Reactive Power Study rEPORT

Truscott Gilliland East Wind Project

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Acronyms

|  |  |
| --- | --- |
| DETC | De-energized Tap Changer |
| Ft | Foot |
| HSL | High Sustainable Limit of a Generation Resource |
| HV | High Voltage |
| LOP | Low Output Point of a Generation Resource |
| Mortenson | Mortenson Engineering Services, Inc. |
| MPT | Main Power Transformer |
| MV | Medium Voltage |
| MVAr | Mega-Volt-Ampere reactive |
| MW | Mega-Watt |
| OLTC | On Load Tap Changer |
| PF | Power Factor |
| POI | Point of Interconnection |
| pu | Per Unit |
| TGE | TG East Wind Project |
| Vpu | Voltage per unit |
| WTG | Wind Turbine Generator |
| WTT | Wind Turbine Transformer |

# Executive Summary

## Overview

Mortenson Engineering Services, Inc. (Mortenson) completed a reactive power study for the TG East Wind Project (TGE). TG East Wind Project is located near Knox County, Texas. The project consists of forty-five (45) Vestas V162-5.6 MW turbines and twenty (20) Vestas V150-4.2 MW turbines for a total nameplate capacity of 336 MW. The project contains two 3-phase, 2-winding main power transformers (MPT). One MPT is rated 60/80/100 MVA. The second MPT is rated 169/225/281 MVA. Both MPTs are equipped with an on-load tap changer (OLTC) located on the high voltage windings. A 200 ft slack span 345kV transmission tie line will interconnect the new project substation (Sisu) with the existing Coulomb substation.

The main purpose of the study is:

1. Size the capacitor banks to meet Electricity Reliability Council of Texas (ERCOT) power factor requirement (PF), if needed
2. Provide the preliminary setpoint for both the OLTCs of the MPTs
3. Provide the P-Q capability of the project assuming points 1 and 2 above

According to ERCOT rules, TGE needs to comply with the 0.95 PF requirement at the POI. The lagging[[1]](#footnote-2) PF shall be met for the voltage range 1.04 Vpu to 0.95 Vpu at the POI, while the leading PF shall be met for the voltage range 1.05 Vpu to 1 Vpu. The 0.95 PF must be dynamic and switched shunts can only be used to compensate for the reactive losses in the collection system.

This study includes the most up-to date wind collection system design as of 07/17/2020, MPTs, turbines, and their nacelle mounted transformers as of the date of this report.

## Key Findings

Mortenson found that TGE can meet ERCOT PF requirement at the POI, if 29.0 MVArs of switched capacitor (cap) banks are installed on bus 2 (the low side bus of the second MPT). It is recommended to install two steps of cap banks at 14.5 MVAr each. Cap banks are only needed at lagging PF.

Finally, the bus 1 MPT OLTC shall be set to schedule the voltage at the low side to 1.0 Vpu at all generation conditions and bus 2 MPT OLTC shall be set to 1.04.

**The findings of this report depend on the design information available as of the publishing of this report. Any changes to the design information and model assumptions could impact the findings and recommendations of this report.**

# Modeling Methodology

Mortenson built a detailed phasor-domain model of the 336 MW TGE in PSS®E version 33.11. Underground cables connecting the individual turbine transformers were modeled as pi-equivalent segments. The grid was represented as a swing source at the POI. The high voltage tie-line to the POI was modeled as a pi-equivalent segment with negligible impedance based on the short slack span tie line modeling assumptions.

Turbines were modeled as machines with reactive power capability according to their reactive power curves. The wind turbine transformers (WTTs) and substation MPTs were modeled along with their no-load losses. Downtower cables were also modeled. Since Vestas hasn’t supplied final data sheet for the WTTs, Mortenson assumed that the WTT impedance is 5% more than what is supplied as a conservative measure. Larger WTT impedance would cause more inductive reactive power losses, and that would produce a conservative cap bank size.

To create the reactive power capability of the project, several power flow cases were created. At each POI voltage level, all turbines were dispatched to absorb or supply the maximum possible reactive power while observing the following constraints:

1. The voltage at the turbine terminals is kept within the range 0.9 Vpu to 1.1 Vpu.
2. The voltage on the 34.5 kV collection system is maintained in the range 0.9 Vpu to 1.1 Vpu.

