GE Energy

Progress Report to:

ISO New England

for

Sheffield Wind Farm System Impact Study

Prepared by:

Leon M. Richardson
Mahmoud Elfayoumy (Pterra Consulting)
Ketut Dartawan (Pterra Consulting)
Ricardo Austria (Pterra Consulting)
Jingjia Chen (Pterra Consulting)
Ramon Tapia (Pterra Consulting)

December 21, 2006

Foreword

This document was prepared by General Electric International, Inc. It is submitted to ISO New England. Technical and commercial questions and any correspondence concerning this document should be referred to:

Leon M. Richardson
GE Energy
1 River Road
Building 2, Room 613
Schenectady, New York 12345
Phone: (518) 385-3890
Fax: (518) 385-5703
E-mail: leon.Richardson@ps.ge.com

Legal Notice

This report was prepared by General Electric International, Inc. as an account of work sponsored by ISO New England. Neither ISO New England nor GE, nor any person acting on behalf of either:

1. Makes any warranty or representation, expressed or implied, with respect to the use of any information contained in this report, or that the use of any information, apparatus, method, or process disclosed in the report may not infringe privately owned rights.

2. Assumes any liabilities with respect to the use of or for damage resulting from the use of any information, apparatus, method, or process disclosed in this report.

Table of Contents

Executive Summary

A 40.0 MW Wind Farm, Sheffield wind farm project (the “Project”) is proposed to be connected to VELCO's 115 kV transmission system between St. Johnsbury and Irasburg substations. The Project anticipated to be operational by 2007 will use Clipper 2.0 MW Wind Turbine Generators (WTGs) with no voltage regulation or reactive capability.

The work involved in the System Impact Study (SIS) includes thermal, voltage, stability and N-2 operability testing for all lines in and N-1 line outage conditions. The objective of this SIS is to determine the required transmission system upgrades, if any, due to the potential impact of the Project on VELCO's and New Hampshire's transmission systems. The study is performed in accordance with the "NEPOOL Reliability Standards" and the NEPOOL Minimum Interconnection Standards".

This study used an incremental approach to determine the impact of the proposed Project on VELCO's power system. First, system performance without the proposed Project was determined in order to establish the benchmark. Then system performance with the proposed Project was determined and compared with the benchmark. This incremental approach evaluates the actual impact of the proposed Project since existing criteria violations, if any, are identified.

Power flow analysis was performed, including voltage and thermal N-1 and N-2 contingency analyses. For the N-1 and N-2 analyses, all branches and buses 34.5 kV and above, in Vermont and New Hampshire, and 115 kV and above in New England are monitored for pre and post-contingency thermal and voltage criteria violations. The Project is modeled in the power flow cases used for the study using Clipper 2. 0 MW WTGs with no reactive capability.

For the N-1 analysis, the obtained results showed no negative thermal impact of the Project on VELCO's transmission system. As for voltage criteria violations, the results showed that for one of the peak load power flow cases, PK3, the presence of the Project resulted in:

a) Post-contingency low voltage criteria violations at Berlin 34.5 kV and White Field 115 kV for contingency U-199/X-178: Littleton - Whitefield – Beebe. Also, one post-contingency voltage deviation criteria violation was detected at the 115kV at White Field.

b) Post-contingency high voltage criteria violations at Lowel 34.5 kV for contingency K41: Irasburg - Highgate.

However, comparison with the pre-Project condition shows a slight negative impact of the Project.

For the N-2 analysis, only two N-1 outages were considered; these are: K29E (Sheffield - St. Johnsbury) and K41 (Irasburg – Highgate), 115 kV lines. The N-2 analysis was performed for the proposed Project integrated into VELCO's power system. Two loading system conditions: peak load with low hydro generation and shoulder load (75% of peak load) were considered in the analysis.

It was found out that all four N-1 cases needed to be repositioned by disconnecting the Project from the system for both (N-1) outages, K29E, and K41, in preparation for the second outage (in particular K41 and K29E, respectively) to avoid post-contingency high voltage criteria violations in the neighborhood of the Point of Interconnection (POI).

Short circuit analysis was not performed since it is understood that the Clipper wind turbine generators contribute no short circuit current, e.g. stator converter current is limited to 110% of full load current (221 amperes at 115 kV). Short circuit studies are normally conducted at generator no-load conditions in which case the Clipper generators would contribute no short circuit current.

A stability analysis was performed to determine the Project's impact on transient stability performance to normal and extreme contingencies for three different operating conditions: light load, light load with low hydro and peak load. For modeling in dynamic simulations, Clipper 2.0 MW WTGs were assumed.

