Southwest Power Pool

System Impact Study for Generation Interconnection Request

GEN-2002-022

SPP Tariff Studies
(#GEN-2002-022)

November 2003

Executive Summary

<OMITTED TEXT> (Customer) has requested a System Impact Study under the Southwest Power Pool Open Access Transmission Tariff (OATT) for the purpose of interconnecting up to a 240 MW (in blocks of 80 MW) wind powered generation facility in Oldham County, Texas to the transmission system of Southwestern Public Service Company (SPS/Xcel Energy). The wind powered generation facility will be comprised of 240 individual 1000kW Mitsubishi MWT-1000a wind turbines. The planned in-service date for the 240MW facility is Fall 2004.

The wind powered generation facility will be located approximately 12 miles northeast of the Bushland Interchange 230kV substation. The generation facility will interconnect to the Bushland Interchange via a new, 12-mile 230kV line. The Bushland Interchange substation is located southeast of Wildorado, Texas and west of Amarillo, Texas in the northwest corner of Randall County.

There were no adverse impacts to the SPS/Xcel Energy transmission system identified through the power flow and single contingency studies, provided the generation facility satisfies the power factor requirements of SPS/Xcel Energy.

Using the machine data provided by the requestor, the stability studies indicate that the SPS/Xcel Energy system will remain stable when the 240MW wind powered generation facility is connected to the transmission system. However, an undesirable tripping of the wind farm occurs due to certain faults on the transmission system. The Mitsubishi turbines have a very fast, tight voltage protection scheme that causes them to be removed from the transmission system in the case of very low voltages. The issue of tripping of the turbines is directly related to the voltage protection scheme of the turbines and not the reactive requirements of the wind farm. Even with large amounts of reactive support, the turbines experience the low voltage caused by the normally cleared fault and automatically trip offline.

Short circuit analysis for this wind powered generation facility will be performed by SPS/Xcel Energy as part of the Facility Study if the customer elects to proceed.

The total estimated cost of construction on the SPS/Xcel Energy system for this interconnection is $990,000. This cost does not include the 12 miles of 230kV line from the generation facility to Bushland interchange or the generation facility substation at the generation site.

1. Introduction

<OMITTED TEXT> (Customer) has requested a System Impact Study under the Southwest Power Pool Open Access Transmission Tariff (OATT) for the purpose of interconnecting up to a 240 MW wind powered generation facility in Oldham County, Texas to the transmission system of Southwestern Public Service Company (SPS/Xcel Energy). The wind powered generation facility will be comprised of 240 individual 1000kW Mitsubishi MWT-1000a wind turbines. The planned in-service date for the 240MW facility is Fall 2004.

The wind powered generation facility will be located approximately 12 miles northeast of the Bushland Interchange 230kV substation. The generation facility will interconnect to the Bushland Interchange via a new, 12-mile 230kV line. The Bushland Interchange substation is located southeast of Wildorado, Texas and west of Amarillo, Texas in the northwest corner of Randall County.

2. Purpose

The purpose of the Interconnection System Impact Study is to evaluate the impact of the proposed interconnection on the reliability of the Transmission System. The Interconnection System Impact Study will consider the Base Case as well as all Generating Facilities (and with respect to (iii) below, any identified Network Upgrades associated with such higher queued interconnection) that, on the date the Interconnection System Impact Study is commenced: (i) are directly interconnected to the Transmission System; (ii) are interconnected to Affected Systems and may have an impact on the Interconnection Request; (iii) have a pending higher queued Interconnection Request to interconnect to the Transmission System; and (iv) have no Queue Position but have executed an LGIA or requested that an unexecuted LGIA be filed with FERC.

Nothing in this System Impact Study constitutes a request for transmission service or confers upon the Interconnection Customer any right to receive transmission service.

