R110-11

Stability Study Report for Q371 Wind Project Interconnecting to Line L-163 near Jackman 115 kV Substation in New Hampshire

Prepared for

ISO-NE

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September 17, 2012	1	Changes to address comments received from ISO-NE 9/7/2012 and Northeast Utilities 9/14/2012
November 30, 2012	2	Corrected a typo in the report title

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Executive Summary

Siemens Industry, Inc., Siemens Power Technologies International (Siemens PTI), conducted a Stability Study ("Study") of Project Q371 ("the Project") under the ISO New England (ISO-NE) Open Access Transmission Tariff ("Tariff") Schedule 22-Standard Large Generator Interconnection Procedures ("LGIP") and Network Capability Interconnection Standard ("NCIS"), PP5-6 on behalf of ISO-NE.

Project Description

The Project can be described as follows:

- 11 Acciona 3.0 MW wind turbine generators (WTG's) with a maximum aggregated output of 33 MW. The Project's net output at the point of interconnection (POI) is, approximately, 32 MW.

- Each WTG will be connected to the 34.5 kV underground collector system via its own 12.0/34.5 kV generator step-up transformer (GSU).

- A single 34.5 kV overhead line will carry the power from an underground wind turbine string to the Project's Collector Substation where a 24 MVA 34.5/115 kV transformer will step up the voltage and connect directly to the Point of Interconnection (POI) at a new 115 kV [redacted] Switching Station tapping the L-163 line between Keene and Jackman 115 kV Substations at about 6.5 miles southwards of Jackman 115 kV Substation.

- The Project will operate in field bus voltage control mode, using a centralized voltage regulator maintaining a scheduled voltage at the POI.

- The proposed commercial operation date for this Project is December of 2013.

Stability Study

- For the Stability Study the Project is modeled as an equivalent model, that is with a single equivalent WTG (33 MW) that connects to an equivalent GSU 12.0/34.5 kV transformer. A single equivalent 34.5 kV underground collector cable connected to the 34.5 kV overhead line that carries the power to the Projects 34.5 kV Collector Substation. The 34.5/115 kV transformer and interconnection to the 115 kV L-163 are modeled explicitly.

- Normal, extreme and Bulk Power System (BPS) contingencies were simulated for light and peak load conditions with high West to East and high East to West interface flows.

- The New England East West Solution & Pittsfield/Greenfield projects were assumed in-service. Sensitivity testing was performed without these projects.

- Testing with Delayed Auto-Reclosing (DAR) schemes on the L163S and L163N lines and with the Greggs series reactor in-service was performed.

Stability Results

- BPS testing was performed [redacted] The total loss of source was less than 1,200 MW in each of the BPS contingencies simulated. Therefore, none of the buses tested needs to be classified as a BPS facility due to the interconnection of the Project.

- Normal contingencies tested in the local area surrounding the Project shown no generating units were tripped. Also, for the post-NEEWS case (not tested for pre-NEEWS conditions), no generating units were tripped for the Delayed Auto-Reclosing schemes on the L163S and L163N lines and with Greggs series reactor in-service.

- No units were tripped following simulation of the EC contingencies.

Final Conclusions

- The Study determined the Project operating with field bus control (centralized voltage regulator) controlling the project's 115 kV Point of Interconnection voltage, nominal tap settings (ratio of 1.0) for the 34.5/115 kV main transformer and 12/34.5 kV Wind Turbine GSU and without any system upgrades, will not have an adverse impact on the stability of the power system.

Section

1

Introduction

Siemens Industry, Inc., Siemens Power Technologies International (Siemens PTI), conducted a Stability Study ("Study") of Project Q371 ("the Project") under the ISO New England (ISO-NE) Open Access Transmission Tariff ("Tariff") Schedule 22-Standard Large Generator Interconnection Procedures ("LGIP") and Network Capability Interconnection Standard ("NCIS"), PP5-6 on behalf of ISO-NE.

This document presents the Stability Study Report.

The Project consists of eleven (11) Acciona 3.0 MW (AW3000) wind turbine generators (WTG's) and the associated collector system. The maximum aggregated output of the WTG's will be 33 MW. The Project's net output at the point of interconnection (POI) is, approximately, 32 MW, once the losses in the collector system have been subtracted. The Project service load is negligible.

The proposed commercial operation date for this Project is December of 2013.

The Project will interconnect to the Public Service of New Hampshire (PSNH) system in New Hampshire at a new 115 kV Switching Station [redacted] tapping the L-163 line about 6.5 miles southwards of the Jackman 115 kV Substation.

The Study included N-1 stability testing for normal conditions with all lines in-service and BPS testing. Peak and light load conditions were considered in the study. Both load conditions were studied with high West to East and East to West New England interface flows, each case was also studied with NEEWS (New England East West Solution) & Pittsfield/Greenfield projects modeled, to be known hereafter as "post-NEEWS".

A sensitivity study was carried out to test the worst fault conditions on the cases without NEEWS (New England East West Solution) & Pittsfield/Greenfield projects.

It was determined that stability simulations of N-1-1 line-out conditions were not required to be studied for this Project. Under line-out conditions, operational restrictions on the Project may be necessary on a case-by-case basis to maintain system reliability

Section

2

Project Description

2.1 Project Description and Interconnection Plan

The Project consists of 11 Acciona 3.0 MW wind turbine generators (WTG's) with a maximum aggregated output of 33 MW. The Project's net output at the point of interconnection (POI) is, approximately, 32 MW, once the losses in the collector system have been subtracted. The service load is negligible. Each WTG will be connected to the 34.5 kV underground collector system via its own 12.0/34.5 kV generator step-up transformer (GSU). A single 34.5 kV overhead line will carry the power from an underground wind turbine string to the Project's Collector Substation where a 24 MVA 34.5/115 kV transformer will step up the voltage and connect directly to the Point of Interconnection (POI) at a new 115 kV [redacted] Switching Station on the L-163 line between Keene and Jackman 115 kV Substations.

The Developer provided a detailed layout showing the individual wind turbine generators and feeders. For this study an equivalent model was used that consists of a single equivalent WTG (33 MW) that connects to an equivalent GSU 12.0/34.5 kV transformer. A single equivalent 34.5 kV underground collector cable connected to the 34.5 kV overhead line that carries the power to the Projects 34.5 kV Collector Substation. The 34.5/115 kV transformer and interconnection to the 115 kV L-163 are modeled explicitly. The equivalent model was derived following the methodology documented in the NREL wind equivalent conference paper [1], using the Project data provided by the Developer.

Figure 2-1 shows a one-line diagram of the equivalent Project model and adjacent substations in the area.

[1] E.Muljadi, C.P.Butterfield (January 2006). *Equivalencing the Collector System of a Large Wind Power Plant*. NREL: Conference Paper NREL/CP-500-38940.

[redacted]

[redacted]

Figure 2-1. Project Interconnection and buses nearby the Project

Figure 2-2 below illustrates the approximate geographical location of the Project and the transmission lines in the area of interest.