The ISO-NE system remained stable and positively damped for all of the contingencies simulated. Oscillations are damped to within 50% within four periods. The Keswick relay is not triggered and no loss of source greater than 1200 MW is observed. The Project tripped offline for several studied contingencies, as follows:

- For the normal contingency involving a three-phase fault on Line K-42 at Georgia (NC-01), the Highgate HVDC trips for all system conditions studied, and the Project trips in the light load low Hydro and peak load cases on low voltage.
- The Project trips offline for the following normal contingencies: three-phase faults on Line K-28W at Sheffield (NC-06), and Line K-28E at St Johnsbury (NC-07), and on Line K-28E at Sheffield (NC-08). The cause of the trips in NC-06 and NC-08 are violations of the high frequency protection, and the cause of the trip in NC-07 is a violation of under-voltage protection for the Clipper wind turbines. The recorded loss of source in each case is 40 MW, equivalent to loss of the whole Project generation. The Project trips are observed in all conditions studied: light load, light load low hydro and peak load.
- For the emergency contingency involving a three-phase fault on the high side of the St Johnsbury transformer, with failure of primary protection for St Johnsbury K28, the Project also trips on low voltage. The Project trips are observed in all conditions studied: light load, light load low hydro and peak load.

1 Introduction

GE Energy under contract to ISO-NE performed a System Impact Study (SIS) for the proposed 40.0 MW Project. Pterra, LLC, under contract to GE Energy, performed the study under the general direction of GE Energy. This wind farm will be connected to VELCO's 115 kV transmission system between St. Johnsbury and Irasburg substations. The Project is anticipated to be operational by 2007 and will use Clipper 2.0 MW WTGs with no voltage regulation or reactive capability.

The work involved in the SIS includes thermal, voltage, stability and N-2 operability testing for all lines in and N-1 line outage conditions. The objective of this SIS is to determine the transmission system upgrades, if any, required due to the potential impact of the proposed project on VELCO's and New Hampshire's transmission systems. The study is performed in accordance with the "NEPOOL Reliability Standards" and the NEPOOL Minimum Interconnection Standards".

2 Benchmark Database Preparation

The objective of this task is to review the databases that will be used in the study. For steady state analysis, VELCO provided the following three power flow cases for 2007 summer peak (2007 summer peak 90/10 probability):

1. Case 1, (PK1), with the following conditions:
    a. High hydro (50MW)
    b. Comerford and Moore generation is high.
    c. Phase I HVDC is off
    d. The flow through Highgate DC line is set at 210 MW
    e. New England East West Interface is set at 2400 MW
    f. Flow through PV20 is set at 100 MW
    g. Vermont load is 1160 MW
    h. NEPOOL load is 29080 MW.
2. Case 2, (PK2): Same as PK1 except for low hydro (15MW).
3. Case 3, (PK3): Same as PK2 except Comerford and Moore generation are off (dispatched Newington ON with resulting increased NNE Scobie)

Also, VELCO provided one additional power flow case representing shoulder loading conditions (75% of peak, 50/50 probability):

4. Case 4, (75PK1B) with the following conditions:
    a. High hydro (100MW)
    b. Comerford and Moore generation is high
    c. Phase I HVDC is off
    d. Highgate DC line is off
    e. New England East West Interface is set at 2400 MW
    f. Flow through PV20 is set at 70 MW
    g. Vermont load is 860 MW
    h. NEPOOL load is 20510 MW.

The hydro dispatch is much higher at the 75% peak load case because generation in the central and southern Vermont regions is increased. In the peak load cases, the hydro dispatch is high only in the region local to the Sheffield location.

All power flow cases provided are in GE's Positive Sequence Load Flow (PSLF) software package format.

3 Sheffield Wind Farm Addition Database Development

The objective of this task is to develop additional databases (from the provided ones) for steady state and stability that will include the proposed Sheffield 40.0 MW Project.

For steady state analysis, four new power flow cases were created from PK1, PK2, PK3, and 75PK1B to include the Project. These cases are:

1. PK1_Sh.sav
2. PK2_Sh.sav
3. PK3_Sh.sav
4. 75PK1B_Sh.sav

The following assumptions were adopted when modeling the Project for steady state analysis:

1. The Point of Interconnection (POI) is located approximately 19.2 miles from VELCO's St. Johnsbury Substation on the 36.5 miles long 115 kV St. Johnsbury to Irasburg transmission line.
2. Individual representation of the WTGs was not adopted; rather an aggregate model consisting of two equivalent wind turbines and the equivalent collector system was adopted according to the one line diagram shown in Figure 2.1 using Clipper 2.0 MW WTGs.
3. Substation service loads were modeled in the power flow cases; the total MW load is 0.8 MW. The breakdown of the substation active and reactive load components is shown in Figure 2.1.
4. The Project is modeled with no reactive capability.
5. Generation re-dispatch was implemented in order to accommodate the 39.2 MW from Project. One re-dispatch scenario was used for the developed cases PK1_Sh.sav, PK2_Sh.sav, and 75PK1B_Sh.sav by re-dispatching generating units at Comerford. One Comerford generating unit was turned off (41 MW). For case PK3_Sh.sav, generation at Merrimack was reduced by 39.2 MW since the Comerford units are off in case PK3.sav.