Several power flow cases were performed to determine the capacitor bank size and OLTC settings of the substation MPTs. Capacitor banks were added since the turbines reactive power is not sufficient to meet the PF requirement at the POI. The minimum capacitor bank size can be achieved only if the turbines are producing maximum reactive power. This maximum reactive power production is only possible if the voltage of the turbines is maintained within the limits stated above. The turbine terminal voltage can be controlled using the OLTC of the MPTs and the WTTs de-energized tap changer (DETC) settings. The lagging capability of the project is obtained when the cap banks are engaged while the turbines are producing max reactive power while observing the two constraints above. The max leading capability is obtained when the turbines are absorbing max reactive power with the cap banks turned off while observing the two constraints above.

In addition to the above constraints, Mortenson followed the study methodology in the ERCOT document Reactive Study Scope dated April 2020. Specifically, the OLTCs of both MPTs are not fixed at a specific tap position, while transitioning from leading to lagging PF for the same MW output and POI voltage level.

All data used to build the model is given in Appendix 1. The collector system layout is given in Appendix 2. The PSS®E single line diagram is given in Appendix 3. Cable data was obtained from typical WTEC data sheets and are provided in Appendix 4.

**The findings of this report depend on the design information available as of the publishing of this report. Any changes to the design information and model assumptions could impact the findings and recommendations of this report.**

# Results

## Capacitor Bank Sizing

Three sets of cases were created to obtain the minimum capacitor bank size required to meet the PF requirement at the POI while observing the constraints in Section ‎2:

1. The first set of cases is just one case. This case is one with the 2nd MPT out of service while the remainder of project is in full output lagging power factor mode with the tie switch open. In this case, the cap bank required on bus 1 is 1.5 MVAr. The POI voltage doesn’t affect the cap bank size due to the LTC of the 1st MPT and since the turbines MVA behind the 1st MPT is rather small.
2. The second set of cases is just one case. The second case is one with the 1st MPT out of service with the tie switch open while the remainder of project is in full output lagging power factor mode but curtailed by the MVA of the second MPT which is 281 MVA. In this case, the cap bank required is at bus 2 and is 21 MVAr. The POI voltage doesn’t affect the cap bank size due to the LTC of the 2nd MPT and since the turbines MVA behind the 1st MPT is moderate.
3. The third set of cases are cases such that both MPTs in service with the tie switch open. Several cases were performed at different POI voltage levels with the turbines producing maximum reactive power while observing the constraints in section ‎2. In this case the cap bank needed is 28 MVAr.

Thus, the small cap bank at bus 1 would only be needed when there is MPT 2 is out of service and the tie switch is open (stuck position). Since this is a low probability event, that cap bank was removed as confirmed by the owner per RFI#40. 1 MVAr of extra cap banks are added as a safety margin. Thus, a 29.0 MVAr cap bank is the final size that needs to be installed on site. It should be noted that no adjustments were needed for the WTT DETCs and only the MPT OLTCs needed adjustment for the full range from 1.05 Vpu to 0.95 Vpu at the POI

## Capacitor Bank Arrangement

It is recommended to split the required capacitor into two steps of 14.5 MVAr each based on Table 1. Per the IEEE Standard 1036-2010, the voltage change, , in percentage at the POI due to capacitor switching is given by the following equation:

Where is the capacitor step size in MVAr and is the three-phase short circuit in MVA. The short circuit fault currents per TGE-RS-212.01 along with the flicker calculations at the high side bus and low side bus are given in Table 1.

Table 1. Flicker Due to Single Step Switching

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |
| Tie Open | POI | 23.247 | 13891 | 14.5 | 0.10 |
| High Side of the MPT | 23.247 | 13891 | 14.5 | 0.10 |
| MV Collector System Bus 1 | 15.53 | 928 | 14.5 | 1.56 |
| MV Collector System Bus 2 | 27.705 | 1656 | 14.5 | 0.88 |
| Tie Closed, MPT1 OFF, F11 OFF | POI | 23.112 | 13811 | 14.5 | 0.10 |
| High Side of the MPT | 23.112 | 13811 | 14.5 | 0.10 |
| MV Collector System Bus 1 | 28.908 | 1727 | 14.5 | 0.84 |
| MV Collector System Bus 2 | 28.908 | 1727 | 14.5 | 0.84 |

The results are below the threshold (3% ) for the flicker limit at the low side bus based on the IEEE 1453 standard.