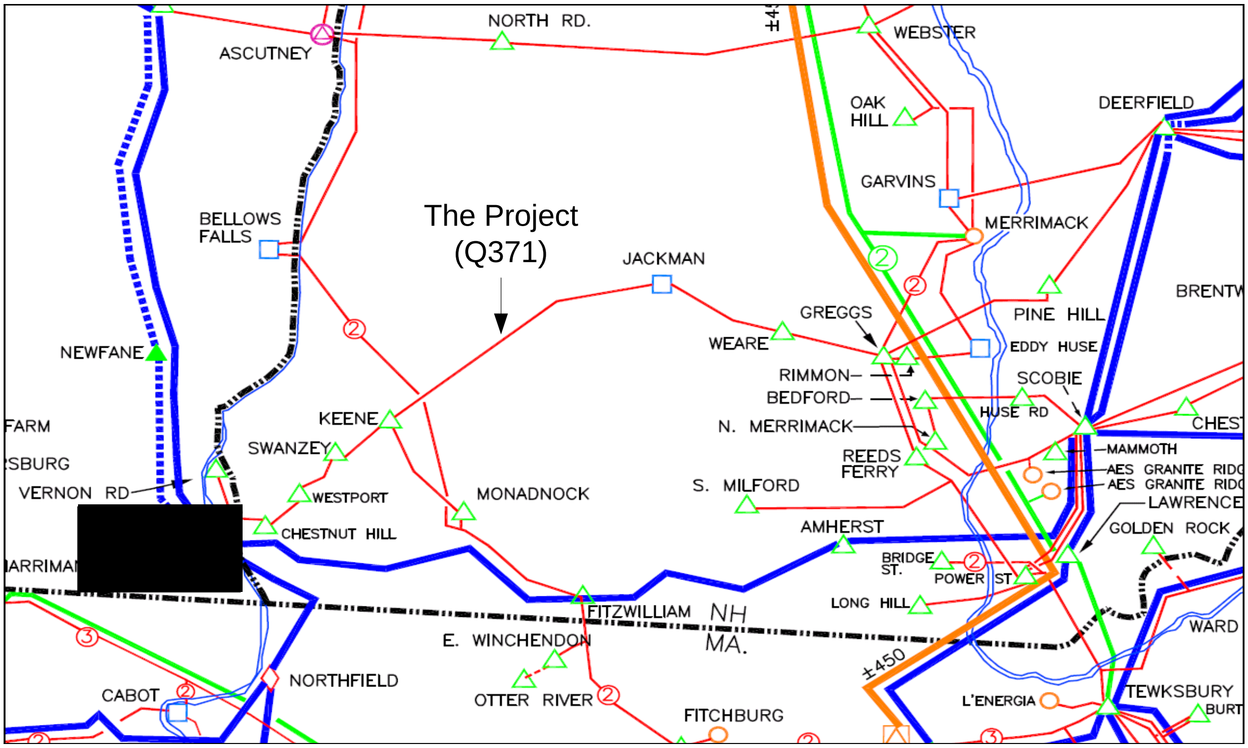

Figure 2-2. Approximate Geographical Location of the Project

2.2 Project Data

The Project data for each WTG and the corresponding GSU transformer are shown below in Table 2-1 and Table 2-2, respectively.

Table 2-1. Wind Turbine Generator (WTG) Data

Ratings of each Wind Turbine Generator	3.23 MVA, 12,000 V
Gross Output of each wind generator	3.0 MW
Exporting Reactive Power Limit at 3.0 MW output [2]	1.2 Mvar (0.928 power factor)
Importing Reactive Power Limit at 3.0 MW output [3]	-1.2 Mvar (0.928 power factor)
Station Service Load	When the WTG's are online, the service load is negligible[4].

[2] For terminal voltages between 0.95 – 1.05 V per unit for each wind turbine, measured at 12 kV terminals.
[3] For terminal voltages between 0.95 – 1.05 V per unit for each wind turbine, measured at 12 kV terminals.
[4] Service load is 0.165MW and 0.044MVAr for the entire wind farm when all WTG's are offline.

Table 2-2. Wind Unit GSU Transformer Data

Nameplate ratings (self cooled/maximum)	3.4/3.4 MVA
Voltage ratio, generator side/system side	12.0/34.5 kV
Winding connections, low voltage/high voltage	Wye grounded/Delta
Available Tap positions	5 steps, each +/- 2.5% of nominal
Tap position for the Study	1.0 (nominal)
Impedance, Z_1 (on self cooled MVA rating)	6.0%, X/R = 8.0
Impedance, Z_0 (on self cooled MVA rating)	6.0%, X/R = 8.0

Figure 2-3 and Figure 2-4 below show the Acciona WTG reactive power output for varying conditions. Both figures were obtained from Acciona documentation [5] provided by the Developer.

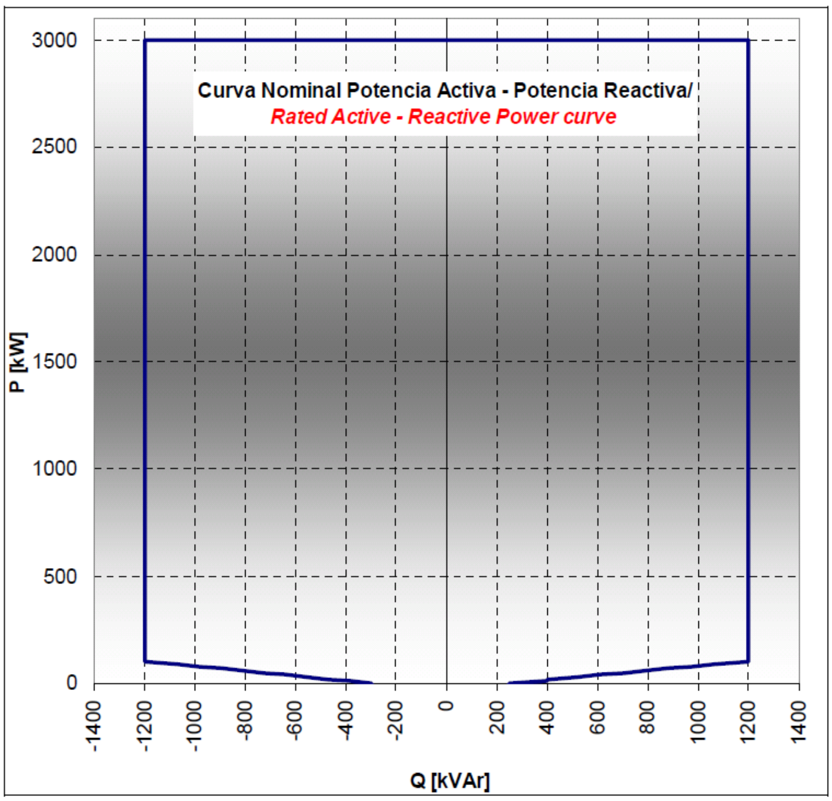

Figure 2-3. WTG Rated Active (P) vs Reactive Power (Q) Curve [6]

Figure 2-4 below, shows the reactive power output limits of each turbine are reduced significantly for terminal voltages outside of the 0.95 – 1.05 V per unit range. This reactive power limit curve is simulated by the Acciona dynamic model (described below in section 2.4) i.e. if the WTG terminal voltage falls outside the 0.95-1.05 per unit range, the dynamic model automatically limits reactive power output as required.