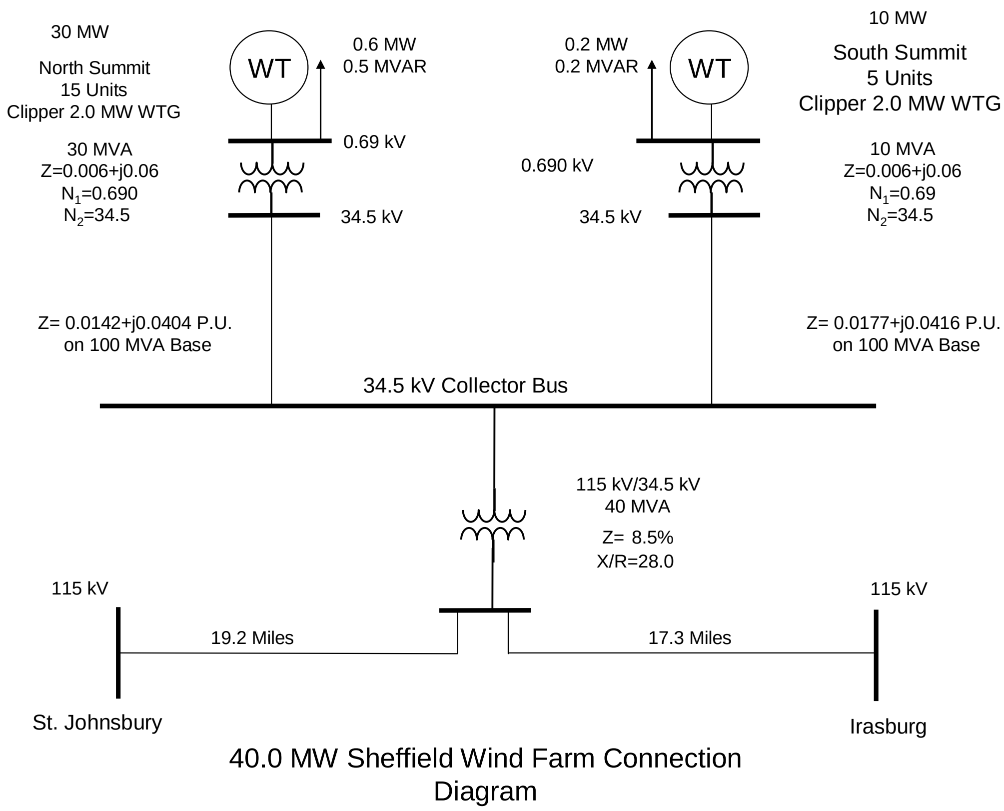

Figure 2.1 Interconnection of the Project to VELCO's 115kV System.

For stability analysis, three additional power flow cases and two additional dynamics databases were developed. Clipper 2.0 MW WTGs were assumed for this analysis. The three new power flow cases are:

1. Light Load Case with the Project: ll09a.sav;
2. Light Load (Low Hydro) Case with the Project: ll09a-lh.sav;
3. Peak Load Case with the Project: pk09a.sav.

The PSLF model package for Clipper 2.0 MW WTGs accounts for a number of important variables such as wind speed, blade pitch angle mechanical torque (based on turbine aerodynamics and wind speed), generator torque, generator rotor speed and system voltages. Table 3.1 lists the parameters of the dynamics models.

Table 3.1 Parameters for Dynamics Models Representing Sheffield Wind Farm

Model: clippertr		**Model: clippergn**		**Model: gpwtg**	
Parameter	*Value*	*Parameter*	*Value*	*Parameter*	*Value*
"kpp"	59.7	"rcomm"	1.1	“vhi1”	1.1
"kpi"	6.54	"xcomm"	1.0	“vhi2”	1.2
"PAmax"	90.0	"cntrbus "	1	“vhi3”	1.3

Model: clippertr		Model: clippergn		Model: gpwtg	
"PAmin"	0.0	"capbus "	0	“vhi4”	99
"PAinit"	0.0	"kp_i "	0.0	"vlo1"	0.9
“H”	5.69	"ki_i "	0.0	"vlo2"	0.1
"PWinit"	1.0	"tdelay_Ipk "	0.0	"vlo3"	0.0
		"tdelay_p "	0.0	"vlo4"	0.0
		"Vthr_Ipk "	0.0	"thi1"	5.0
		"Imin"	0.0	"thi2"	0.05
		"Imax"	0.0	"thi3"	0.01
		"T_ImPk "	0.0	"thi4"	0.0
		"T_ImPk "	0.0	"tlo1"	3.0
		"T_Im_rmp "	0.0	"tlo2"	0.01
		"V_hg_p "	0.0	"tlo3"	0.0
		"V_lw_p "	0.0	"tlo4"	0.0
		"pk_mw "	0.0	“fhi”	63.0
		"rate_p "	0.0	“flo”	57.0
		"tdisc"	0.0	“tfhi”	0.2
		"delay_c"	0.0	“tflo”	0.2
		"B_cap"	0.0		
		"V_cap_off "	0.0		
		"vref_lw "	0.0		
		"vref_hg "	0.0		
		"accel "	0.0		

Note: Refer to Appendix J for explanation of the Parameter names.

4 Power Flow Analysis

The objective of this task is to study the impact of the proposed Project. Pre and post-contingency thermal and voltage criteria violations are identified for the power flow cases with and without the proposed Project for 2007 summer peak load and shoulder load system models as shown in Table 4.1.