In summary, two (2) steps of 14.5 MVAr cap banks for a total of 29.0 MVAr are needed to meet the PF requirements at the POI. These two steps shall be connected to 34.5kV MV Bus 2.

## Reactive Power Capability (P-Q Curve)

Various power flow cases were created at different output levels and at different POI voltage levels. At each output level and voltage level, a lagging and leading power flow case was created. The wind turbines were dispatched to supply or absorb as much reactive power as possible to meet the PF requirement at the POI. The Vestas V150 P-Q curve is included in Figure 1. The Vestas V162 P-Q curve is included in Figure 2. These power flow cases were created while observing the constraints mention in Section ‎2.

To calculate the maximum reactive power that the project can supply with a lagging PF, the wind turbines were set to supply as much reactive power without the voltage at their terminals exceeding 1.1 Vpu with the capacitor banks engaged at all output levels. It should be noted that the Vestas turbines can operate at a voltage level as high as 1.13 Vpu as is shown in Figure 1 and Figure 2 but a 1.1 Vpu voltage was chosen as the overexcitation capability of the WTTs was not known. In the leading PF cases, the reactive power of the wind turbines was set to absorb as much reactive power without the voltage at their terminals exceeding 0.9 Vpu with the capacitor banks de-energized at all output levels.

Analysis revealed that TGE wind project is capable of meeting the 0.95 lagging PF requirement for the voltage range of 0.95 Vpu to 1.04 Vpu at the POI, and is capable of meeting the 0.95 leading PF requirement for the voltage range of 1 Vpu to 1.05 Vpu at the POI. The project is capable of meeting the lagging PF requirement if 29 MVAr of cap banks are installed at the low side of the 2nd MPT. The project does not require any reactor banks to meet the leading PF requirement. The full reactive power capability of the project at different voltage levels is provided in Figure 3. The capability is tabulated in Table 2 for lagging PF, and Table 3 for leading PF. The ERCOT form for reactive power is given in Table 4.

Lastly, the LTC of the first MPT needs to be set to target 1 Vpu at Bus 1, while the OLTC of the second MPT needs to set to target 1.04 Vpu at Bus 2.

**The findings of this report depend on the design information available as of the publishing of this report. Any changes to the design information and model assumptions could impact the findings and recommendations of this report.**

Machine generated alternative text:
The reactive power capability for the 4.2 MW Power Optimized Mode (POI) is as 
illustrated in Figure 1 ()-4: 
0.4 
10.7 
1.0 
3 0.0 
Operational Envelope — Reactive Power Capability in 
4.2 MW Power Optimized Mode (POI) 
-0.6 
-0.8 
00 
— a_lv u_wxg• 
— a_lv 
—a_lv 
—o_lv 
— a_iv 
0.3 
0.9 
1.2 
2.4 2.7 
Active power @ LV•Side (M W) 
3.0 
4.3 
3.6 
3.9 
Figure 10-4: Reactive power capability for 4.2 MW Power Optimized Mode (POI). 

Figure 1. Vestas V150 P-Q Curve

Machine generated alternative text:
3.5 
Operational Envelope — Reactive Power Capability 
The turbine has a reactive power capability on the low voltage side of the HV transformer 
as illustrated in Figure 3-2: 
— a_lv 
— a-IV@ 
0.0 
Active power @ LV•side (MWJ 
side 
e.' side 
Sid 
u -087 
3103 
500 
5'.67 
-2033 
-2033 
Figure 3-2: Reactive power capability. 
The turbine is able to maintain the reactive power capability at low wind with no active 
power production. 

Figure 2. Vestas V162 P-Q Curve

Figure 3. P-Q Capability of the Project at Different POI Voltages with 29.0 Cap Bank