[5] Acciona (Approved 04-28-2011). *AW3000 Electric Grid Data.* Document: DG200032, REF: F
[6] For WTG terminal voltage between 0.95 and 1.05 per unit

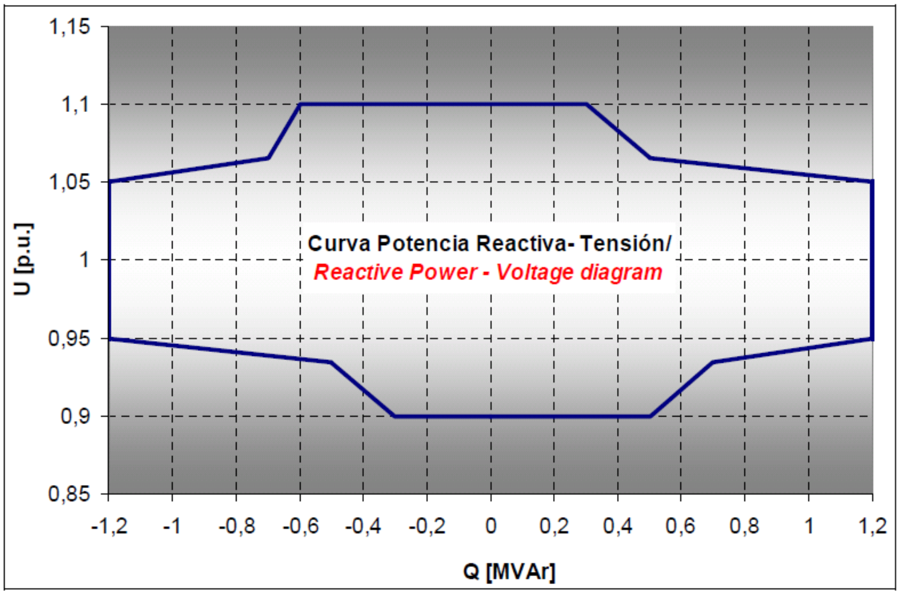

Figure 2-4. WTG Reactive Power (Q) vs Terminal Voltage (U) at Full Rated Active Power Output

The parameters of the main transformer are shown in Table 2-3 below.

Table 2-3. Main Transformer at Collector station

Nameplate ratings (self cooled/maximum)	30/50 MVA
Voltages, High/Low voltage/Tertiary	115/34.5/13.2 kV
Winding connections, High/Low/Tertiary	Wye grounded/Wye grounded/Delta
Available Tap positions	5 steps, each +/- 2.5% of nominal
Tap position for the Study	1.0 (nominal)
Impedance Z_1 (% on self cooled MVA rating)	9.0 %, X/R = 26
Impedance Z_0 (% on self cooled MVA rating)	9.0 %, X/R = 26

Table 2-4 below, shows the parameters of the 34.5 kV overhead line that will connect the WTG strings to the 34.5 kV Project Collector Substation, based on values calculated by the Project Developer.

Table 2-4. 34.5kV Overhead Line Feeder Data

Length (feet)	Positive Sequence – Ohms			Zero Sequence –Ohms	
	R	Xl	Xc (MOhms)	R	Xl
4,500	0.1185	0.5185	0.16548	0.2765	1.356

2.3 Power Flow Model

As stated in the Project Description section, an equivalent power flow model of the Project was used. Table 2-5 and Table 2-6 provide the equivalent WTG and the corresponding GSU transformer data.

Table 2-5. Equivalent Wind Turbine Generator (WTG) Data

Equivalent Rating	35.53 MVA, 12,000 V
Equivalent Gross Output	33.0 MW
Equivalent Exporting Reactive Power Limit at 33.0 MW output [7]	13.2 Mvar (0.928 power factor)
Equivalent Importing Reactive Power Limit at 33.0 MW output [8]	-13.2 Mvar (0.928 power factor)

The actual equivalent WTG reactive power limits are set specifically for each power flow case to ensure the initial conditions fall within the reactive power vs terminal voltage bounded area as shown in Figure 2-4 above, that is, if the reactive power output from the equivalent WTG fell outside of the bounded area, then the reactive power limits were reduced in the power flow case to ensure the initial conditions were within the physical capabilities of the WTG.

Table 2-6. Equivalent Wind Unit GSU Transformer Data

Nameplate ratings (self cooled/maximum)	37.4/37.4 MVA
Voltage ratio, generator side/system side	12.0/34.5 kV
Winding connections, low voltage/high voltage	Wye grounded/Delta
Available Tap positions	5 steps, each +/- 2.5% of nominal
Tap position for the Study	1.0 (nominal)
Impedance, Z_1 (on self cooled equivalent MVA rating)	6.0%, X/R = 8.0
Impedance, Z_0 (on self cooled equivalent MVA rating)	6.0%, X/R = 8.0

Table 2-7 below, shows the equivalent 34.5 kV collector cable data.

Table 2-7. Equivalent 34.5 kV Collector Cable Data

Positive Sequence – Per Unit (on 34.5 kV 100 MVA base)		
R	**Xl**	**B**
0.04782	0.04437	0.0007

[7] For terminal voltages between 0.95 – 1.05 V per unit for each wind turbine, measured at 12 kV terminals.
[8] For terminal voltages between 0.95 – 1.05 V per unit for each wind turbine, measured at 12 kV terminals.

2.3.1 Voltage Control and Transformer Tap Settings

The reactive power exchanged with the power system can be controlled in real time by means of the power converter within the limits defined above. This control may be either local or remote for constant reactive power or power factor operation. The remote control allows the implementation at plant-wide level of different reactive controls. The most commonly used control modes are listed below:

- Field bus voltage control, to balance the field bus voltage and therefore the machine voltages. The voltage at the POI would be controlled according to a set point. This voltage is periodically sampled to determine whether the POI voltage is different from the set point, and if so, command signals are sent to the turbines via SCADA to adjust their reactive power.

- Remote voltage control. In this mode, the reactive power set point to be generated by the wind farm comes directly from remote controls of system operators.

- Scheduled power factor. The power factor of the turbines is changed periodically during the day according a scheduled program usually established by the electric grid operator.

Field bus voltage control, modeled as a centralized voltage regulator (described further in Section 2.4) was selected by the Developer and as such was modeled for this Study.

Currently there is no specific voltage schedule at the POI as it is a new Switching Station on the L-163 line. To ensure that the Project is capable of operating at a range of voltage set points, without voltage violations on transmission buses and without turbine trips due to under- or over-voltage, the Project was set to maintain a scheduled voltage of [redacted] for light load conditions and [redacted] for peak load conditions.

The equivalent wind turbine GSU transformer and the main 34.5/115 kV transformer are both set at the nominal tap position (ratio of 1.0).

Figure 2-5 below shows the equivalent Project one line diagram with the impedance data.

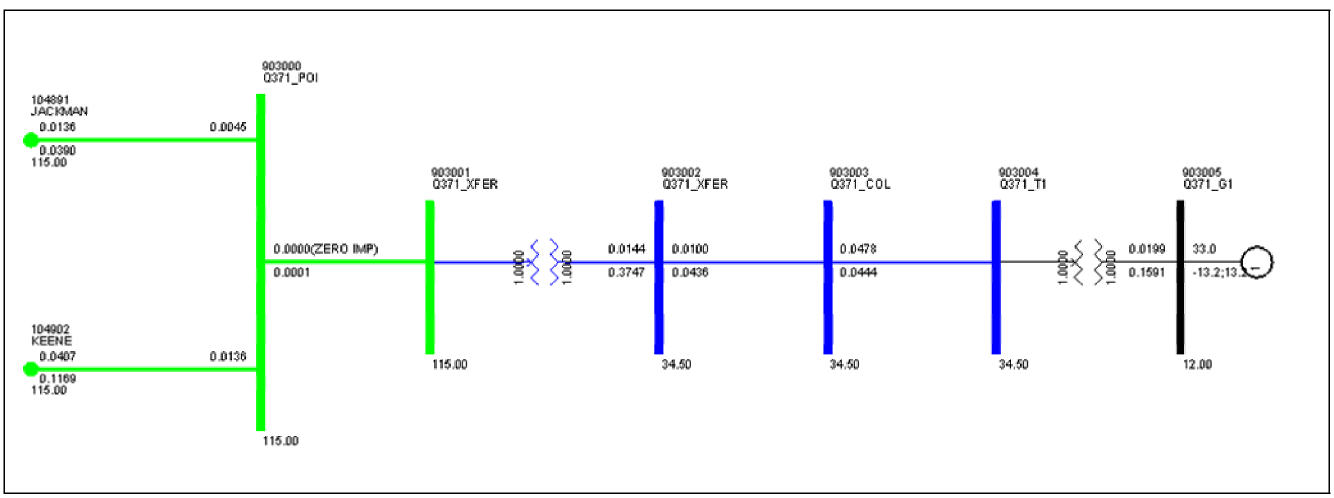

Figure 2-5. Equivalent Project Impedance One Line Diagram

The IDV file to incorporate the Project to the PSS®E Version 30.3.3 CVF, power flow database is included in Appendix C.