Table 4.1 Base Cases for Thermal and Voltage Analysis

Case Description	Case Name	Sheffield in Service
Summer peak load	PK1	NO
	PK1-SH	YES
	PK2	NO
	PK2-SH	YES
	PK3	NO
	PK3-SH	YES
Shoulder Load (75% peak)	75PK1B	NO
	75PK1B-SH	YES

The developed one line diagrams for the base cases, shown in Table 4.1, are provided in Appendix A.

For N-1 analysis, thermal criteria require branch loading to be less than 100% of normal rating (Rate 1) for pre-contingency conditions, and to be less than the long term emergency (LTE) rating (Rate 2) for post-contingency conditions. Any branch loading greater than the LTE rating requires mitigation. For N-2 analysis, thermal criteria require mitigation for any branch loading greater than the Short Term Emergency (STE) rating for stuck breaker and double circuit tower fault scenarios. The voltage criteria for pre and post-contingency conditions used for the Vermont system are shown in Table 4.2. (The voltage criteria for different regions in New England system are summarized in section 3.2 of the scope of work).

Table 4.2 Voltage Criteria

Region	kV	Pre-contingency Voltage Criteria	Post-contingency Voltage Criteria	ΔV
Vermont	345 kV	1.00 pu < Vbus < 1.05 pu	0.95 pu < Vbus < 1.05 pu	5%
	230 kV	1.00 pu < Vbus < 1.05 pu	0.95 pu < Vbus < 1.05 pu	5%
	115 kV	0.95 pu < Vbus < 1.05 pu	0.92 pu < Vbus < 1.05 pu	10%
	34.5 kV-46 kV	0.95 pu < Vbus < 1.05 pu	0.90 pu < Vbus < 1.05 pu	10%

All branches and buses 34.5 kV and above in Vermont and New Hampshire and 115 kV and above in New England are monitored for pre and post-contingency thermal and voltage criteria violations. Also, National Grid facilities, as defined in Appendix B, are monitored.

VELCO provided the contingency file that was used for thermal and voltage analysis. The provided list of contingencies was reviewed against the provided power flow cases; several modifications were applied to the original list. VELCO reviewed and approved the revised contingency file. The revised contingency file is included in Appendix C.

4.1 Pre-Contingency Thermal Analysis Results

Pre-contingency analysis for the provided power flow cases revealed several thermal criteria violations shown in Table 4.3.

Table 4.3 Pre-Contingency Thermal Criteria Violations

Monitored Element	Area	Rate MVA	% Overload	Case	% Overload	Case
73244 N.BLMFLD 115 73288 NESMBY 115	NE	221.00	110.6	PK1	110.60	PK1_SH
73701 CRRA JCT 115 73703 ASHCREEK 115	NE	340.00	107.0		107.00	
71832 BELLOWS 115 71846 BELWS T3 99	NE	10.00	129.7		129.80	
87760 NASON ST 35 87764 NASON-V 35 1	VELCO	50.0	100.0	PK2	100.6	PK2_SH
73244 N.BLMFLD 115 73288 NESMBY 115	NE	221.00	111.0		110.6	
73701 CRRA JCT 115 73703 ASHCREEK 115	NE	340.00	107.0		107.2	
71832 BELLOWS 115 71846 BELWS T3 99	NE	10.00	130.0		130.1	
87760 NASON ST 35 87764 NASON-V 35 1	VELCO	50.0	99.8	PK3	100.2	PK3_SH
73244 N.BLMFLD 115 73288 NESMBY 115	NE	221.00	110.7		110.6	
73701 CRRA JCT 115 73703 ASHCREEK 115	NE	340.00	107.4		107.3	
71832 BELLOWS 115 71846 BELWS T3 99	NE	10.00	132.4		132.2	

Per discussions with VELCO, the following ratings were corrected in the provided power flow cases:

1. The ratings of the St Albans transformers; for transformer 1, the corrected ratings are 28/31/35 MVA, and for transformer 2 the corrected ratings are 30/35/40 MVA.

2. The ratings of two Maine facilities in the Maxcys area, line-Section 60 (Maxcy's x Brown's Crossing x Bowman Street); the corrected ratings are 190.1/232.5/251.5 MVA.

Comparison of the pre and post-Project thermal criteria violations listed in Table 4.3 shows insignificant impact caused by the proposed Project.

4.2 Post-Contingency Thermal Analysis Results

Post-contingency thermal analysis for the power flow cases, listed in Table 4.1, revealed several thermal criteria violations as shown in Appendix D. Comparison of the pre and post-project thermal criteria violations listed in Appendix D reveals that most of the thermal criteria violations are due to base case overloads. However, in general, insignificant impact is caused by the proposed Project.

4.3 Pre-Contingency Voltage Analysis Results

Pre-contingency analysis for the provided power flow cases revealed several voltage criteria violations as reported in Appendix E.