3.0 Facilities

3.1 Generating Facility

The generating facility is proposed to consist of Mitsubishi MWT-1000a wind turbines. The nameplate rating of each turbine is 1.0MW (1000kW) with a machine base of 1111kVA. The turbine output voltage is 600V. The MWT-1000 turbines utilize conventional induction machine technology. The generator supplies itself with reactive power via switchable 260kVar capacitors (2 each 100kVar and 1 each 60kVar) onboard each turbine. The power factor with the capacitors on and the generator at full output is approximately 0.97 lagging. This means that at 240MW of output, the farm requires approximately 60Mvar of reactive support. The reactive support is to be supplied by the customer via switched capacitor banks located at the generating facility substation.

3.2 Interconnection Facility

The Customer has proposed constructing an interconnection facility to the SPS/Xcel Energy transmission system via the 230kV Bushland Interchange located in Randall County, Texas. The interconnection would be via a tap of the 230kV Bushland Interchange substation with an approximately 12-mile radial 230kV line to the wind powered generation facility. The tap will consist of a single breaker feeding the radial line to the wind powered generation facility and a bus extension of the 230kV Bushland Interchange. Tapping the 230kV Bushland Interchange would require an extension of the bus to accommodate the extra breaker.

4.0 Analysis

4.1 Powerflow Analysis

A powerflow analysis was conducted for the facility using various seasonal representations. The output of the Customer's facility was offset in each model by a reduction in output of SPS generation. Modified versions of the 02 Series Southwest Power Pool 2004 Summer Peak, 2004 Spring Peak, and 2009 Summer Peak base case were used for this study.

The analysis of the customer's project shows that the proposed location can handle the 240MW of output under steady state conditions without system upgrades in all seasons out to the end of SPP's planning horizon. Of course, short circuit analysis performed as part of the Facility Study will determine if any breaker duty ratings are exceeded or should be adjusted.

There are several other proposed wind generation additions in the general area of the Customer's facility. It was assumed in the analysis that not all of these other projects were in service. Those previously queued projects that have advanced to nearly complete phases were included in this System Impact Study.

4.1.1 Powerflow Analysis Methodology

The Southwest Power Pool (SPP) criteria states that: The transmission system of the SPP region shall be planned and constructed so that the contingencies as set forth in the Criteria will meet the applicable *NERC Planning Standards* for System Adequacy and Security – Transmission System Table I hereafter referred to as NERC Table I) and its applicable standards and measurements.

Thus, the following conditions must be met in order to maintain a reliable and stable system:

1) More probable contingency testing must conclude that:

   a) All facility loadings are within their emergency ratings and all voltages are within their emergency limits (0.90-1.05 per unit) and
   b) Facility loadings can be returned to their normal limits within four hours

2) Less probable contingency testing shall conclude that:

   a) Uncontrolled islanding does not result
   b) Uncontrolled loss of large amounts of load will not result

More probable contingency testing is defined as losing any single piece of equipment or multi-circuit transmission lines. Less probable contingency testing involves the loss of any two critical pieces of equipment such as 345kV autotransformers and generating units or the loss of critical transmission lines in the same right-of-way.

Using the created models and the ACCC function of PSS\E, single contingencies in the SPS control area were applied and the resulting scenarios analyzed. This satisfies the 'more probable' contingency testing criteria mandated by NERC and the SPP criteria.

4.2 Stability Analysis

A 2004 Summer Peak stability case was used to analyze the effects of various transmission system faults on the wind farm and the resulting effects of the wind farm response to the system.

The faults that were performed were defined by SPS and are as follows:

1. FLT13PH – 3-phase fault

   Fault on the Potter County (50887) – Bushland (50993), 230kV line, near Potter.
   a. Apply Fault at the Potter Bus (50887).
   b. Clear Fault after 5 cycles by removing the line from 50887 - 50993.
   c. Wait 20 cycles, and then re-close the line in (b) into the fault.
   d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.

2. FLT21PH – 1-phase fault
   - Same as FLT13PH above.

3. FLT33PH – 3-phase fault

   Fault on the Potter County (50888) – Finney Switch Station (50858) 345kV line, near Finney.
   a. Apply fault at the Finney bus (50858).
   b. Clear fault after 5 cycles by removing the line from 50888 – 50858.
   c. Wait **30** cycles, and then re-close line in (b) into the fault.
   d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.