Table 2. Lagging Reactive Power Capability Results

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| POI Voltage [pu] | Gross Generation | POI [MW] | POI [MVAr] | MPT OLTC Tap | Switched Shunt [MVAr] | Bus 1 Voltage [pu] | Bus 2 Voltage [pu] | Minimum Terminal Voltage [pu] | Maximum Terminal Voltage [pu] | Minimum Collection Voltage [pu] | Maximum Collection Voltage [pu] |
| 0.95 | 10% | 30.84 | 210.47 | 7 | 29 | 0.975 | 1.040 | 1.026 | 1.100 | 0.975 | 1.053 |
| 0.95 | 25% | 80.95 | 206.00 | 8 | 29 | 0.969 | 1.034 | 1.022 | 1.097 | 0.969 | 1.049 |
| 0.95 | 65% | 213.49 | 179.86 | 7 | 29 | 0.970 | 1.030 | 1.024 | 1.100 | 0.970 | 1.050 |
| 0.95 | 100% | 328.81 | 110.07 | 0 | 29 | 0.991 | 1.035 | 1.035 | 1.100 | 0.991 | 1.058 |
| 1.0 | 10% | 30.81 | 210.41 | 15 | 29 | 0.974 | 1.039 | 1.026 | 1.099 | 0.974 | 1.053 |
| 1.0 | 25% | 80.93 | 205.98 | 16 | 29 | 0.969 | 1.034 | 1.022 | 1.097 | 0.969 | 1.049 |
| 1.0 | 65% | 213.47 | 179.75 | 15 | 29 | 0.970 | 1.029 | 1.024 | 1.100 | 0.970 | 1.050 |
| 1.0 | 100% | 328.82 | 109.53 | 8 | 29 | 0.988 | 1.032 | 1.033 | 1.098 | 0.988 | 1.056 |
| 1.04 | 10% | 31.64 | 178.65 | 16 | 29 | 0.996 | 1.053 | 1.036 | 1.100 | 0.996 | 1.064 |
| 1.04 | 25% | 81.81 | 172.62 | 16 | 29 | 0.995 | 1.051 | 1.035 | 1.100 | 0.995 | 1.063 |
| 1.04 | 65% | 214.32 | 147.56 | 16 | 29 | 0.992 | 1.043 | 1.034 | 1.100 | 0.992 | 1.061 |
| 1.04 | 100% | 328.72 | 109.04 | 16 | 29 | 0.986 | 1.030 | 1.031 | 1.096 | 0.986 | 1.053 |

Note 1: 10% dispatch case required in the ERCOT *Reactive Study Scope*

Note 2: 100% dispatch case required in the ERCOT *Reactive Study Scope*

Table . Leading Reactive Power Capability Results

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| POI Voltage [pu] | Gross Generation | POI [MW] | POI [MVAr] | MPT OLTC Tap | Switched Shunt [MVAr] | Bus 1 Voltage [pu] | Bus 2 Voltage [pu] | Minimum Terminal Voltage [pu] | Maximum Terminal Voltage [pu] | Minimum Collection Voltage [pu] | Maximum Collection Voltage [pu] |
| 1 | 10% | 31.09 | -191.72 | -9 | 0 | 1.006 | 0.961 | 0.904 | 0.960 | 0.951 | 1.006 |
| 1 | 25% | 81.12 | -196.96 | -9 | 0 | 1.005 | 0.960 | 0.905 | 0.960 | 0.951 | 1.005 |
| 1 | 65% | 212.94 | -233.21 | -10 | 0 | 1.008 | 0.954 | 0.905 | 0.968 | 0.949 | 1.010 |
| 1 | 100% | 327.59 | -210.25 | -5 | 0 | 0.986 | 0.936 | 0.908 | 0.969 | 0.936 | 0.993 |
| 1.025 | 10% | 31.07 | -191.86 | -5 | 0 | 1.004 | 0.960 | 0.902 | 0.958 | 0.949 | 1.004 |
| 1.025 | 25% | 81.11 | -197.14 | -5 | 0 | 1.004 | 0.958 | 0.903 | 0.959 | 0.950 | 1.004 |
| 1.025 | 65% | 212.92 | -233.57 | -6 | 0 | 1.006 | 0.951 | 0.903 | 0.966 | 0.947 | 1.008 |
| 1.025 | 100% | 327.63 | -210.60 | -1 | 0 | 0.985 | 0.935 | 0.907 | 0.968 | 0.935 | 0.992 |
| 1.05 | 10% | 31.05 | -192.02 | -1 | 0 | 1.003 | 0.958 | 0.900 | 0.956 | 0.948 | 1.003 |
| 1.05 | 25% | 81.08 | -197.31 | -1 | 0 | 1.002 | 0.956 | 0.902 | 0.957 | 0.948 | 1.002 |
| 1.05 | 65% | 212.88 | -233.96 | -2 | 0 | 1.005 | 0.949 | 0.901 | 0.964 | 0.945 | 1.006 |
| 1.05 | 100% | 327.59 | -210.88 | 3 | 0 | 0.984 | 0.934 | 0.906 | 0.967 | 0.934 | 0.991 |