Per discussion with VELCO, the identified pre-contingency voltage criteria violations are as expected. The buses listed in Appendix E are in three different radial systems as follows:

1. Woodsville is served radially from Comerford.

2. Putney is radial out of Bellows Falls.

3. Lyndonville is radial out of St Johnsbury.

These buses need additional voltage support. Some proposed capacitors at Woodsville and Lyndonville are somewhat close to the Project, but were kept off because they will not be in service prior to the Project. The proposed capacitor at Putney was kept in the cases because it is far away and does not have an impact to the Sheffield study. There is a proposed capacitor modeled at N Elm St. which was kept in the cases since it is supposed to come on line prior to the Project.

These voltage violations are considered as pre-Project deficiencies. The changes in these voltages post-Project are insignificant.

4.4 Post-Contingency Voltage Analysis Results

Post-contingency analysis for the provided power flow cases revealed the following:

1. There are no voltage deviation criteria violations for the Shoulder Load (75% peak) cases (75PK1B and 75PK1B_SH) and for the peak load cases PK1 and PK1_SH.

2. The voltage deviation criteria violations are identified mostly in the 34.5 kV level; few violations are identified in the 115 kV level.

3. For cases PK2 and PK2_SH, the comparison of the pre and post-Project voltage deviation criteria violations shows insignificant improvement of some existing voltage deviation criteria violations in case PK2 in Vermont and New Hampshire 34.5 kV sub-transmission systems for contingency K29: Littleton - St. Johnsbury. This is mainly because of the adopted dispatch scenario since the Project has no reactive capability.

4. For cases PK3, PK3_SH, the comparison of the pre and post-project voltage deviation criteria violations show slight improvement of some voltage deviation criteria violations in PK3_SH for contingencies K29: Littleton - St. Johnsbury and K42: Highgate - Georgia, trip Highgate & shed St. Albans/Milton load. For contingency U-199/X-178: Littleton - Whitefield – Beebe, voltage deviation criteria violations for 34.5 kV and 115 kV buses in VELCO and New Hampshire areas south and east to the proposed Project, respectively, were detected. The 34.5 kV buses are Whitefield, Berlin, Pinet PF, Pontook, Lost Nation, and Errol PH. The 115 kV buses are at Berlin, SMITH HY, Pontook PH and Lost Nation. However, these violations exist pre-Project in case PK3; the presence of the proposed Project insignificantly impacted the voltage deviation at the 115kV at White Field.

The results are provided in Appendix F.

For post-contingency voltage criteria violations, the following conclusions are made:

1. For case PK1_SH, the project did not introduce any new post-contingency low/high voltage criteria violations.

2. For case PK2_SH, the presence of the proposed Project removed post-contingency low voltage criteria violations existing in case PK2 at FAIRBNKS, BAY, BARKER A, FAIRBK T, and St. John 34.5 kV buses, for contingency K29: Littleton - St. Johnsbury. This is mainly because of the adopted dispatch scenario since the Project has no reactive capability. The new post-contingency voltage criteria violations at Newbury 34.5 kV for contingency K26: West Barre – Granite are due to voltage criteria violations in the base case.

3. For case PK3_SH, the adopted dispatch scenario of the proposed Project removed post-contingency low voltage criteria violations existing in case PK3 at several buses, mostly at 34.5 kV and 46 kV, for contingencies 340: Coolidge - Vermont Yankee,K29: Littleton - St. Johnsbury, D-204: Comrfrd-Littltn-Moore,Litt auto,MrG3&4, and K42: Highgate - Georgia, trip Highgate & shed St. Albans/Milton load.

4. For case PK3_SH, several post-contingency low voltage criteria violations were detected. The presence of the proposed Project causes slight post-contingency improvements on the post-contingency low voltage criteria violations existed in case PK3 at 34.5 kV, 46 kV, and 115 kV voltage levels. However, as shown in Table 4.4, the presence of the Project resulted in:

    a. Post-contingency low voltage criteria violations at Berlin 34.5 kV and White Field 115 kV for contingency U-199/X-178: Littleton - Whitefield – Beebe. Comparison with the pre-Project condition shows slight impact.

    b. Post-contingency high voltage criteria violations at Lowel 34.5 kV for contingency K41: Irasburg - Highgate. Comparison with the pre-Project condition shows slight impact.

Table 4.4 Summary of the N-1 Post-Contingency Voltage Criteria Violations for Case PK3_SH

Bus	Name	kV	Area	Zone	PK3	PK3-clpr	Diff	Outage description
72845	BERLIN	35	701	28	0.9048	0.8937	-0.0111	U-199/X-178: Littleton - Whitefield - Beebe
87860	LOWL VEC	35	9	287	1.0492	1.0518	0.0026	K41: Irasburg - Highgate
72752	WHITEFLD	115	701	28	0.9209	0.9163	-0.0046	U-199/X-178: Littleton - Whitefield - Beebe

5. For case 75PK1B_SH, several post-contingency high voltage criteria violations were detected. However, these violations already exist pre-Project in case 75PK1B. The adopted dispatch scenario of the proposed Project causes slight post-contingency improvements on the post-contingency high voltage criteria violations.

The detailed output voltage report is presented in Appendix G.