2.4 Stability Models

The electrical generation is based on a doubly fed induction generator that is electronically controlled. The rated stator line voltage is 12 kV while the generation power (active and reactive) is controlled through the rotor currents. Those currents are produced by means of a hard switching electronic power converter based on IGBTs.

The PSS®E dynamic modeling package includes the module of the wind turbine unit employing the DFIG machine and the module of the centralized voltage regulator (field bus control). The wind turbine dynamic simulation model includes the rotor aerodynamics, a two-mass mechanical drive train, the blade pitch control system and the electrical generator and power electronic converter. The dynamic models provided by the Developer and used for this Study are:

- awt1530_p303cvf_v700_Tf1.lib
- AWT1530MODULE_V501.OBJ
- AWTVRG_V501.OBJ

Available set points of over- and under frequency protection implemented within the turbine model are shown in Table 2-8 below. The set points used for the Study are based on data provided by the Developer.

Table 2-8. Frequency Protection Settings

Description	Min	Set Point for Study	Max
Over-frequency Trip point (Per Unit)	0 (60 Hz)	0.05	0.05 (63 Hz)
Under-frequency Trip Point (Per Unit)	-0.05 (57 Hz)	-0.05	0 (60 Hz)
Over-frequency delay (seconds)	0	5	5
Under-frequency delay (seconds)	0	5	5

The standard normal operation voltage range is 90% to 110% of rated voltage (12 kV line-to-line). Outside these limits the turbine control changes its operational mode from Normal to Fault mode and tries to get the voltage back to normal range through reactive current injection. Figure 2-6 below, shows the voltage protection curve that represents the set points implemented in the model. Should the terminal voltage remain outside of the grey area for a sustained period of time the WTG will trip offline.

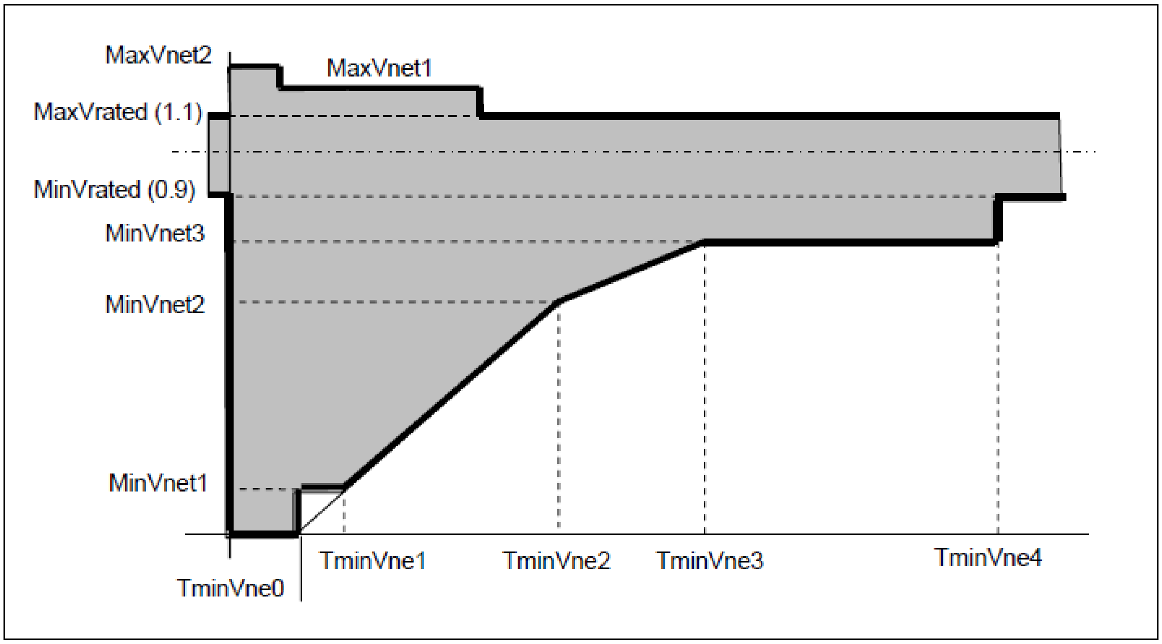

Figure 2-6. Voltage Protection Curves

Available set points of over and under voltage protection implemented within the turbine model are shown in Table 2-9 below. The set points used for the Study are based on data provided by the Developer.

Table 2-9. Voltage Protection Settings

Description	Name	Min	Set Value	Max
Overvoltage limit 1 (pu)	MaxVnet1	>1.1	1.15	1.18
Overvoltage limit 2 (pu)	MaxVnet2	>MaxVnet1	1.2	1.3
Maximum time for overvoltage limit 1 (seconds)	TmaxVnet1	0	5	5
Maximum time for overvoltage limit 2 (seconds)	TmaxVnet2	0	0.1	5
Undervoltage #1 (pu)	MinVnet1	0.1	0.1	1.0
Undervoltage #2 (pu)	MinVnet2	0.75	0.9	1.0
Undervoltage #3 (pu)	MinVnet3	0.85	0.9	1.0
Undervoltage #0 Delay (seconds)	TminVne0	0	0.5	0.5
Undervoltage #1 Delay (seconds)	TminVne1	>TminVne0	1.0	1.0

Description	Name	Min	Set Value	Max
Undervoltage #2 Delay (seconds)	TminVne2	>TminVne1	2.0	5.0
Undervoltage #3 Delay (seconds)	TminVne3	>TminVne2	15.0	20.0
Undervoltage #4 Delay (seconds)	TminVne4	>TminVne3	210.0	250.0

Table 2-10 and Table 2-11 below, show the complete list of parameters and values set for the dynamic modeling of the Acciona WTG for this Project.

Table 2-10. WTG Model Parameters for this Study

Constant	Description	Name	Set Value
CON(J)	Rated Wind Speed (m/s)	Vv_nom	15
CON(J+1)	Over-frequency Trip point (Per Unit)	MaxFnet	0.05 (63 Hz)
CON(J+2)	Under-frequency Trip Point (Per Unit)	MinFnet	-0.05 (57 Hz)
CON(J+3)	Over-frequency delay (s)	TmaxFnet	5
CON(J+4)	Under-frequency delay (s)	TminFnet	5
CON(J+5)	Overvoltage limit 1 (pu)	MaxVnet1	1.15
CON(J+6)	Overvoltage limit 2 (pu)	MaxVnet2	1.2
CON(J+7)	Maximum time for overvoltage limit 1 (s)	TmaxVnet1	1.5
CON(J+8)	Maximum time for overvoltage limit 2 (s)	TmaxVnet2	0.2
CON(J+9)	Undervoltage #1 (pu)	MinVnet1	0
CON(J+10)	Undervoltage #2 (pu)	MinVnet2	0.8
CON(J+11)	Undervoltage #3 (pu)	MinVnet3	0.85
CON(J+12)	Undervoltage #0 Delay (s)	TminVne0	1.6
CON(J+13)	Undervoltage #1 Delay (s)	TminVne1	1.6
CON(J+14)	Undervoltage #2 Delay (s)	TminVne2	3.5
CON(J+15)	Undervoltage #3 Delay (s)	TminVne3	15
CON(J+16)	Undervoltage #4 Delay (s)	TminVne4	210
CON(J+17)	Undervoltage for MaxIc (pu)	V_MaxIc	0.5
CON(J+18)	Maximum reactive current (Voltage dips) (pu)	MaxIc	1
CON(J+19)	Minimum reactive current (Voltage dips) (pu)	MinIc	0.2
CON(J+20)	Maximum reactive current (Overvoltage) (pu)	MaxIi	1
CON(J+21)	Minimum reactive current at MaxVrated	MinIi1	0.2

