Aquila Networks

105 MW Kiowa, County Wind Farm near Mullinville, Kansas

Final Report

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1.0 Introduction

A customer within the Aquila interconnection queue (Customer) has proposed adding 105 MW of wind generation near Mullinville, Kansas (projected in-service date of June 1, 2003, referred to as the Kiowa County wind project). The proposed generation would interconnect with the Aquila Networks transmission system (Aquila, Inc. d/b/a Aquila Networks-WPK, denoted WEPL) on the existing 115 kV line from Judson Large Substation near Dodge City, Kansas to the Greensburg Substation near Greensburg, Kansas. Aquila Networks has performed a transmission interconnection study to assess the impacts of the proposed project on the WEPL transmission system. This report summarizes the findings of the study. The following topics will be discussed:

- System modeling
- Load flow analysis
- Voltage swing analysis
- Short circuit analysis
- Transient and dynamic stability studies
- Additional System Issues
- Estimated interconnection and mitigation costs

Note that the focus of this study was determining interconnection impacts due to integrating the proposed facility into the WEPL system. Additional study will be required to assess the full impacts and costs of delivering the generation to specific load sinks.

2.0 Model Development

Models representing the WEPL system as well as the surrounding bulk electric transmission system were developed for each of the studies performed. In each case, the most recently available Southwest Power Pool (SPP) model was used as the starting point.

2.1 Load Flow Models

The output of a wind farm is known to be unpredictable and relatively uncontrollable. Because of this, the wind farm could be at full output at any time during the year. Therefore, the interconnection of the proposed wind generation was evaluated for the full range of available SPP seasonal load flow models including the following:

- 2003 April Minimum (03AP)
- 2002 Summer Shoulder (03SH)
- 2003 Summer Peak (03SP)
- 2003 Fall Peak (03FA)
- 2003/04 Winter Peak (03WP)
- 2004 Spring Peak (04G)
- 2008 Summer Peak (08SP)

Each of these base case models was modified to include the full 110 MW output of the existing Gray County Wind Energy (GCWE) wind farm near Montezuma, Kansas. The proposed Customer facility was interconnected with the WEPL system at a 115 kV bus approximately 7.5 miles from the existing WEPL Greensburg 115 kV bus. The wind generation was modeled at the end of a 115 kV line seven miles from the point of interconnection. A 10 percent impedance (on 80 MVA base) 115/34.5 kV transformer was assumed to step up the wind farm voltage. The output was dispatched approximately one third east (to Western Resources), one third north (to Nebraska Public Power District), and one third south (to Excel Energy). The phase shifting transformer at Guymon, Oklahoma was adjusted to carry approximately 30 MW of the southerly schedule.

The reactive characteristics of the wind farm were modeled two different ways as directed by the Customer. The first method assumed the wind farm to be capable of supplying up to 34.5 Mvar (95 percent lagging power factor) and absorbing up to 34.5 Mvar (95 percent leading power factor) at the low side of the 115/34.5 kV step up transformer. This var range was estimated from technical specifications for the General Electric 1.5/70.5 wind turbine with an allowance made for var losses in the collection system. The second method (for a NEG Micon NM72c turbine) assumed that the wind farm would absorb vars at a 95 percent power factor (leading). This assumption was based on an induction generator style wind turbine. Additionally, 14 Mvar of capacitors were assumed in the base case in order to have adequate base case voltage. Load flow and stability results are divided into two categories corresponding to the two types of turbines modeled

2.2 Short Circuit Model

The 2001 series SPP short circuit model was used to assess the short circuit impacts of the proposed wind farm. The 115/34.5 kV transformer impedance was estimated based on the actual values for the GCWE wind farm. The wind turbines were modeled as induction machines and were assumed to self-excite for the length of time of a fault event due to the capacitor banks present and the inertial mass of the farm.

2.3 Stability Model

A stability model was developed using the SPP 2001 Series stability model (2002 summer peak conditions). The SPP base case was modified to include the proposed wind farm as well as the existing GCWE wind farm at full output. Both types of wind turbines were modeled using induction motor models using parameters supplied in the manufacturer's specifications. The GE turbine additionally required a parallel static var compensator (SVC) model to represent the turbine's ability to adjust var supply/consumption based on system conditions. Typical model parameters for an SVC were used as supplied by GE. Additionally, the wind turbines at the proposed wind farm were assumed to trip off when voltage on the Kiowa County 34.5 kV bus dipped below 70 percent of nominal regardless of the turbine manufacturer. It was further assumed that after tripping, the wind turbines would not come back on line within the 10-second time frame of the simulation.

