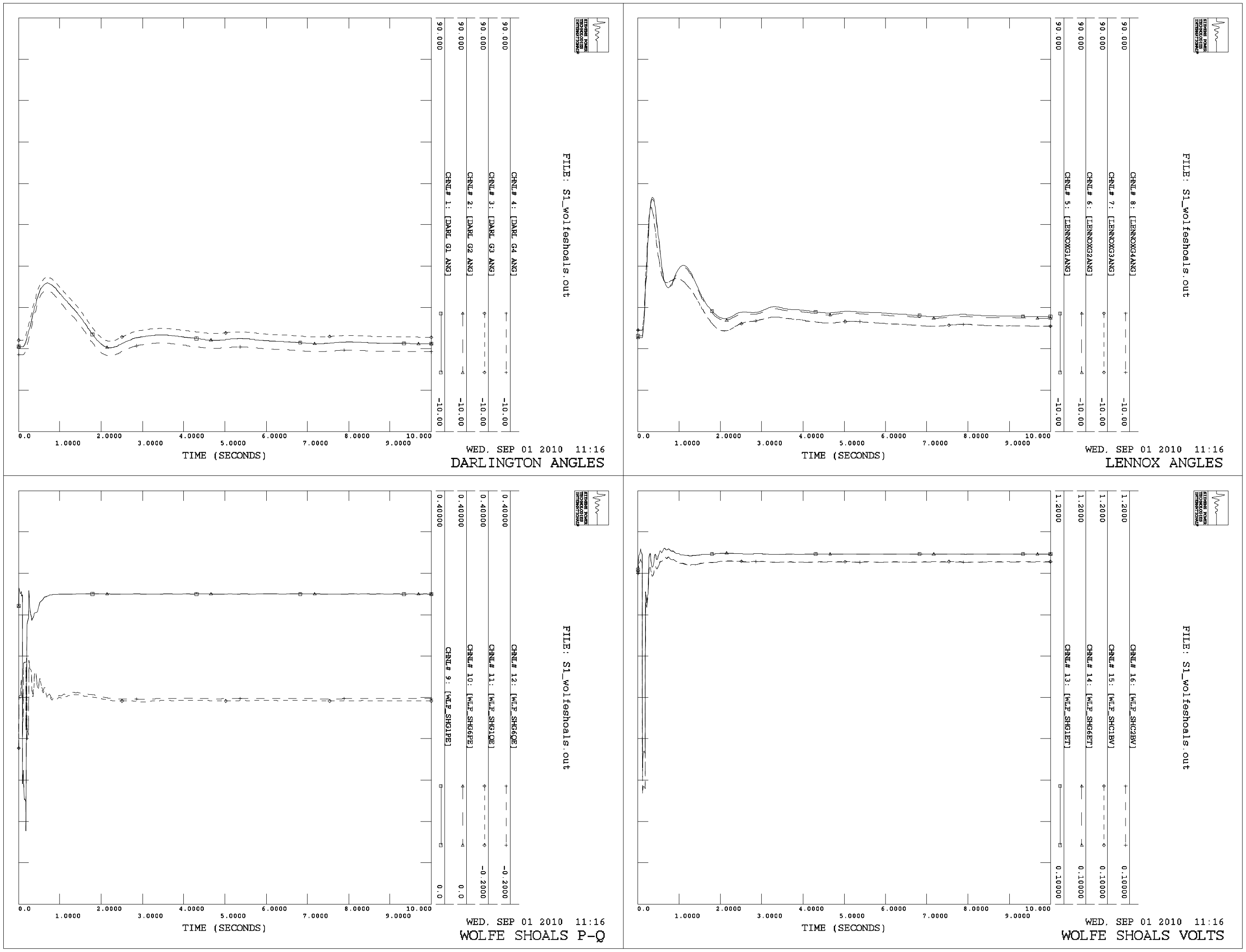


Figure 32: 10 seconds simulation showing a normally cleared 3 Phase fault applied near Lennox T52 on 500kV side.