Constant	Description	Name	Set Value
CON(J+22)	Minimum reactive current at MaxVnet1	MinIi2	1
CON(J+23)	Minimum reactive current at MaxVnet2	MinIi3	1
CON(J+24)	External Reactive Power Control Flag (1 = enable, 0 = disable)	DYN_Q	1
CON(J+25)	Grid side power converter reactive power contribution - activation Flag (1 = enable, 0 = disable)*.	PC_Q_ON	1
CON(J+26)	Time for reactive power priority during voltage dips (s)	TimeQ_VD	3
CON(J+27)	Time for reactive power priority during over-voltage (s)	TimeQ_SW	3
CON(J+28)	Rotor current control – Proportional factor (ohm)	Kp	25
CON(J+29)	Rotor current control – Integral factor (ohm/s)	Ki	500
CON(J+30)	Active power ramp (kW/s) (steady state)	P_ramp	6000
CON(J+31)	Reactive power ramp (kVA/s) (steady state)	Q_ramp	6000
CON(J+32)	Duration of the post-fault Q ramping	T_POST_ PRIOR_Q	20
CON(J+33)	Rate of the post-fault Q ramping	Q_RAMP_ POST	40

Table 2-11. Centralized Voltage Regulator Model Parameters for this Study

Constant	Description	Name	Set Value
CON(J)	Proportional Gain, p.u.	Kp	3
CON(J+1)	Integral Gain, p.u./sec.	Ki	1.8
CON(J+2)	Transducer Time Constant, sec.	VTtau	0.01
CON(J+3)	SCADA Cycle Time, sec.	SCDEL	0.1
CON(J+4)	Maximum Reactive Power, p.u. on SBASE	MaxQ	1.2
CON(J+5)	Minimum Reactive Power, p.u. on SBASE	MinQ	-1.2
CON(J+6)	Lower limit of normal voltage range	Min_Vsub	0.85
CON(J+7)	Upper limit of normal voltage range	Max_Vsub	1.15
CON(J+8)	Duration of anti-wind-up after fault is detected	Tmax_AWU	4

2.4.1 Acciona Dynamic Model TF Parameter

During the initial stability contingency analysis for several contingencies, some sustained oscillations were observed from the Projects reactive power output, in particular for the peak load cases as shown below in Figure 2-7and Figure 2-8.

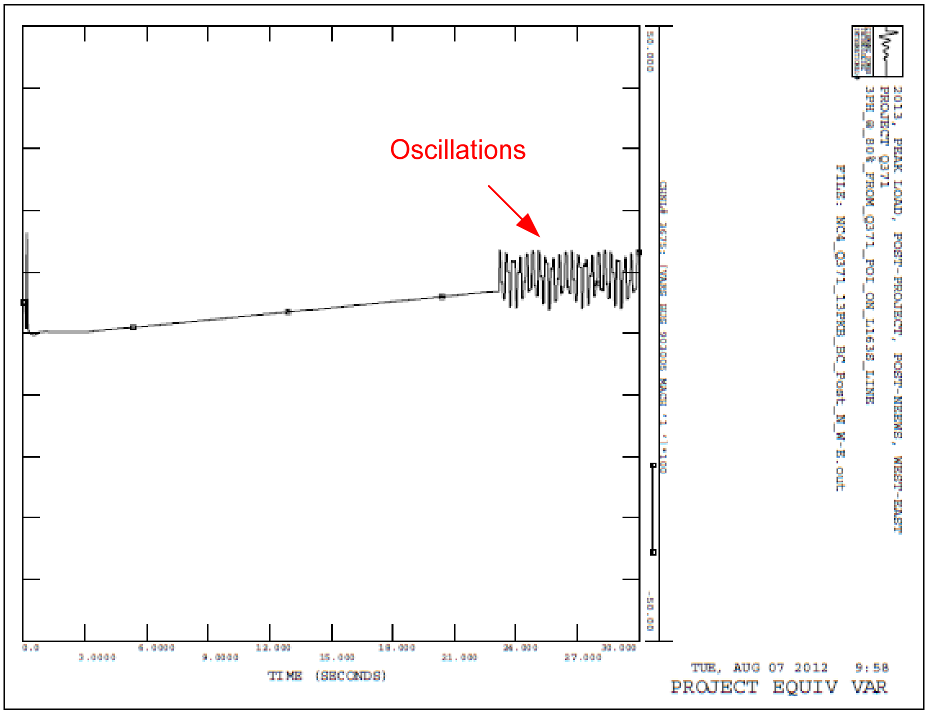

Figure 2-7. Project Q output for PK E-W Post NEEWS case for contingency NC4

[redacted]

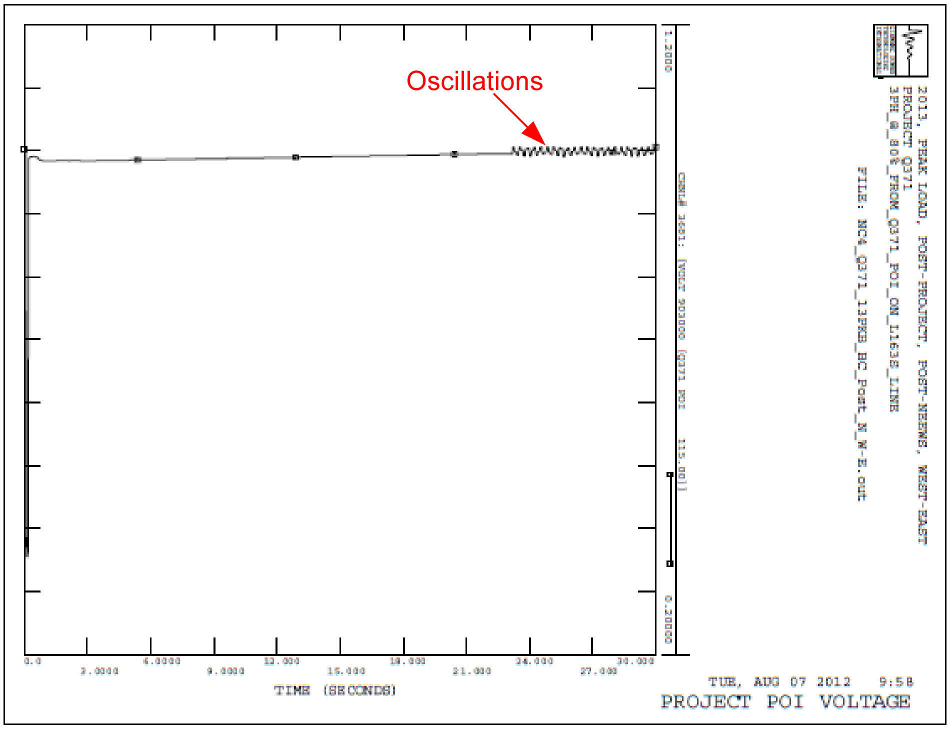

Figure 2-8. POI Voltage for PK E-W Post NEEWS case for contingency NC4

Following a discussion with the Developer and Acciona, it was determined an internal model parameter change to a gain function "TF" should be set to equal 1 (TF=1). With this change, as reflected in the model "awt1530_p303cvf_v700_Tf1.lib", the oscillation problem was resolved as shown in the latest results below in Figure 2-9 and Figure 2-10. When the Project is constructed, the Acciona turbines must be set to reflect this choice of Tf = 1 second