Note 1: 10% dispatch case required in the ERCOT *Reactive Study Scope*

Note 2: 100% dispatch case required in the ERCOT *Reactive Study Scope*

Table 4. Reactive Device Inventory

* Generation Resource High Sustained Limit, net power deliverable to POI: 329 MW.
* Generation Resource LOP net power deliverable to POI: 31 MW.
* Required VAR capability @ POI, calculated as 32.9% of HSL: ± 108.2 MVAr.
* Inventory total gross reactive capability (nominal, @ device terminals, excluding losses):
  1. Generating Units (LOP): 204.0 MVAr lag / -175.985 MVAr lead
  2. Generating Units (HSL): 159.84 MVAr lag / -119.215 MVAr lead
  3. Switchable Shunts: 29.0 MVAr lag / 0.0 MVAr lead
  4. Auxiliary Dynamic Devices (SVC, STATCOM)[[2]](#footnote-3): 0.0 MVAr lag / 0.0 MVAr lead
  5. Grand Total (add #2, 3, 4): 188.84 MVAr lag / -119.215 MVAr lead
  6. Total Dynamic at low output point (add #1, 4): 204.0 MVAr lag / -175.985 MVAr lead
  7. Total Dynamic at HSL (add #2, 4): 159.84 MVAr lag / -119.215 MVAr lead
* What is the estimated response time of the shunts to a low voltage? 5 seconds
* Paste manufacturer charts showing:
  + Reactive capability versus real power output (“PQ chart”, or “D-curve”). (See Figure 1 and Figure 2)
  + Reactive capability versus terminal voltage (“QV chart” or family of D-curves).
* List acceptable steady-state voltage ratings:
  + Generating units: 648 volts low / 792 volts high

Appendix 1. Modeling Assumptions

* High Voltage Tie-line Specifications

The overhead line structure that connects the project to the POI is short slack span (approximately 200’) based on the data from RFI #26, from Burns & McDonnell on 01/09/2019. The approximated model data is included in Table 5.

Table 5. High Voltage Tie-Line Specification

|  |  |
| --- | --- |
| Positive/negative sequence resistance [Ω] | 1e-5 |
| Positive/negative sequence reactance [Ω] | 1e-5 |
| Positive/negative sequence capacitance [Mho] | 1e-8 |
| Zero sequence resistance [Ω] | 1e-5 |
| Zero sequence reactance [Ω] | 1e-5 |
| Zero sequence capacitance [Mho] | 1e-8 |

* Utility Contribution

Utility model data is summarized in Table 6. These values were received from NorthRenew via RFI #11, dated 12/12/2019.

Table 6. Utility Fault Current Data

|  |  |  |
| --- | --- | --- |
| 3P | Short Circuit [MVA] | 12,852.3 |
| Short Circuit Current [kA] | 19,484.7 |
| X/R | 10.7129 |
| SLG | Short Circuit [MVA] | 9,406.8 |
| Short Circuit Current [kA] | 14,527.5 |
| X/R | 8.06676 |
| [pu base= 100 MVA] | Positive Sequence Resistance | 0.00072 |
| Synchronous Xdi | 0.0074 |
| Transient X'di | 0.0074 |
| Subtransient X''di | 0.0074 |
| Negative Sequence Resistance | 0.00072 |
| Negative Sequence X2v | 0.0074 |
| Zero Sequence Resistance | 0.00176 |
| Zero Sequence X0i | 0.016 |

* Underground Cable Specification

Impedance data based on an operating temperature of 105 °C is used for this assessment. Positive, Table 7, and zero sequence, Table 8, data is provided below. This data is received from WTEC through email.