3.0 Load Flow Analysis

The load flow impacts of the proposed generation were analyzed using the models described in Section 2.2. Single contingencies within five busses of the interconnection bus as well as any single contingencies within the WEPL system not within 5 busses of the interconnection bus were performed. Also, breaker failure double contingencies in the WEPL system were performed. The cases with the proposed wind farm added were compared with the appropriate base case to determine facility overload and/or low voltages that were attributable to the proposed wind farm.

3.1 Analysis Assuming Installation of GE Wind Turbine

The following facility overloads were identified as overloaded due to the wind farm addition when use of the GE turbine was assumed:

- **Greensburg to Kiowa County 115 kV**- this facility was loaded beyond the conductor emergency rating for the 03FA and 03WP cases (as high as 103.3 percent) for loss of the North Judson to Spearville 115 kV line. The location of the outage in this case makes this a transmission service issue. Therefore, any mitigation will be dealt with further in transmission service studies. This facility also overloaded for a breaker failure outage of either breaker 6028 or 6026 at Spearville (as high as 110.7 percent in the 03FA case). NERC planning standards allow curtailment of firm transfers for this category of outage. Therefore, it was assumed that curtailment would be utilized for mitigating this overload. Note that breaker failure outage of breaker 6028 results in loss of the Spearville 345/230 kV transformer and the Spearville to Mullergren 230 kV line. Breaker failure outage of breaker 6026 results in loss of the 345/230 kV and 230/115 kV transformers at Spearville.
- **Medicine Lodge to Sun City 115 kV** - this facility overloaded for several contingencies for each seasonal model with the worst overload occurring for loss of the North Judson to Spearville 115 kV line (as high as 159.4 percent for the 03FA case). Mitigation of this overload can be accomplished by replacing the 400-ampere wave trap and the 600-ampere current transformers at Medicine Lodge. This line loaded beyond the resulting conductor limit (after replacing terminal equipment) for breaker failure outages of breakers 6028 and 6026 at Spearville. It was assumed that this overload would be mitigated by curtailment.
- **Judson Large to Kiowa County** - this facility overloaded for loss of any portion of the 115 kV line between the interconnection bus and Medicine Lodge (as high as high as 137.5 percent in the 08SP case). This overload can be mitigated by replacing line relaying equipment at Judson Large and a 400-ampere wave trap at Judson Large.
- **Medicine Lodge 138/115 kV** – this facility overloaded (102.2 percent) for loss of North Judson to Spearville in the 02FA case. The location of the outage in this

case makes this a transmission service issue which and will be dealt with further in transmission service studies.

The GE turbine was assumed to be capable of supplying reactive power to the system with a response time similar to a conventional generator (in accordance with manufacture's literature). Using this assumption, the proposed wind farm did not produce any adverse voltage impacts. Note that due to the voltage sensitive nature of the WEPL system, guarantee of the turbines' reactive capabilities will be required.

3.2 Analysis Assuming Installation of NEG Turbine

Assuming the installation of NEG turbines, system voltage performance was considerably worsened compared to the performance with the GE turbine. Several contingencies resulted in voltage collapse for each of the seasonal models, including loss of the line from Judson Large to the interconnection bus. Addition of capacitors was examined as mitigation for the voltage problems. A minimum of 40 Mvars of capacitors were required in some seasonal cases to produce adequate voltage. In other cases, this amount of capacitors produced voltage collapse while a smaller amount produced acceptable voltages. Additionally, a difference as small as 2 Mvar made as large as a 6 percent difference in area voltages for a critical outage. Clearly, capacitor banks will not provide adequate voltage controllability. Therefore, a device such as a static var compensator (SVC) will be required in parallel with the NEG turbines should they be used. A range of +35 Mvar to –35 Mvar will be required. With this assumption, systeme impact of wind farm using the NEG turbine was identical to the system impact of the wind farm using the GE turbine (documented in Section 3.1).

4.0 Voltage Swing Analysis

The output of a wind farm has been known to go from approximately 50 percent of maximum output to full output within a few minutes when a surge of wind occurs (such as a storm front moving through). This phenomena could cause a change in system voltage, which could be unsatisfactory for other WPEK customers. Therefore, this voltage impact was quantified using the load flow models described in Section 2.1. Simulations were performed which raised the output of the proposed Customer wind farm as well the existing GCWE wind farm from 50 percent output to 100 percent output without allowing transformer taps to adjust. Additionally, the reactive output of the Judson Large generator was locked to produce a conservative case.

Due to the requirement of an SVC with the NEG turbine (from analysis documented in Section 3.0), both types of turbines will behave similarly for the wind surges and corresponding voltage swings analyzed in this section. Therefore, the analysis was only performed for the GE turbine. Using this turbine, the voltage change measured at the adjacent Greensburg 34.5 kV bus for each seasonal case was well below the acceptable levels defined by Aquila Networks operating standards (allowable change for this type of event would be 4 percent). Therefore, the potential voltage swings were considered acceptable.