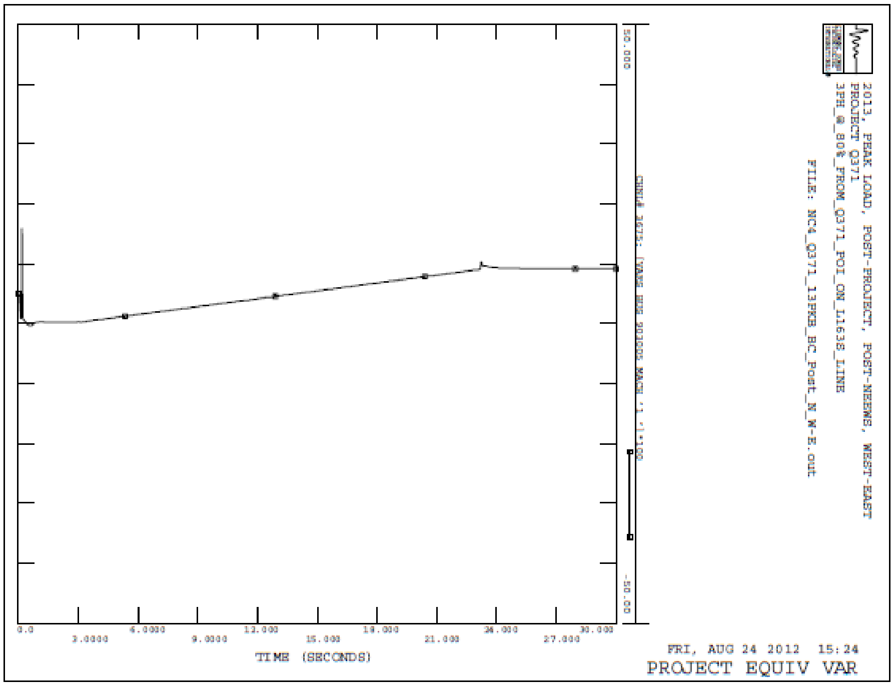

Figure 2-9. Project Q output for PK E-W Post NEEWS case for NC4 with TF=1

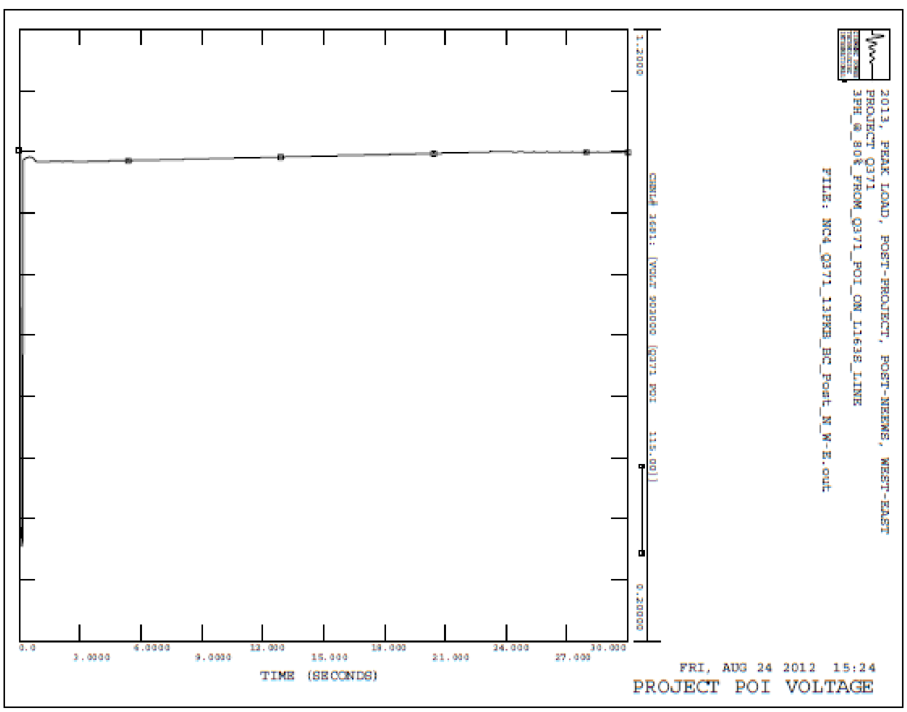

Figure 2-10. POI Voltage for PK E-W Post NEEWS case for NC4 with TF=1

Appendix C includes the DYR file with the stability parameters for the WTG including the protection settings and the centralized voltage regulator used for this Study.

Section

3

Study Methodology

3.1 Introduction

The Study was performed under the ISO New England (ISO-NE) Open Access Transmission Tariff ("Tariff") Schedule 22-Standard Large Generator Interconnection Procedures ("LGIP"), and in accordance with:

- Northeast Power Coordinating Council (NPCC) Document A-2 "Basic Criteria for Design and Operation of Interconnected Power Systems".
- Interconnection Procedures contained in Schedule 22 of the Tariff.
- ISO-NE Planning Procedure No. 3, "Reliability Standards for the New England Area Bulk Power System" (October 2006).
- ISO-NE Planning Procedure No. 5-3, "Guidelines for Conducting and Evaluating Proposed Plan Application Analyses".
- ISO-NE Planning Procedure 5-6, "Scope of Study for System Impact Studies under the Network Capability Interconnection Standard (NCIS)".
- ISO-NE Operating Documents.
- Transmission Reliability Standards for Northeast Utilities (May 2008).

3.2 Criteria and Methodology

The study was performed using the ISO-NE stability criteria in the ISO-NE Reliability Standards dated February 2005, and in accordance with the "Transmission Planning Guideline for Northeast Utilities", dated May 2008. The criteria are included in Appendix D.

- Stability testing was performed for normal conditions with all lines in-service (N-1 analysis) with the Project modeled in-service.
- BPS testing was performed as per NPCC's Document A-10 of December 01, 2009.

Siemens PTI software PSS®E Version 30.3.3 CVF was used in the stability analysis.

Section

4

Base Cases and Generation Dispatch

ISO-NE provided 6-digit power flow base cases representing 2013 peak and light load conditions. The New England loads represented in the cases match the CELT 2011 forecast load levels. Additionally, generating units in New England were represented with the most updated maximum power outputs at 0°F.

4.1 Local Area Voltage Setup

To ensure the Project can operate under different local 115 kV area voltage levels, low area voltages were simulated for the peak load conditions and conversely high area voltages for the light load conditions.

To achieve the high area voltage conditions, local switched shunt capacitors modeled at Jackman 115 kV and Chestnut Hill 115 kV were locked at the highest dispatch possible, whilst ensuring the local voltages were below the N-0 steady state criteria of 1.05 per unit. In addition the Fitzwilliam Auto transformer was set to regulate a voltage of [redacted]

To achieve the low area voltage conditions, local switched shunt capacitors modeled at Jackman 115 kV and Chestnut Hill 115 kV were locked to the lowest dispatch possible (i.e. offline), whilst ensuring the local voltages were above the N-0 steady state criteria of 0.95 per unit. In addition the Fitzwilliam Auto transformer was set to regulate a voltage of [redacted]

As previously described in Section 2.3, to be consistent with local pre-Project voltages and typical system operating levels, the reactive power output of the Project WTG's adjust to maintain a scheduled voltage at the POI of [redacted] for light load conditions and [redacted] for peak load conditions.

4.2 Development of Base Cases

Power flow cases representing 2013 peak and light load conditions were used in the Study. The peak load represents, approximately, the 2013 summer peak 90/10 load of the CELT 2011 forecast and the light load is calculated as the 45% of the summer 50/50 peak load.

Table 4-1 below, shows the New England (NE) loads and the transmission losses in the peak and light load post-Project base cases that were considered in the Study.