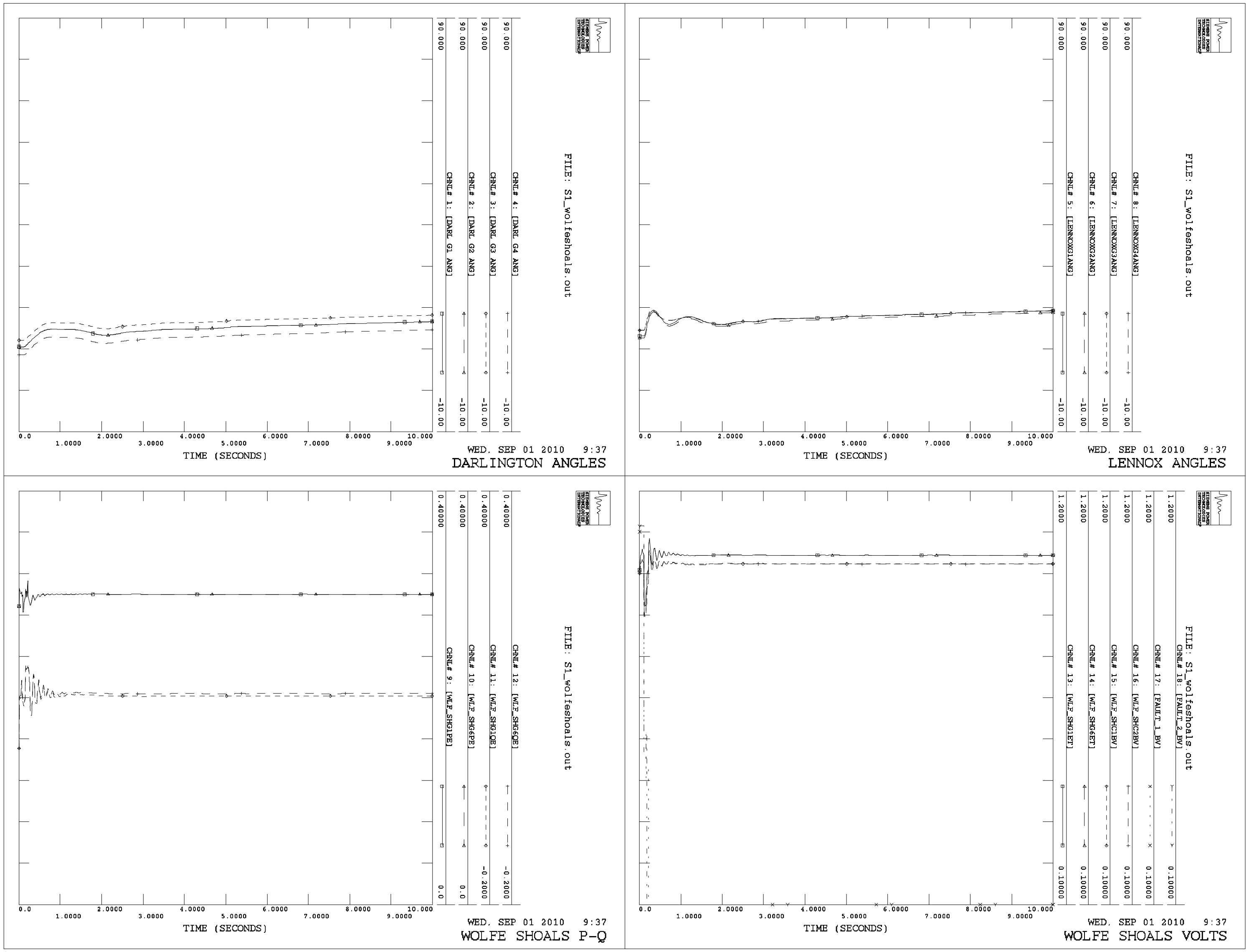


Figure 33: 10 seconds simulation showing normally cleared simultaneous LG Faults applied to double circuits X522A and M29C with all other elements in service.