4. FLT43PH – 3-phase fault

   Fault on the Bushland (50992) – Coulter (51002) 115kV line, near Coulter.
   a. Apply fault at the Coulter bus (51002).
   b. Clear fault after 5 cycles by removing line from 50992 – 51002.
   c. Wait 20 cycles, and then re-close line in (b) into the fault.
   d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.

5. FLT51PH – 1-phase fault
   - Same as FLT43PH above.

6. FLT63PH – 3-phase fault

   Fault on the Harrington (50907) – Randall Interchange (51021) 230kV line, near Randall.

a. Apply fault at the Randall bus (51021).
b. Clear fault after 5 cycles by removing the line from 50907 – 51021.
c. Wait 20 cycles, and then re-close line in (b) into the fault.
d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.

7. FLT71PH – 1-phase fault
   - Same as FLT63PH above.

8. FLT83PH – 3-phase fault
   Fault on the Bushland (50993) – Deaf Smith (51111) 230kV line, near Deaf Smith.
   a. Apply fault at the Deaf Smith bus (51111).
   b. Clear fault after 5 cycles by removing the line from 50993 - 51111.
   c. Wait 20 cycles, and then re-close the line in (b) into the fault.
   d. Leave fault on for 5 cycles, then trip the line in (b) and remove the fault.

9. FLT91PH – 1-phase fault
   - Same as FLT83PH above.

10. FLT103PH – 3-phase fault
   Fault on the Grapevine (50827) – Elk City (54153) 230kV line, near Elk City.
   a. Apply fault at the Elk City bus (54153).
   b. Clear fault after 5 cycles by removing line from 54153 - 50827.
   c. Wait 20 cycles, and then re-close line in (b) into the fault.
   d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.

11. FLT111PH – 1-phase fault
   - Same as FLT103PH above.

12. FLT123PH – 3-phase fault
   Fault on the Wolfforth Interchange (51762) – Terry County (51830) 115kV line, near Terry County.
   a. Apply fault at the Terry County bus (51830).
   b. Clear fault after 5 cycles by removing line from 51762 -51830.
   c. Wait 20 cycles, and then re-close line in (b) into the fault.
   d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.

13. FLT131PH – 1-phase fault
   - Same as FLT123PH above.

The above cases were run for the following conditions:

Wind farm output at 240MW with 30MVAR of capacitors
Wind farm output at 240MW with 75MVAR of capacitors
Wind farm output at 80MW with 30MVAR of capacitors
Wind farm output at 240MW with an SVC
Wind farm output at 80MW with an SVC
Wind farm output at 240MW with 75MVAR of capacitors and improved trip scheme

4.2.1 Dynamic Modeling of the Wind Powered Generation Facility

The rated output of the generation facility is 240MW, comprised of two hundred forty (240) Mitsubishi MWT-1000a wind turbines. The base voltage of the Mitsubishi turbine is 600 V, and a generator step up transformer (GSU) of 1.11MVA connects each unit to the high side of 34.5kV. The rated power output of each turbine is 1.0MW while the actual power output depends on the wind.

In performing a system impact study, existing on-line generation in the local control area is displaced by the addition of the generator in order to preserve control area interchange schedules in the model. Upon advice from SPS/Xcel Energy, the following dispatches were utilized:

Wind Generator OFF			Wind Generator 240MW			Wind Generator 80MW		
Bus #	Name	Output (MW)	Bus #	Name	Output (MW)	Bus #	Name	Output (MW)
50721	BlackHawk 1	108	50721	BlackHawk 1	0	50721	BlackHawk 1	80
50722	BlackHawk 2	108	50722	BlackHawk 2	0	50722	BlackHawk 2	80
51441	Tolk 1	459	51441	Tolk 1	435	51441	Tolk 1	435
	Wind Generator	0		Wind Generator	240		Wind Generator	80

The generating facility substation will consist of three (3) 80MVA 230kV/34.5kV transformers connected in parallel. From the preliminary one-lines received from the customer, on the 34.5kV side of each transformer, three feeder circuits will extend into the generating facility. Each feeder will consist of 26 or 27 turbines. Each of these feeders will then further subdivide to three (3) junctions consisting of 8 or 9 turbines at each junction. Each turbine then has its own pad-mounted transformer rated 600V/34.5kV and 1.111MVA. Please see the one-line drawing (Figure 1) attached to this document.