5 N-2 Analysis

The N-2 analysis evaluates system performance with two elements out of service. After the first element is lost, the system is repositioned via generation re-dispatch in preparation for the next outage. The available 10-minute reserves, which can be used for this re-dispatch, are typically 1200MW. Practically, VELCO's system has much lower generation reserve capability. The LTE rating will be used for single line contingencies and STE for stuck breaker and double circuit tower fault scenarios.

Per discussion with VELCO, the following assumptions are adopted in the N-2 analysis:

1. Only two N-1 outages will be considered; these are:
    a. K29E: Sheffield - St. Johnsbury
    b. K41: Irasburg – Highgate

2. The N-2 analysis will be conducted for the following power flow cases:
    a. Peak load with low hydro generation (PK2).
    b. Shoulder Case (75PK1B).

3. Only power flow cases with the proposed Project will be analyzed.

4. No stuck breaker and double circuit tower fault scenarios will be considered. Consequently, the LTE rating will be used.

5. The voltage criteria for pre and post-contingency conditions that will be used for the Vermont system were previously shown in Table 4.2. (The voltage criteria for different regions in New England system are summarized in section 3.2 of the scope of work).

6. All branches and buses 34.5 kV and above in Vermont and New Hampshire and 115 kV and above in New England are monitored for pre and post-contingency thermal and voltage criteria violations. Also, National Grid facilities, as defined in Appendix B, are monitored.

Power flow cases representing two N-1 conditions were then created. For each of the peak and shoulder loading conditions, one case representing the system with Sheffield Tap -ST. Johnsbury 115 kV line out of service, and another one representing the system with Irasburg – Highgate 115 kV line out of service, were created. Controlling devices such as transformer taps were allowed to act. A summary of the developed N-1 power flow cases is shown in Table 4.5.

Table 4.5 Summary of the N-1 Developed Cases

Case Description	Outaged Element	N-1 Power Flow Case Name	Sheffield in Service
Summer peak load with low hydro generation	Sheffield Tap -ST. Johnsbury 115 kV line	PK2_SH_K29E	YES
	Irasburg – Highgate 115 kV line	PK2-SH_K41	YES
Shoulder Load (75% peak)	Sheffield Tap -ST. Johnsbury 115 kV line	75PK1B _SH_K29E	YES
	Irasburg – Highgate 115 kV line	75PK1B-SH_K41	YES

Several pre-contingency thermal and voltage criteria violations observed in the primary PK2_SH case, where all lines were in service, were also observed in the N-1 power flow cases. No modifications were made to address these violations. Thermal criteria violations are shown in Table 4.6 while voltage criteria violations are shown in Table 4.7.

Neither thermal nor voltage criteria violations were found in the N-1 shoulder power flow cases.

Table 4.6 Summary of Thermal Criteria Violations in N-1 Peak Load Cases

From	Name	kV	To	Name	kV	ck	Area	Zone	Rated Mva	PK2_SH _K29E %	PK2_SH _K41 %	Outage description
87760	NASON ST	35	87764	NASON-V	34.5	1	9	285	49	102.6	-	Base system (n-1)
71832	BELLOWS	115	71846	BELWS T3	99	1	701	21	10	129.7	129.6	Base system (n-1)

Table 4.7 Summary of Voltage Criteria Violations in N-1 Peak Load Cases

Bus	Name	kV	Area	Zone	PK2_SH _K29E	PK2_SH _K41	Outage description
87500	WELLSRVR	46	9	280	0.9432	0.9388	Base system (n-1)
87501	WOODSVL	46	9	280	0.9391	0.9347	Base system (n-1)
87502	WDSVL TP	46	9	280	0.9401	0.9357	Base system (n-1)
87503	NEWBURY	46	9	280	0.9236	0.9191	Base system (n-1)
87512	NEWBRY T	46	9	280	0.9244	0.9200	Base system (n-1)
87906	LYNDN 34	34.5	9	288	0.9495	0.9329	Base system (n-1)
88005	PUTNEY	69	9	290	0.946	0.9451	Base system (n-1)
88006	PUTNEY P	69	9	290	0.946	0.9451	Base system (n-1)
87801	W MILTON	34.5	9	285	0.944	-	Base system (n-1)
87815	W MLTN T	34.5	9	285	0.9445	-	Base system (n-1)
87816	PETERSON	34.5	9	285	0.9445	-	Base system (n-1)

All contingencies, listed in Appendix C, were then applied to the N-1 power flow cases. The resulting N-2 contingency performance was evaluated against LTE ratings. The following conclusions can be made:

1. Initially, all four developed N-1 cases were repositioned by re-dispatching the Project at 16 MW in preparation for the second outage; in particular either K29E or K41. A combination of N-1 and N-2 outages, K29E and K41, leaves the Project connected to Irasburg 115/46 kV autotransformer. Because of this combination, the full output of the Project, pre re-dispatch of 40 MW, is injected to the 34.5 kV feeders at Lowell, VT Asbestos, Eden Corners, and North Hyde Park (LTE ratings 22 MVA) connected to Irasburg 46 kV causing severe local overloads. The presence of the existing local generation at Coventry (4 MW) imposes an additional constraint to the dispatch of the Project in the N-1 cases. Generation re-dispatch was implemented at Moore, Barnet, Hgate CU, and Pierce to carry the reduction of 24 MW of the Project's output power.