Table 4-1. NE Load and Losses for 2013 (MW)

	Load	Losses	Total
Peak	30,150	890	31,040
Light	13,692	512	14,204

The following approved projects and their associated upgrades were assumed in service and were modeled in all base cases:

- Closing of the Y138 line from White Lake 115 kV Substation to Saco Valley 115 kV Substation.
- 115 kV capacitors at Beebe and White Lake substations.
- Monadnock transmission project.
- Q166 Granite Wind project (99 MW) interconnecting on the W179 line. The following upgrades are related to this Project: closing of 1J95 Switch at Littleton 115kV Substation; W179 line (Paris-Pontook-Berlin 115 kV) uprated to [redacted] O154 line (Paris-Lost Nation 115kV) uprated to [redacted] D142 (Lost Nation-Whitefield 115 kV) uprated to [redacted] added 4x4.8 MVAR capacitor bank and 4 MVAR DVAR at the project 34.5 kV collector bus.
- Q172 wind project (40 MW) interconnecting in Vermont on the St. Johnsbury-Irasburg line.
- Q197 wind project (50 MW), named Record Hill in the power flow cases, interconnecting in Maine to the Rumford 115 kV Substation.
- Southern Loop transmission project.
- Q251 Laidlaw Berlin Biomass project (65.9 MW) plus associated line rating upgrades of the following 115 kV lines caused by the project: O154 line (Paris-Lost Nation 115 kV) upgraded to [redacted] D142 line (Lost Nation to Whitefield 115 kV) upgraded to [redacted] and S136 line (Whitefield to Berlin 115 kV) upgraded to [redacted] for all ratings.
- Q290 wind project (18 MW), interconnecting in Maine to the Woodstock 115 kV Substation.
- Q291 Merrimack G2 up-rate to the following ratings: gross output 354 MW, gross over-excited [redacted] gross under-excited [redacted] with a service station load of [redacted]
- Q311 Wind project interconnecting in the 46.0 kV distribution system in VT.

[redacted]

- Q323 wind project up-rate of former project Q290 to 20 MW (increase of 2 MW) in Maine.

- Lyndonville reliability project, that adds a [redacted] Substation, a 115/34.5 kV transformer and two 12.5 MVAr capacitors. The project taps the St Johnsbury to Sheffield 115 kV line in Vermont.

- Q345 Wind Project (24 MW) interconnecting between Beebe River and Ashland Tap on the E-115 115 kV line in New Hampshire.

- Wind project Q368 interconnecting at Monadnock Substation to the 34.5 kV bus in New Hampshire at an output of 16.1 MW.

The following changes were made to the **light load** cases originally provided by ISO-NE:

- Two, 4 MVAr statcom devices required as upgrades for project Q345 were added and modeled as a single 8 MVAr device, connected to the 34.5 kV collector bus via a 34.5/0.5 kV transformer. The reactive power output is set close to zero MVAr output pre-contingency.

- Bearswamp and Northfield pumped storage units were set to maximum power output in pumping mode.

- Millstone 2 units were turned online.

- Phase II HVDC was to set to a total of [redacted] into New England.

- Blissville and Sandbar PAR's set to [redacted] transfer.

- Interfaces of interests were stressed to recommended levels.

- The power output from generating units in NH and VT were set to maximum power output according data provided by ISO-NE.

- The local area to the Project was configured to simulate high area voltages by switching local capacitors online were possible, thereby forcing the Project to import reactive power (within the capable limits of the WTG's).

- VT Yankee generating unit turned offline in all East-West stressed cases only, to stress the system by eliminating one of the major sources of reactive support in that area.

The following changes were made to the **peak load** cases originally provided by ISO-NE:

- Errors in several zone numbers were resolved using an IDEV file provided by ISO-NE.

- Two, 4 MVAr statcom devices required as upgrades for project Q345 were added and modeled as a single 8 MVAr device, connected to the 34.5 kV collector bus via a 34.5/0.5 kV transformer. The reactive power output is set close to zero MVAr output pre-contingency.

- The power output from generating units in NH and VT were set to maximum power output according data provided by ISO-NE.
- The local area to the Project was configured to simulate low area voltages by switching local capacitors offline were possible, thereby forcing the Project to export reactive power (within the capable limits of the WTG's).
- VT Yankee generating unit turned offline in all East-West stressed cases only, to stress the system by eliminating one of the major sources of reactive support in that area

4.3 Generation Dispatch

The generation dispatch in ISO-NE can be found in Table 4-2 below for all cases studied along with several New England interface flows. "OOS" refers to a generating unit being "Out Of Service".

Complete power flow case summaries and one line diagrams can be found in Appendix A and Appendix B, respectively.

For the light load West to East cases, the ME and NH interface flows were significantly reduced to enable high West to East flows due to the light load conditions and only minimal MA and RI generation already online.

Table 4-2. Generation Dispatch (MW) and Interface Flows (MW) for the Post-Project Cases

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Section

5

Stability Contingencies

The list of contingencies tested in the Study is shown in Table 5-1, along with the clearing times at each terminal.

The list includes Normal Contingencies (NC), Extreme Contingencies (EC), and Bulk Power System (BPS) contingencies. The contingencies were tested for the peak and light load scenarios documented in Section 4.

Each NC 115kV line contingency was simulated twice a) with a three-phase line fault adjacent to the bus (zone 1 local clearing) and b) with a three-phase fault 80% along the line from the same bus (zone 2 clearing).

Delayed Auto-Reclosing (DAR) schemes [redacted] were simulated with one shot [redacted] after the initial fault with reclose by the circuit breaker closest to the fault and the remote terminal remaining open (synchronized closing).

Contingencies NC1–NC3 and NC6-NC8 were re-tested with the Greggs series reactor in-service i.e. bypass switch in the open position (current flowing through the series reactor).

Table 5-1. List of Stability Contingencies

[redacted]

[redacted]

[redacted]

Section

6

Stability Results

Dynamic simulations of the contingencies described in Section 5 were performed for the post-NEEWS peak and light load scenarios described in Section 4. The analysis was performed as per the applicable reliability standards.

The stability results are described below and shown in Table 6-1. Simulation plots are provided in Appendix E.

6.1 BPS Testing

Peak Load Results

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Light Load Results

[redacted]

[redacted]

[redacted]

The BPS testing results show that the total loss of source was less than 1,200 MW in each of the BPS contingencies simulated; therefore none of the buses tested needs to be classified as a BPS facility due to the Project.

6.2 NC Testing

These results are for both the light and peak load conditions with both East to West and West to East flows.

Results for normal contingencies NC1 through NC16 show no loss of source occurs, including contingencies re-tested with DAR (Delayed Auto Reclose) and with the Greggs 115 kV series reactor bypass switch in the open position (current flowing through the series reactor).

6.3 EC Testing

These results are for both the light and peak load conditions with both East to West and West to East flows.

[redacted]

Results for contingencies EC19 to EC21, show no loss of source occurs.

As no units were tripped following simulation of the EC contingencies, re-testing these contingencies as single-line-to-ground faults was not required.

[redacted]

6.4 POI Voltage Recovery

For several contingencies: [redacted] the reactive power output limit of the turbines was reached due to the terminal voltage limitation shown previously in Figure 2-4 and again below in Figure 6-1 for reference.