Table 7. Cable Positive Sequence Impedance

|  |  |  |  |
| --- | --- | --- | --- |
| MV cable | R [µΩ/ft] | XL [µΩ/ft] | Capacitance [µF/kft] |
| 1250 MCM | 20 | 37 | 0.08992 |
| 750 MCM | 34 | 41 | 0.07346 |
| 500 MCM | 49 | 43 | 0.06309 |
| 4/0 AWG | 117 | 48 | 0.04907 |
| 1/0 AWG | 250 | 54 | 0.03901 |

Table . Cable Zero Sequence Impedance

|  |  |  |  |
| --- | --- | --- | --- |
| MV cable | R [µΩ/ft] | XL [µΩ/ft] | Capacitance [µF/kft] |
| 1250 MCM | 74 | 604 | 0.08992 |
| 750 MCM | 88 | 708 | 0.07346 |
| 500 MCM | 103 | 625 | 0.06309 |
| 4/0 AWG | 171 | 733 | 0.04907 |
| 1/0 AWG | 304 | 746 | 0.03901 |

* The V150 WTG model was received from NorthRenew via RFI #17, dated 12/17/2019. Applicable modeling data includes transformer data in Table 9, machine sequence data in Table 10, and machine reactive power data in Table 11. Impedance of the WTT is assumed 5% more than what is listed to produce conservative results.

Table 9. V150 Transformer Model Data

|  |  |
| --- | --- |
| Model Parameter | Quantity |
| Rating [MVA] | 5.15 |
| Vector Group | Dyn5 |
| Voltage [kV] | 34.5 |
| Positive Sequence Impedance [pu on 100 MVA basis] | 1.9223 |
| Positive Sequence X/R | 12.4 |
| No-Load Losses [kW] | 7.75 |
| Taps | 5 |
| Zero Sequence Impedance [pu on rating basis] | 1.612 |
| Zero Sequence X/R | 11.9 |

Table 10. V150 Sequence Model Data

|  |  |
| --- | --- |
| Model Parameter | Quantity [pu on 100 MVA base] |
| Positive Sequence Resistance | 0.0 |
| Synchronous Reactance | 0.95 |
| Transient Reactance | 0.5882 |
| Subtransient Reactance | 0.5882 |
| Negative Sequence Resistance | 0.0 |
| Negative Sequence Reactance | 0.5882 |
| Zero Sequence Resistance | 0.0 |
| Zero Sequence Reactance | 0.5882 |

Table 11. V150 Reactive Power Model Data

|  |  |
| --- | --- |
| Model Parameter | Quantity |
| Rated Voltage [kV] | 0.72 |
| Rating [MVA] | 4.7 |
| Peak Real Power Output [MW] | 4.2 |
| Peak Lagging Reactive Power Output [MVAr] | 1.938 |
| Peak Leading Reactive Power Output [MVAr] | -1.392 |
| Minimum Terminal Voltage [pu] | 0.9 |
| Maximum Terminal Voltage [pu] | 1.1 |

* The assumed V162 WTG model data includes transformer data in Table 12, machine sequence data in Table 13, and machine reactive power data in Table 14. Impedance of the WTT is assumed 5% more than what is listed to produce conservative results.

Table 12. V162 Transformer Model Data

|  |  |
| --- | --- |
| Model Parameter | Quantity |
| Rating [MVA] | 7.0 |
| Vector Group | Dyn5 |
| Voltage [kV] | 34.5 |
| Positive Sequence Impedance [pu on 100 MVA basis] | 1.4143 |
| Positive Sequence X/R | 9.8494 |
| No-Load Losses [kW] | 3.7 |
| Taps | 5 |
| Zero Sequence Impedance [pu on rating basis] | 1.286 |
| Zero Sequence X/R | 8.994 |

Table 13. V162 Sequence Model Data

|  |  |
| --- | --- |
| Model Parameter | Quantity [pu on 100 MVA base] |
| Positive Sequence Resistance | 0.0 |
| Synchronous Reactance | 0.95 |
| Transient Reactance | 0.5882 |
| Subtransient Reactance | 0.5882 |
| Negative Sequence Resistance | 0.0 |
| Negative Sequence Reactance | 0.5882 |
| Zero Sequence Resistance | 0.0 |
| Zero Sequence Reactance | 0.5882 |

Table 14. V162 Reactive Power Model Data

|  |  |
| --- | --- |
| Model Parameter | Quantity |
| Rated Voltage [kV] | 0.72 |
| Rating [MVA] | 6.26 |
| Peak Real Power Output [MW] | 5.6 |
| Peak Lagging Reactive Power Output [MVAr] (Note 1) | 2.584 |
| Peak Leading Reactive Power Output [MVAr] (Note 1) | -1.856 |
| Minimum Terminal Voltage [pu] | 0.9 |
| Maximum Terminal Voltage [pu] | 1.1 |

* The applicable MPT #1 model data is Table 15. These values were received from NorthRenew via RFI #20, dated 12/7/2019.