The actual parameters (R, X and B) of the 34.5kV collector circuits are calculated based on the data provided by the customer. The cable impedance characteristic table as provided by the customer is as follows:

Cable Impedance Characteristic Table				
Drake	795 ACSR	RDC=0.0222 Ohm/1000'	XL=0.1091 Ohm/1000'	XC=0.0257 Ohm/1000'
Hawk	477 ACSR	RDC=0.0371 Ohm/1000'	XL=0.1149 Ohm/1000'	XC=0.0272 Ohm/1000'
Raven	1/0 ACSR	RDC=0.1682 Ohm/1000'	XL=0.1345 Ohm/1000'	XC=0.0315 Ohm/1000'
MV-105	1/0 Cu Shielded	RDC=0.1060 Ohm/1000'	XL=0.0500 Ohm/1000'	XC=negligible

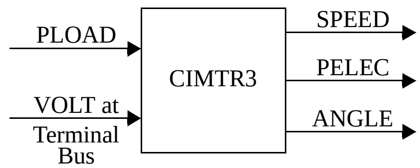
4.2.2 Machine Dynamics Data

The Mitsubishi MWT-1000a wind turbine generators utilized in the customer facility represent conventional induction generator technology. The data provided by Mitsubishi and the customer is consistent with the CIMTR3 induction generator model with rotor flux transients. The PSS/E data sheet for the CIMTR3 model is provided on the next page.

CIMTR3

Induction Generator Model

This model is located at system bus #_______ IBUS,
machine #_______ I.
This model uses CONs starting with #_______ J,
and STATEs starting with #_______ K,
and VARs starting with #_______ L,
and ICON #_______ M.
The machine MVA is __________ for each of
__________ units = __________ MBASE.



CONs	#	Value	Description
J			T' (sec) (>0)
J+1			T" (sec) (≥0)*
J+2			Inertia, H
J+3			X
J+4			X'
J+5			X"*
J+6			X_l
J+7			E_1 (≥0.)
J+8			$S(E_1)$
J+9			E_2
J+10			$S(E_2)$
J+11		0.	Switch
J+12			SYN-POW, mechanical power at synchronous speed (>0). Used only to start machine, otherwise ignored.

STATEs	#	Description
K		E'_q
K+1		E'_d
K+2		E''_q
K+3		E''_d
K+4		Δ speed (pu)
K+5		Angle deviation

VARs	#	Description
L		Admittance of initial condition Mvar difference
L+1		Motor, Q
L+2		T_{elec}

ICON	#	Description
M		Memory

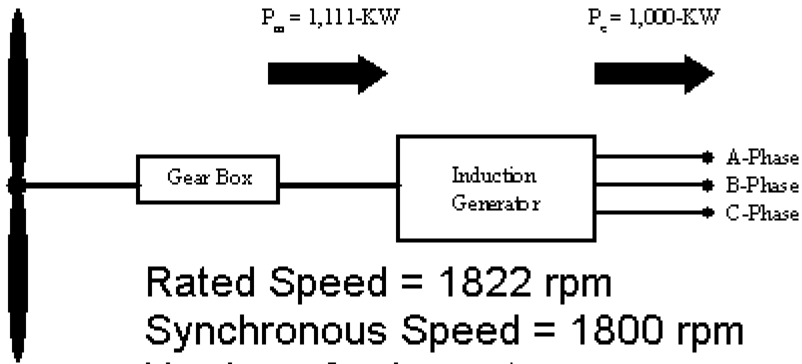
*If T" = 0. or X" = 0., machine is assumed to be single cage and ZSORCE should be set equal to X'.

X, X', X", X_l, and H are in pu, machine MVA base.