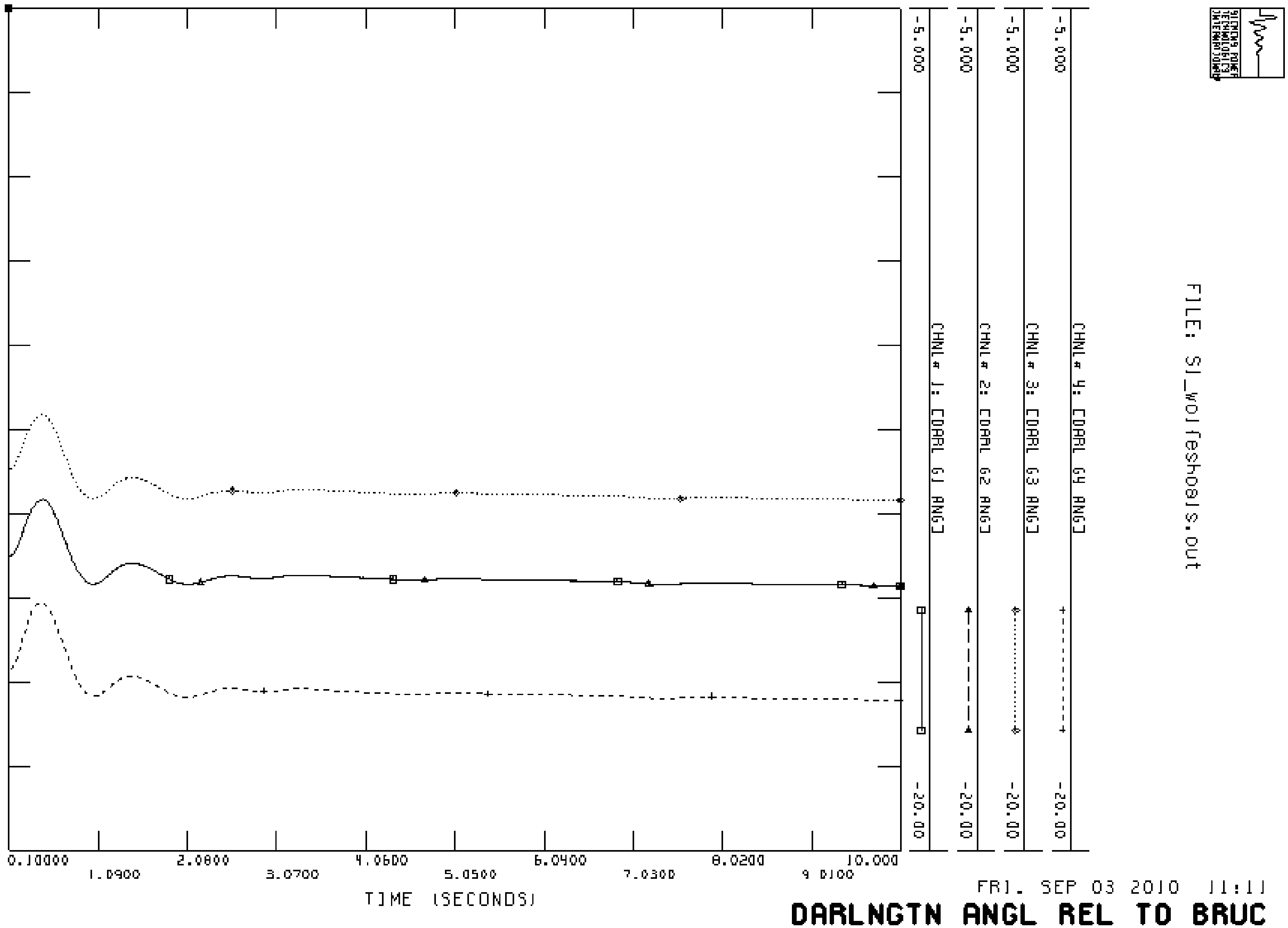


Figure 34: Darlington (G1 to G4) Machine Angles during X522A + M29C fault plotted relative to Bruce G7 to show synchronism of ICG.