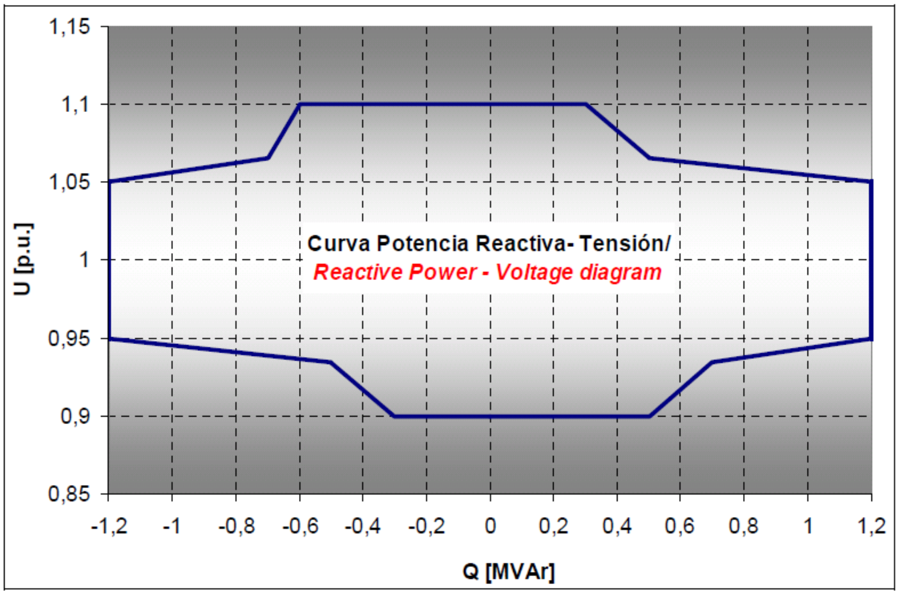

Figure 6-1. WTG Reactive Power (Q) vs Terminal Voltage (U) at Full Rated Active Power Output

For these contingencies the scheduled POI voltage is not maintained. The results show the highest voltage occurred for the light load case with East to West flows for contingency NC11 with [redacted] at the POI, as shown below in Figure 6-2 and Figure 6-3 below.

[redacted]

Figure 6-2. Project Q output for LL E-W Post NEEWS case for contingency NC11

[redacted]

Figure 6-3. POI Voltage for LL E-W Post NEEWS case for contingency NC11

As the light load case is stressed for high area voltages with local switchable shunt capacitors at Jackman 115 kV and Chestnut Hill 115 kV locked at maximum dispatch [redacted] this high voltage will only last a short duration until these capacitors are redispatched. Following a steady state power flow solution of this

[redacted]

contingency, allowing the capacitors to redispatch, the scheduled voltage of [redacted] at the POI was reached. For the peak load case the lowest voltage of [redacted] was found at the POI for contingency NC6.

The Project is not required to make any system upgrades to maintain a voltage schedule at the POI.

Table 6-1. Post-NEEWS Peak and Light Load Stability Results

[redacted]

[redacted]

[redacted]

[redacted]

Section

7

Sensitivity Stability Results

Dynamic simulations of the contingencies described in Section 5 were performed for the pre-NEEWS peak and light load scenarios described in Section 4. The Delayed Auto-Reclosing (DAR) schemes [redacted] and Greggs series reactor in-service conditions were not simulated for pre-NEEEWS conditions. The analysis was performed as per the applicable reliability standards.

The stability results are described below and shown in Table 7-1. Simulation plots are provided in Appendix E.

The results shown the generating units that tripped offline due to each contingency, matched exactly the results found for the post-NEEWS conditions described in Section 6 above. As such a detailed description of the results is not provided.

Table 7-1. Pre-NEEWS Peak and Light Load Stability Results

[redacted]

[redacted]

[redacted]

Section

8

Conclusions

The stability study results are summarized as follows:

8.1 BPS Testing

BPS testing was performed [redacted] The total loss of source was less than 1,200 MW in each of the BPS contingencies simulated. Therefore, none of the buses tested needs to be classified as a BPS facility due to the interconnection of the Project.

8.2 Normal Contingencies (NC) Testing

Normal contingencies tested in the local area surrounding the Project shown no generating units were tripped. Also, for the post-NEEWS case (not tested for pre-NEEWS conditions), no generating units were tripped for the Delayed Auto-Reclosing schemes [redacted] and with Greggs series reactor in-service.

8.3 Extreme Contingencies (EC) Testing

No units were tripped following simulation of the EC contingencies.

8.4 Final Conclusions

The Study determined the Project operating with field bus control (centralized voltage regulator) controlling the project's 115 kV Point of Interconnection voltage, nominal tap settings (ratio of 1.0) for the 34.5/115 kV main transformer and 12/34.5 kV Wind Turbine GSU and without needing any upgrades, will not have an adverse impact on the stability of the power system.

Appendix

A

Power flow Summaries

Appendix

B

Power Flow One-Line Diagrams

[redacted]

Appendix

C

Project IDEV and DYR Files

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Appendix

D

ISO-NE Stability Criteria

D.1 BPS Testing Criteria

- System instability is a significant adverse impact outside the local area.
- An oscillatory or negatively damped system response is a significant adverse impact outside the local area.
- If a discrete bounded sub-area of the system that is susceptible to voltage collapse or separation from the rest of the system cannot be determined then the system response is considered to have a significant adverse impact outside the local area.
- If analysis results in isolation of a sub-area, the net load and/or generation in that sub-area must be quantified. If the sub-area is supplying more than 1,200 MW to the rest of the system, or if it is absorbing more than 1,200 MW of power it has a significant adverse impact outside the local area.
- If the sub-area is supplying < 1,200 MW or absorbing < 1,200 MW, the result may be classified as not having a significant adverse impact outside the local area, and the bus may not be part of the bulk power system. However, net source or load served by an area may not necessarily be the only determining factor in deciding if a significant adverse impact outside the local area has occurred. Gross load, gross generation, number of buses, or the geographic area of impact, etc., may also discretionarily be used to determine if a significant adverse impact outside the local area has occurred. This is covered with the next bullet.
- Islanding of any control Area is a significant adverse impact outside the local area. [redacted]
- If a discrete bounded sub-area of the system that is susceptible to voltage collapse included portions of another control Area, or if the facilities of another control Area exceed their STE ratings, then the results will be coordinated with that control Area to determine if a significant adverse impact outside the local area has occurred.

D.2 Normal Contingency Criteria

The guideline defining acceptable transient stability performance of the transmission system for **normal contingencies** (3-phase faults cleared by the slower of the two fastest protection groups or 1-phase faults with backup clearing) are as follows:

- All units should be transiently stable with positive damping
- A 53% reduction in the magnitude of system oscillations must be observed over four periods of the oscillation
- A loss of source greater than 1,200 MW is not acceptable

D.3 Extreme Contingency Criteria

The guideline defining acceptable transient stability performance of the transmission system for these 3-phase faults with delayed clearing extreme contingencies are as follows:

- A loss of source greater than 1,400 MW is not immediately acceptable
- A loss of source between 1,400 MW and 2,200 MW may be acceptable depending upon a limited likelihood of occurrence and other factors
- A loss of source greater than 2,200 MW is not acceptable
- A 53% reduction in the magnitude of system oscillations must be observed over four periods of the oscillation
- Transiently stable with positive damping

D.4 ISO-NE VOLTAGE SAG Guidelines

The minimum post-fault positive sequence voltage sag must remain above 70% of nominal voltage and must not exceed 250 milliseconds below 80% of nominal voltage within 10 seconds following a fault.

These limits are supported by the typical sag tolerances shown in IEEE Standard 1346-1998.

[redacted]

Appendix

E

Stability Plots

E.1 Post NEEWS Peak Load East to West

[redacted]

E.2 Post NEEWS Peak Load West to East

[redacted]

E.3 Post NEEWS Light Load East to West

E.4 Post NEEWS Light Load West to East

[redacted]

E.5 Pre NEEWS Peak Load East to West

E.6 Pre NEEWS Peak Load West to East

[redacted]

E.7 Pre NEEWS Light Load East to West

E.8 Pre NEEWS Light Load West to East

[redacted]

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