Table 15. MPT #1 Model Data

|  |  |  |
| --- | --- | --- |
| Rating [MVA] | 60/80/100 | |
| Voltage [kV] | 345.0/34.5 | |
| Cooling Class: | ONAN/ONAF1/ONAF2 | |
| Winding configuration: | YNyn0 | |
| No load losses [kW] | 125 | |
| LTC | Regulated bus | MV bus |
| Min/Max tap | ±10% |
| Number of taps | 33 |
| Positive Sequence Impedance [pu 100 MVA base]: | Z | 0.12 |
| X/R | 39.3 |
| Zero Sequence Impedance [pu 100 MVA base]: | Z | 0.114 |
| X/R | 35.6 |

* The assumed MPT #2 model data is Table 16. These anticipated values were provided to NorthRenew and SMIT via RFI #30, dated 01/28/2020.

Table 16. MPT #2 Model Data

|  |  |  |
| --- | --- | --- |
| Rating [MVA] | 169/225/281 | |
| Voltage [kV] | 345.0/34.5 | |
| Cooling Class: | ONAN/ONAF1/ONAF2 | |
| Winding configuration: | YNyn0 | |
| No load losses [kW] | 110 | |
| LTC | Regulated bus | MV bus |
| Min/Max tap | ±10% |
| Number of taps | 33 |
| Positive Sequence Impedance [pu 100 MVA base]: | Z | 0.0727 |
| X/R | 58 |
| Zero Sequence Impedance [pu 100 MVA base]: | Z | 0.0727 |
| X/R | 58 |

Appendix 2. Collection System Design

The study was based on the collector system as of 07/17/2020.