IBUS, 'CIMTR3', I, T', T", H, X, X', X", X_l, E_1, $S(E_1)$, E_2, $S(E_2)$, 0., SYN-POW/

The data provided for the CIMTR3 model from Mitsubishi is as follows:

Mitsubishi Heavy Industries
MWT-1000A Wind Turbine-Generator
Rated Operating Conditions



Rated Speed = 1822 rpm
Synchronous Speed = 1800 rpm
Number of poles = 4
Gear Box Ratio = 1:90.9

Vl-l = 600V
I1 = 960A
F1 = 60Hz
PF = 0.97

Dynamics Data -- Induction Generator:

Item	Value	Description
Machine kVA base	1111	kVA
T' (seconds)	0.87	Transient open-circuit time constant
T'' (seconds)	0.87	Subtransient open-circuit time constant (0 for single cage)
H (PU on machine base)	128.50	Inertia constant
X (PU on machine base)	3.97	Synchronous reactance
X' (PU on machine base)	0.21	Transient reactance
X'' (PU on machine base)	0.21	Subtransient reactance (0 for single cage)
X1 (PU on machine base)	0.11	Leakage reactance
E1	1.0000	From Saturation curve
S(E1)	0.0580	From Saturation curve
E2	1.2000	From Saturation curve
S(E2)	0.4520	From Saturation curve

The Inertia constant provided by Mitsubishi for the wind turbine generator is very atypical. The Inertia constant (H) that was provided was 128.5. However, typical wind turbine generator H values for this size machine are in the range of 4.0 to 6.0. The equation used to calculate the H constant is:

$$H = \frac{1.37 * (GD^2) * (rpm^2) * 10^{-6}}{R}$$

where:

H = Inertia constant in kW-sec/kVA.
GD^2 = Moment of inertia in kg-m^2 (based on diameter)
rpm = Rotational speed of the mass in revolutions per minute.
R = Machine kVA rating.

Using the GD^2 values provided by Mitsubishi, an H constant of 1.1886 was calculated. However, upon further examination of the data, it was determined that the GD^2 values provided by Mitsubishi were in-fact the mass moment of inertia (I) of the turbine. The conversion equation for mass moment of inertia to moment of inertia is:

$$GD^2 = 4 * I$$

Thus, the correct H constant for the turbine is 4 * 1.1886 = 4.75 PU on machine base. This is the H constant used in the following stability analysis.

Also, Mitusbishi provided T'=T" and X'=X" to indicate that these are single cage induction machines. Using the CIMTR3 model in PSS/E, T" and X" are set equal to zero.

4.2.3 <u>Turbine Protection Schemes</u>

The Mitsubishi MWT-1000a turbines utilize an under/overvoltage protection scheme and an under/overfrequency protection scheme. The various protection schemes are designed to protect the wind turbines in the case of system disturbances that can cause damage to the mechanical systems on board the turbine. Generally, the protection schemes will disconnect the generator from the electric grid if the sampled frequency or voltage is outside of a specified band for a specified amount of time. The sample rate for the turbine control system is reported by Mitsubishi as 1 sample every 50ms (1sample every 3 cycles).

The voltage protection scheme is outlined in Table 1 below:

Voltage	**Time Limit**	
1.200000pu	3 cycles (0.05s)	Turbine cannot return automatically
1.100000pu -- 1.19999pu	3 cycles (0.05s)	Turbine will return automatically
0.900001pu -- 1.09999pu	Continuous operation	
0.850001pu -- 0.90000pu	3 cycles (0.05s)	Turbine will return automatically
0.850000pu	3 cycles (0.05s)	Turbine cannot return automatically

Table 1: MWT-1000a Voltage Protection

The frequency protection scheme is outlined in Table 2 below:

Frequency	**Time Limit**	
61.00000Hz	3 cycles (0.05s)	Turbine cannot return automatically
60.50000Hz -- 60.99999Hz	6 cycles (0.10s)	Turbine will return automatically
59.00000Hz -- 60.49999Hz	Continuous operation	
58.99999Hz	6 cycles (0.10s)	Turbine cannot return automatically

Table 2: MWT-1000a Frequency Protection

4.2.4 Stability Results

The wind farm and the surrounding transmission system appear to remain stable for all faults applied and for all scenarios analyzed. However, the wind farm does trip due to low voltage for certain faults. All cases and scenarios are tabulated below with an indication of whether or not the wind farm tripped offline.