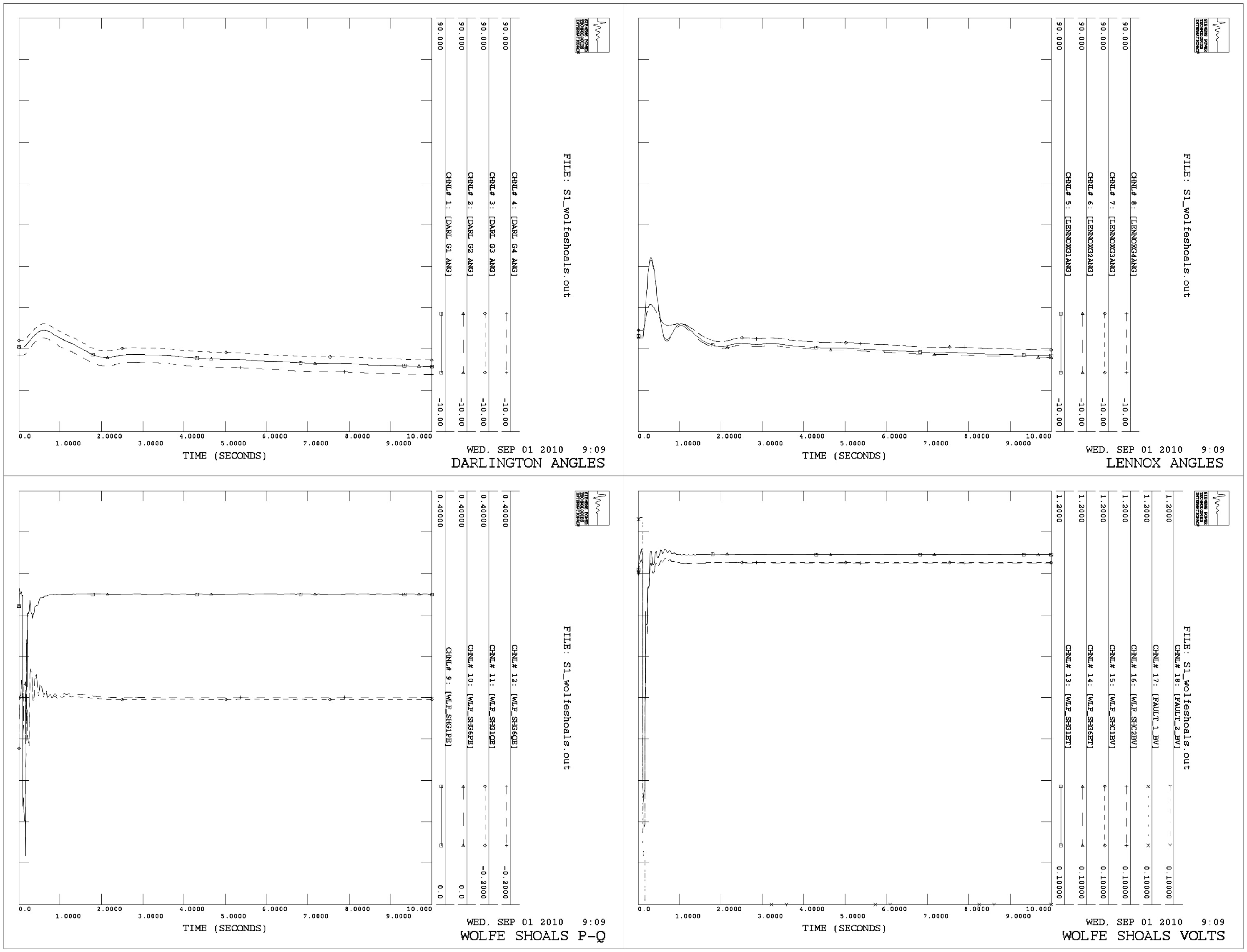


Figure 35: 10 seconds simulation showing normally cleared simultaneous LG Faults applied to double circuits X3H and X4H with all other elements in service.

Appendix D: Protection Impact Assessment

Hydro One Networks Inc.
483 Bay Street
Toronto, Ontario
M5G 2P5

PROTECTION IMPACT ASSESSMENT

WOLFE ISLAND SHOALS WIND FARM PROJECT

300 MVA WIND FARM GENERATION CONNECTION

FIT-FALCB9K

Date: Sept 7, 2010

Prepared by:

Hydro One Networks Inc.

1.0 DISCLAIMER

This Protection Impact Assessment has been prepared solely for the IESO for the purpose of assisting the IESO in preparing the System Impact Assessment for the proposed connection of the proposed generation facility to the IESO–controlled grid. This report has not been prepared for any other purpose and should not be used or relied upon by any person, including the connection applicant, for any other purpose.
This Protection Impact Assessment was prepared based on information provided to the IESO and Hydro One by the connection applicant in the application to request a connection assessment at the time the assessment was carried out. It is intended to highlight significant impacts, if any, to affected transmission protections early in the project development process. The results of this Protection Impact Assessment are also subject to change to accommodate the requirements of the IESO and other regulatory or legal requirements. In addition, further issues or concerns may be identified by Hydro One during the detailed design phase that may require changes to equipment characteristics and/or configuration to ensure compliance with the Transmission System Code legal requirements, and any applicable reliability standards, or to accommodate any changes to the IESO-controlled grid that may have occurred in the meantime.