| Feeder | From Node | To Node | Length [ft] | Cable Size |
| --- | --- | --- | --- | --- |
| 11 | T02 | JB11A-1 | 2163.139 | '4/0' |
| 11 | T03 | T02 | 1666.348 | '4/0' |
| 11 | T04 | JB11A-1 | 1883.32 | '4/0' |
| 11 | T01 | fdr11A | 4604.604 | '1250' |
| 11 | fdr11A | sub11 | 1 | '1250' |
| 11 | T05 | T04 | 5641.287 | '4/0' |
| 11 | JB11A-1 | T01 | 142.9963 | '750' |
| 11 | JB11B-1 | T08 | 3067.089 | '4/0' |
| 11 | T10 | JB11B-1 | 4448.471 | '4/0' |
| 11 | T07 | T06 | 1864.95 | '750' |
| 11 | T06 | fdr11B | 1334.85 | '1250' |
| 11 | fdr11B | sub11 | 1 | '1250' |
| 11 | T08 | T07 | 1673.894 | '500' |
| 11 | T09 | JB11B-1 | 3113.736 | '4/0' |
| 12 | T14 | T13 | 3690.769 | '1/0' |
| 12 | T13 | T12 | 1923.815 | '500' |
| 12 | T12 | T11 | 3758.647 | '750' |
| 12 | T11 | fdr12A | 12627.94 | '1250' |
| 12 | fdr12A | sub12 | 1 | '1250' |
| 12 | T18 | T17 | 1996.271 | '1/0' |
| 12 | T17 | T16 | 2264.803 | '500' |
| 12 | T16 | T15 | 5794.774 | '750' |
| 12 | T15 | fdr12B | 11140.78 | '1250' |
| 12 | fdr12B | sub12 | 1 | '1250' |
| 21 | T20 | JB21A-1 | 3144.054 | '4/0' |
| 21 | T22 | T21 | 1952.656 | '4/0' |
| 21 | T21 | JB21A-1 | 5022.649 | '500' |
| 21 | T19 | fdr21A | 6289.57 | '1250' |
| 21 | fdr21A | sub21 | 1 | '1250' |
| 21 | JB21A-1 | T19 | 148.1391 | '750' |
| 21 | T26 | T25 | 2029.651 | '4/0' |
| 21 | T24 | T23 | 4196.764 | '750' |
| 21 | T23 | fdr21B | 7468.547 | '1250' |
| 21 | fdr21B | sub21 | 1 | '1250' |
| 21 | T25 | T24 | 3125.274 | '500' |
| 22 | T31 | T30 | 2933.78 | '4/0' |
| 22 | T30 | T29 | 2561.615 | '4/0' |
| 22 | T27 | fdr22A | 4310.091 | '1250' |
| 22 | fdr22A | sub22 | 1 | '1250' |
| 22 | JB22A-1 | T27 | 356.0775 | '750' |
| 22 | T28 | JB22A-1 | 5444.238 | '4/0' |
| 22 | T29 | JB22A-1 | 2435.945 | '500' |
| 22 | T32 | fdr22B | 6738.444 | '1250' |
| 22 | fdr22B | sub22 | 1 | '1250' |
| 22 | T34 | T33 | 2776.593 | '500' |
| 22 | T33 | T32 | 2868.226 | '750' |
| 22 | T35 | T34 | 1888.398 | '4/0' |
| 22 | T36 | T35 | 1739.474 | '1/0' |
| 23 | T40 | T38 | 2295.171 | '1/0' |
| 23 | JB23A-1 | T37 | 1969.359 | '750' |
| 23 | T39 | JB23A-1 | 3325.35 | '1/0' |
| 23 | T37 | fdr23A | 16154.22 | '1250' |
| 23 | fdr23A | sub23 | 1 | '1250' |
| 23 | T38 | JB23A-1 | 45.66115 | '500' |
| 23 | T44 | T43 | 1742.948 | '1/0' |
| 23 | T43 | T42 | 2698.183 | '500' |
| 23 | T42 | T41 | 2158.601 | '750' |
| 23 | T41 | fdr23B | 25910.28 | '1250' |
| 23 | fdr23B | sub23 | 1 | '1250' |
| 24 | T48 | JB24A-2 | 5975.898 | '1/0' |
| 24 | T47 | JB24A-2 | 1216.808 | '1/0' |
| 24 | JB24A-1 | fdr24A | 17968.63 | '1250' |
| 24 | fdr24A | sub24 | 1 | '1250' |
| 24 | JB24A-2 | T46 | 673.2793 | '500' |
| 24 | T45 | JB24A-1 | 3292.274 | '1/0' |
| 24 | T46 | JB24A-1 | 5674.353 | '750' |
| 24 | T52 | T51 | 2066.946 | '1/0' |
| 24 | T50 | T49 | 2988.636 | '1/0' |
| 24 | JB24B-1 | fdr24B | 12586.24 | '1250' |
| 24 | fdr24B | sub24 | 1 | '1250' |
| 24 | T51 | JB24B-1 | 3780.796 | '500' |
| 24 | T49 | JB24B-1 | 3264.297 | '500' |
| 25 | T56 | JB25A-1 | 4610.399 | '4/0' |
| 25 | T55 | T54 | 2324.279 | '4/0' |
| 25 | T54 | JB25A-1 | 2765.212 | '500' |
| 25 | T53 | fdr25A | 12166.5 | '1250' |
| 25 | fdr25A | sub25 | 1 | '1250' |
| 25 | JB25A-1 | T53 | 168.8629 | '750' |
| 25 | T58 | T57 | 4543.817 | '500' |
| 25 | T57 | fdr25B | 12741.99 | '750' |
| 25 | fdr25B | sub25 | 1 | '750' |
| 25 | T59 | T58 | 1488.781 | '1/0' |
| 26 | T62 | T61 | 1585.545 | '1/0' |
| 26 | T60 | fdr26A | 13833.84 | '750' |
| 26 | fdr26A | sub26 | 1 | '750' |
| 26 | T61 | T60 | 5437.041 | '500' |
| 26 | T64 | JB26B-1 | 1628.595 | '4/0' |
| 26 | T65 | JB26B-1 | 1992.111 | '4/0' |
| 26 | T63 | fdr26B | 11331.45 | '750' |
| 26 | fdr26B | sub26 | 1 | '750' |
| 26 | JB26B-1 | T63 | 153.738 | '500' |

Appendix 3. PSSE Single Line Diagram

(Click to open attachment)

Appendix 4. WTEC Cable Impedance Data

(Click to open attachment)

1. Lagging PF means the project is supplying reactive power to the POI. Leading PF means the opposite. [↑](#footnote-ref-2)
2. The overload rating of the STATCOM can be used on this line. If so, provide documentation from the manufacturer stating the overload multiplier and how many cycles or seconds that overload can be sustained. [↑](#footnote-ref-3)