Fault Case/Scenario	240MW with 30MVAR capacitors	240MW with 75MVAR capacitors	80MW with 30MVAR capacitors	240MW with SVC	80MW with SVC	240MW with 75MVAR capacitors and improved voltage trip scheme
FLT13PH	X	X	X	X	X	X
FLT21PH	X	---	X	X	X	---
FLT33PH	---	---	---	---	---	---
FLT43PH	X	---	X	X	X	---
FLT51PH	---	---	---	---	---	---
FLT63PH	X	X	X	X	X	---
FLT71PH	---	---	---	---	---	---
FLT83PH	X	X	X	X	X	---
FLT91PH	---	---	---	---	---	---
FLT103PH	---	---	---	---	---	---
FLT111PH	---	---	---	---	---	---
FLT123PH	---	---	---	---	---	---
FLT131PH	---	---	---	---	---	---

X = wind farm tripped due to low voltage

As can be seen in the table above, certain faults caused the wind farm to experience low voltage and trip offline in all scenarios. This tripping is unquestionably attributed to the very conservative trip scheme employed by the Mitsubishi turbines. This can be determined by examining the results when the wind farm output was lowered and the reactive compensation was increased. For both of these scenarios, the wind farm still tripped offline.

4.2.4.1 Effects of Improved Voltage Trip Scheme

The customer did provide an “improved” trip scheme from Mitsubishi to be investigated. This trip scheme lowered the instantaneous trip to 0.6pu and the delayed trip to 0.9pu. Using the assumed pickup time of 0.05s (3 cycles) and a breaker operation time of 0.5s (30 cycles), the wind farm appeared to remain online and survive the voltage dip for all faults except FLT13PH, the 3 phase fault at Potter on the Potter to Bushland 230kV line.

The SVC placed at the wind farm was sized up to 300MVAR and utilized very fast settings. However, the SVC was not able to stop the wind farm voltage from depressing to the point that the instantaneous voltage trip limit was reached. In order to provide enough voltage support to the wind farm, the amount of reactors placed online at the 34.5kV bus was increased from 30 to 75MVAR and the cases re-run. This also did not stop the wind farm from tripping offline. Only when the voltage trip scheme was relaxed did the farm stay online for all faults except FLT13PH.

A 3 phase fault at Potter on the 230kV line connecting to the wind farm would most likely be identified as a “close in, severe” fault by SPS and thus the farm would not be required to ride through the fault. The improved voltage trip scheme appears to satisfy this criterion.

The Mitsubishi turbines also utilize onboard capacitors to correct the power factor of the turbine output at various levels. It is assumed that for high voltage situations, the Mitsubishi control system would switch out these capacitors at varying levels. However, at no point did the wind farm experience “high” voltage during the faults. As such, this portion of the control system was not investigated.

5.0 Conclusion

The minimum cost of interconnecting the Customer project is $990,000. However, as stated earlier, previously queued projects were assumed to not be in service in this System Impact Study. If any of those projects are constructed, then this System Impact Study may have to be revisited to determine the impacts of this customer’s project on other SPS transmission facilities. These costs also do not take into account any breaker duty ratings or settings. The short circuit analysis will be performed as part of the Facilities Study performed by SPS if the customer elects to have the study performed.

The issue of the wind farm tripping offline appears to be able to be mitigated by providing significant reactive compensation at the wind farm and altering of the voltage trip scheme by Mitsubishi. The lower limits of the voltage trip scheme will need to be at least as low as the alternative that was provided or else the wind farm would likely trip offline for numerous remote faults.

The costs do not include any costs associated with the deliverability of the energy to final customers. These costs are determined by separate studies if the Customer requests transmission service through Southwest Power Pool’s OASIS.