5.0 Short Circuit Analysis

Three phase and single-line-to-ground fault currents were calculated before and after the addition of the proposed unit using the model described in Section 2.2. The results are shown in table 5-1.

Table 5-1: Maximum Fault Currents Before and After Proposed Wind Farm Addition

Bus	Maximum Fault Current (kA)	
	Before Addition	After Addition
Judson Large 115 kV	9.38	9.95
Medicine Lodge 115 kV	2.66	2.76
Greensburg 115 kV	2.55	3.01
Judson Large 34.5 kV	7.46	7.57

The fault currents with the proposed generation addition in service were subsequently compared with the interrupting ratings of the breakers at Medicine Lodge and Judson Large. The maximum fault levels after the wind farm addition were within the rated capabilities of the existing equipment.

6.0 Transient and Dynamic Stability Analysis

The angular stability impacts of the proposed wind farm addition were assessed using the models described in Section 2.3. Normally cleared three-phase faults were simulated on the interconnection 115 kV bus, the Judson Large 115 kV bus and the North Judson Switching Station 115 kV bus out to 10 seconds. Single-line-to-ground faults with delayed clearing were simulated on the Judson Large and North Judson Switching Station 115 kV busses out to 10 seconds. Additionally, each fault simulation was performed on the model without the wind farm addition to provide a baseline for comparison.

All normally cleared three-phase faults exhibited stable rotor angle swings and positive damping. Single-line-to-ground faults with delayed clearing that were simulated without the proposed wind farm also exhibited stable rotor angle swings and positive damping. However, with the addition of the proposed wind farm, a single-line-to-ground fault at the North Judson Large Switching Station on the line to Spearville with a breaker failure outage of the 115 kV line to South Dodge resulted in instability. Two mitigation measures were tested - reduction of the breaker failure time delay (from 15 cycles to 12 cycles); and additional transmission additions. Both mitigation measures eliminated the instability. Since reduction of the breaker failure time delay is a more economical solution, this solution was assumed to be the solution of choice.

7.0 Additional System Issues

The Greensburg 115 kV Substation and the Sun City 115 kV Substation have switches equipped with 30 kV interrupting bottles. These switches are occasionally needed to open the Greensburg to Sun City line under load conditions. These switches can successfully open the line under a range of operating conditions with the present system configuration. Calculations of the phase angle across the switch with and without the proposed wind farm added to the system indicated that the range of conditions under which the existing switches will be adequate to switch this line would be greatly narrowed if not eliminated altogether. Therefore, additional interrupting capability will be required. For the purpose of providing mitigation costs, it was assumed that a circuit switcher will be required at Greensburg (along with required synchronizing relaying and a 115 kV potential transformer) and whips will need to be installed on the existing switch at Sun City. This alternative was assumed in order to cover the full range of opening and closing requirements of the system with the new generation installed. It is possible that a vacuum switch could be installed at Greensburg in lieu of the circuit switcher. This can be investigated further at the detailed design stage. This issue was not a function of turbine selection.

8.0 Estimated Interconnection and Mitigation Costs

Interconnection costs and the costs required to address the adverse system impacts identified were estimated as follows:

Facility	Estimated Cost
New 115 kV Substation with 3 positions – not including step-up transformer*	$3,100,000
Replacement of wave traps at Medicine Lodge and Judson Large*	$102,000
Replacement of relaying on Judson Large terminal*	$114,000
Replacement of breaker current transformers at Medicine Lodge*	$25,000
Installation of 115 kV circuit switcher at Greensburg Substation, and whips at Sun City Substation*	$275,000
Rebuilding of the Kiowa County to Greensburg 115 kV line to operate at a 100 C maximum conductor temperature**	$475,000
Replacement of Medicine Large 138/115 kV transformer with a 70 MVA unit**	$1,300,000
Change breaker failure timing at N Judson Large Switching Station, test relays*	$1,000
TOTAL ESTIMATED COST	**$5,392,000**
*Costs required in order to permit interconnection. Remaining costs related to delivery of power **Note that these mitigation costs could be dealt with alternatively by curtailment of wind farm generation and/or redispatch options Cost to install SVC if NEG turbine is selected has not been included.	

The estimated connection costs include a tax gross-up to cover anticipated income tax consequences (estimated at 25 percent). Note that the costs presented here are preliminary and subject to change should a detailed facilities study be requested. The estimated cost for the 115 kV interconnection substation includes line sectionalizing breakers and switches, a sectionalizing breaker (and switches) for the 115 kV interconnection to the Customer facilities, associated relaying (not including any transformer protection), control building, lightning arresters, foundations, grounding, etc. Note that the cost of required reactive compensation and associated controls was not included.