2. The following conclusions can be made for the power flow cases used in the analysis:

    a. In addition to the re-dispatch implemented in the previous step, the N-1 cases for peak load were repositioned by re-dispatching generation at Merrimack, Lerg, and Moore in preparation for the second outage; in particular N-214: AES-Tewksbury 230 kV line which results in a thermal criteria violation; the 115 kV line from Garvins to Merrimack is overloaded by 6.5%, and 5.6% pre re-dispatch in PK2-SH_K29E and PK2-SH_K41 respectively.

b. For shoulder load cases, several thermal criteria violations were observed for contingencies F-206, K24-West 2, K24-East, O-215, and k26-West; the N-1 shoulder cases were re-positioned by generation re-dispatch at Shel, Dxbry, Beldens, GT, Burlington, and Moore in preparation for the second outage.

c. Contingency X61: ST. Albans 115/34.5 kV transformer Ckt #1 resulted in thermal criteria violation; ST. Albans 115/34.5 kV transformer Ckt#2 is overloaded. No action was implemented in the N-1 cases.

d. For power flow case PK2-SH_K41, it was found out that contingency K29: ST. Johnsbury – Littleton 115 kV line was a non-converging case. However, reviewing the same contingency pre-Project revealed a non-converging case. Consequently, the presence of the Project in the system is not contributing to that problem.

e. For power flow case PK2-SH_K41, it was found out that contingency X22: outage of the St. Johnsbury 115/34.5 kV transformer resulted in few post-contingency high voltage criteria violation at the Sheffield 34.5 kV and Irasburg 115 kV buses. Based on the voltage criteria listed in Table 4.2, the Project's dispatch has a slight negative impact on these post-contingency voltage violations.

f. For all (N-1) power flow cases, it was found out that contingencies K41: Irasburg – Highgate and K29E: Sheffield - Irasburg respectively, resulted in several post-contingency high voltage criteria violations at Sheffield and Irasburg 115 kV buses and in the neighborhood of the POI mostly in the 34.5 kV. Details of these violations are shown in Appendix H. Also, several voltage deviation criteria violations were observed as a result of contingency K41 are shown in Appendix H.

g. The post-contingency high voltage criteria violations detected in all the N-1 power flow case for contingencies K41 and K29E were removed or reduced substantially by switching off the capacitors at CV Johnson, Wilkins, and St. J CTR and adjusting the transformer taps of the Irasburg and Lowell transformers in all N-1 power flow cases in preparation for the second outage (in particular K41 and K29E, respectively). However, as a result of these adjustments, several post-contingency low voltage criteria violations resulted from contingency X 67: Fairfax 115/34.5 kV transformer. Consequently, the Project needs to be totally disconnected from the system in the N-1 power flow cases to avoid post-contingency high voltage criteria violations in the neighborhood of the POI.

6 Short Circuit Assessment

Short circuit analysis was not performed since it is understood that the Clipper wind turbine generators contribute no short circuit current, e.g. stator converter current is limited to 110% of full load current (221 amperes at 115 kV). Short circuit studies are normally conducted at generator no-load conditions in which case the Clipper generators would contribute no short circuit current.

Prior short circuit studies with Gamesa wind turbine-generators had indicated a three phase short circuit contribution at the 115 kV POI of 700 amperes. The Clipper turbines will contribute no more than 221 amperes (110% load current) at the 115 kV POI.

7 Stability Assessment

The primary objective of the stability analysis is to analyze the impact of the Project on transient stability performance of VELCO's system for normal and emergency contingencies. Stability simulations were conducted to confirm performance with respect to applicable criteria with and without the proposed Project.

ISO-NE provided a fault contingency list for the study, consisting of both normal and extreme contingencies. The list of contingencies is summarized in Table 7.1.

Table 7.1: List of Contingencies for Stability Analysis

Fault #	Description	Clearing times	Pre-Project	Post-Project

Fault #	Description	Clearing times	Pre-Project	Post-Project
EC2	3ph on high side of Irasburg transformer, Irasburg K28 fails	Irasburg K41 and low side in 6 cy, Sheffield in 18 cy	N/A	
EC3	3ph on high side of St Johnsbury transformer, St Johnsbury K28 fails	St Johnsbury K29 and low side in 6 cy, Irasburg in 18 cy		N/A
EC4	3ph on high side of St Johnsbury transformer, St Johnsbury K28 fails	St Johnsbury K29 and low side in 6 cy, Sheffield in 18 cy	N/A	

Notes: NC – normal contingency; EC – emergency contingency; and, "N/A" means that the contingency is not applicable to either the pre- or post-Project analysis.

The selected contingencies focus on 115 kV lines adjacent to the Project's ring bus.

A complete stability analysis was performed comprising of all the applicable contingencies shown in Table 7.1 applied to each of the six load flow cases as the following:

1. Light Load Case without the Project: ll09b;
2. Light Load (Low Hydro) Case without the Project: ll09b-lh;
3. Peak Load Case without the Project: pk09b;
4. Light Load Case with the Project: ll09a;
5. Light Load (Low Hydro) Case with the Project: ll09a-lh;
6. Peak Load Case with the Project: pk09a.