Hydro One shall not be liable to any third party, including the connection applicant, which uses the results of the Protection Impact Assessment under any circumstances, whether any of the said liability, loss or damages arises in contract, tort or otherwise.

EXECUTIVE SUMMARY

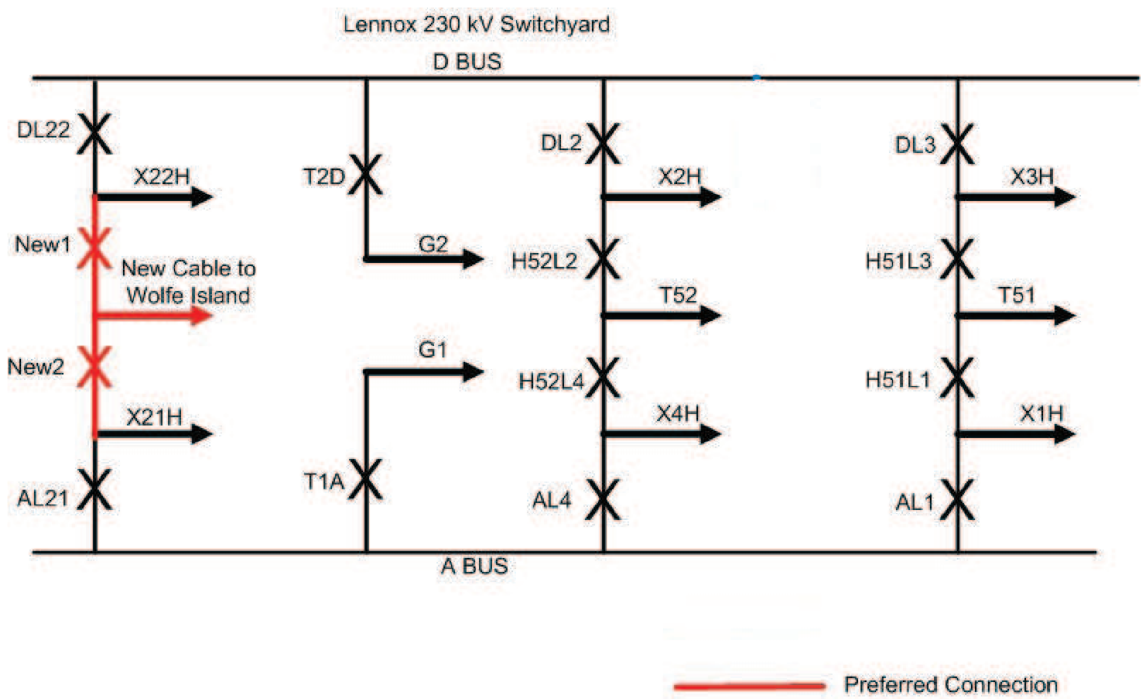


Figure 1: Wolfe Island Shoals WF Connection at Lennox TS

It is feasible for Wolfe Island Shoals Wind Farm to connect the proposed 300 MW generation at the location in Figure 1 as long as the proposed changes are made:

PROTECTION HARDWARE

- Due to connection of the new Wolfe Island Shoals Wind Farm between the 230 kV A and D buses, two new 230 kV breakers along with dual microprocessor based breaker failure relays for each breaker are required. Breakers adjacent to the new breakers will have their existing electromechanical relays replaced by a microprocessor based relay. Existing 230 kV lines X21 and X22 protections will be revised to accommodate the new 230 kV breakers in the new diameter. New 'A' and 'B' line distance protections (including three phase CVTs) will be installed for the 230 kV line between Lennox TS and Wolfe Island Shoals Wind Farm.

PROTECTION SETTINGS

- Both 'A' and 'B' protections for the new line to Wolfe Islands Shoals Wind Farm will operate in a direct under reaching transfer tripping, directional comparison overreaching tripping mode. Line End Open (LEO) logic on 230 kV lines X21 and X22 will require modifications to accommodate the additional breakers connected to these lines.

TELECOMMUNICATIONS

- New fully redundant and separated high speed communications will be required between Islands Shoals Wind Farm and Lennox TS for transfer trip and blocking signals.