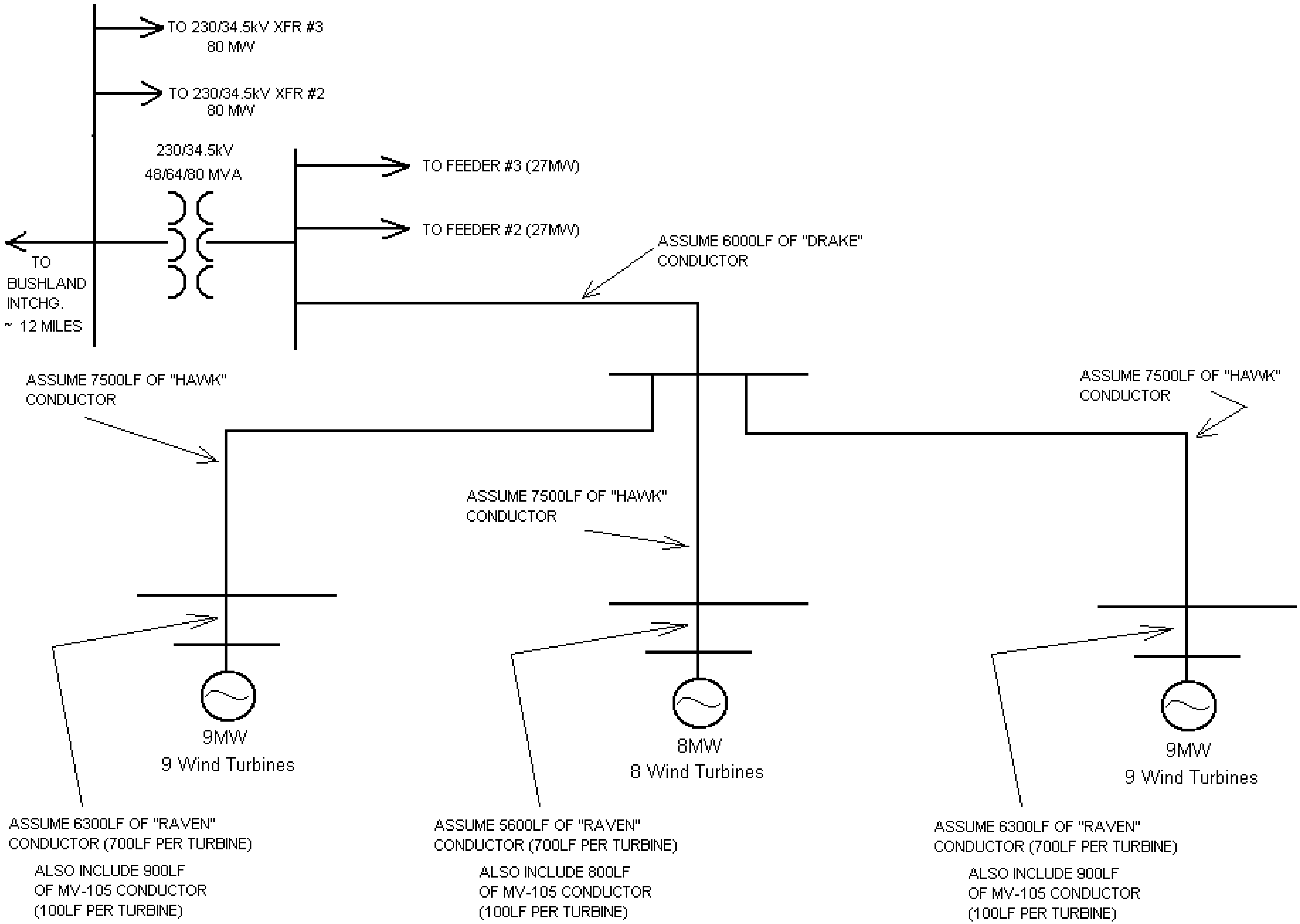


FIGURE 1:EQUIVALENT FACILITY ONE-LINE