The analysis determined any performance criteria violations. The criteria defining stable transmission system performance 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 must be transiently stable except for units tripped for fault clearing
- A 50% reduction in the magnitude of system oscillations must be observed over four periods of the oscillation
- A loss of source less than 1200MW is acceptable
- Keswick GCX entry is not acceptable

The criteria defining stable transmission system performance for extreme contingencies (3-phase faults with breaker failure and backup clearing) are as follows:

- Transiently stable with positive damping
- A loss of source less than 1400MW is acceptable
- A loss of source between 1400MW and 2200MW may be acceptable depending upon a limited likelihood of occurrence and other factors
- A loss of source above 2200MW is not acceptable
- A 50% reduction in the magnitude of system oscillations must be observed over four periods of the oscillation

Selected 345kV and 115kV bus voltages as well as lower level branch loading in Vermont and New Hampshire were monitored. The generator angle, field voltage, terminal voltage, machine speed, real and reactive power output were also monitored for all units in the area, as well as all units in the rest of New England. Signals pertaining to the operation of relevant SPS such as the Keswick relay were also monitored. The results of the stability analysis are summarized in Table 7.2.

Table 7.2: Summary of Stability Analysis Cases

Contin-gency	Light Load				Light Load - Low Hydro				Peak Load			
	Sheffield Not in Service (Case ll09b)		Sheffield Online (Case ll09a)		Sheffield Not in Service (Case ll09b-lh)		Sheffield Online (Case ll09a-lh)		Sheffield Not in Service (Case pk09b)		Sheffield Online (Case pk09a)	
	Result	**MW Loss**	**Result**	**MW Loss**	**Result**	**MW Loss**	**Result**	**MW Loss**	**Result**	**MW Loss**	**Result**	**MW Loss**
NC01	Stable	**150**	Stable	**150**	Stable	**150**	Stable	**190**	Stable	**200**	Stable	**240**
NC02	Stable	0	Stable	0	Stable	0	Stable	0	Stable	0	Stable	0
NC03	Stable	0	N/A		Stable	0	N/A		Stable	0	N/A	
NC04	Stable	0	N/A		Stable	0	N/A		Stable	0	N/A	
NC05	N/A		Stable	0	N/A		Stable	0	N/A		Stable	0
NC06	N/A		Stable	**40**	N/A		Stable	**40**	N/A		Stable	**40**
NC07	N/A		Stable	**40**	N/A		Stable	**40**	N/A		Stable	**40**
NC08	N/A		Stable	**40**	N/A		Stable	**40**	N/A		Stable	**40**
NC09	Stable	0	Stable	0	Stable	0	Stable	0	Stable	0	Stable	0
NC10	Stable	0	Stable	0	Stable	0	Stable	0	Stable	0	Stable	0
EC01	Stable	0	N/A		Stable	0	N/A		Stable	0	N/A	
EC02	N/A		Stable	0	N/A		Stable	0	N/A		Stable	0
EC03	Stable	0	N/A		Stable	0	N/A		Stable	0	N/A	
EC04	N/A		Stable	**40**	N/A		Stable	40	N/A		Stable	**40**

Notes: NC – normal contingency; EC – emergency contingency; and, “N/A” means that the contingency is not applicable to either the pre- or post-Project analysis.

For normal contingencies, all simulations show generating units as transiently stable, except for trips of the Project's units noted below. Oscillations are damped to within 50% within four periods. The Keswick relay is not triggered and no loss of source greater than 1200 MW is observed.

The Project tripped offline in several studied contingencies, as follows:

- For the normal contingency involving a three-phase fault on Line K-42 at Georgia (NC-01), the Highgate HVDC trips for all system conditions studied, and the Project trips in the light load low Hydro and peak load cases on low voltage. Note that normal contingency NC-01, includes as part of the contingency specification, loss of the Highgate HVDC inverter. This is recorded as a loss of source equivalent to the import on the Highgate HVDC for the specific case and the Project outage.

- The Projects trips offline for the following normal contingencies: three-phase faults on Line K-28W at Sheffield (NC-06), and Line K-28E at St Johnsbury (NC-07), and on Line K-28E at Sheffield (NC-08). The cause of the trips in NC-06 and NC-08 are violations of high frequency protection, while the cause of the trip in NC-07 is a violation of undervoltage protection. The recorded loss of source in each case is 40 MW, equivalent to loss of the whole Project generation. The Project trips are observed in all conditions studied: light load, light load low hydro and peak load.

- For the emergency contingency involving a three-phase fault on the high side of the St Johnsbury transformer, with failure of primary protection for St Johnsbury K28 the Project also trips on low voltage. The Project trips are observed in all conditions studied: light load, light load low hydro and peak load.

For extreme contingencies, all simulations show generating units as transiently stable with positive damping. Oscillations are damped to within 50% within four periods. No loss of source greater than 1200 MW is observed.

A full set of multi-channel plots and databases from the stability analysis is provided in an accompanying CD-ROM to this report.