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FIELD VERIFICATION PROGRAM FOR SMALL WIND TURBINES

"Supplemental power for the Town of Browning waste-water treatment facility"

Quarterly Report for the Period October 1999 – December 1999

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1. Background

Cooperative Agreement No. DE-FC36-99GO10459 was put in place and authorized on Sept 30, 1999. The agreement between the USDOE (DOE) and Siyeh Development Corporation (Siyeh) of Browning, MT, is under The Field Verification Program For Small Wind Turbines and is titled "*Supplemental power for the Town of Browning wastewater treatment facility*".

A team of organizations was assembled as project partners and contributors in this endeavor. Included in that number are: Siyeh, the Town of Browning, MT (Browning), Bergey Windpower (Bergey), the Indian Health Service (IHS) and the Blackfeet Indian Housing Authority (BIHA).

The funding levels requested will cover a project duration of three full years, in which time the hardware will be installed/commissioned and performance data collected for purposes of program assessment. The project will be closely examined at the end of the three-year project period, in terms of hardware performance, overall applicability and effectiveness of the operation. A reporting of the evaluation will be provided to the DOE and to each of the project partners. The report will also be made available to others as a matter of public record.

Martin Wilde (Wilde), Director of Energy Development for Siyeh, in coordination with William Morris (Morris), the Mayor of Browning, made a proposal the DOE "Field Verification Program for Small Wind Turbines" program to install four small turbines to provide supplemental power the waste water treatment facility located immediately to the east of the town. It was agreed that this would be a good community development project and an opportunity to put wind power to good use, as well as an opportunity to test the Bergey Excel/S turbines in the "winds of the Blackfeet".

2. Summary of work-to-date

Project manager, Wilde worked in conjunction with Morris and IHS engineer, Justin Weiser (Weiser), to develop project schedule and a site plan of the Browning sewer lagoon. The site plan was used to plan the project, develop the work schedule and to assist contractors in preparing accurate and meaningful bids.

Project schedule

The project was planned using a Gaant chart (**Appendix 1**). The printout gives an accurate display of the project tasks, the resources used to accomplish the tasks and the timelines for each of the tasks. The chart has been adjusted to be accurate as of this writing. Future tasks are predicted with best estimate accuracy.

Project Site Plan

Wilde and Weiser developed a site plan (**Appendix 2**) based on preliminary readings “shot” with a laser detector around the perimeters of the lagoon cells. The points were incorporated into an AutoCAD drawing.

The locations of the turbine bases were selected based upon optimal positioning with respect to the prevalent wind direction (see diagram below), whilst using the sparse areas of available ground in the aprons surrounding the lagoon. Trenches for conduit and site wiring were sketched in reference to the building.

Trenching

Late in September, Wally John Boggs (Boggs) of the town of Browning began backhoe excavation of the trenches. Trenches were dug 2 feet in width and approximately 3 feet in depth.

Three separate “braches” were dug outward from the building to bury the wiring/conduit for the aerators and the turbines:

- 1) To the west - a leg out to and along the dike between cells 1 and 2
- 2) To the north - a leg along the dike between cells 2 and 3, which branched out to turbines 2, 3 and 4
- 3) To the east - to the aerators in cell 4

Wiring

A table was produce to assist contractors in bidding out the job to proper specifications (**Appendix 3**).

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#8 THWN conductor is normally sufficient for Bergey turbines located within 300' of the inverter. For distances greater than that the gauge thickness is increased to handle the heat build up. At this project site, turbine #2 was at approximately 1300' and turbine #4 was at a distance of 1100'. At distances such as these it was decided that 2/O conductor would have to be used for turbines 2, 3 and 4.

Turbine #1 was spec'd out for # 8 copper however, out of convenience, it was wired with the same #4 THWN as the site aerator wiring.

Concrete

The foundations for the four turbines were bid and constructed as per drawings provided by Rohn, the manufacturer of the 100' SSV tower used in this project. The "slab" style base was selected for purposes of durability under varying soil conditions and it's ease of manufacture. A copy of the Rohn drawing is found in **Appendix 4**.

Bergey shipped a bolt template for use in suspending the anchor bolts in the mold during the pour. The plates are welded at the exact spacing required to match the tower legs. The template had to be adjusted to meet the specifications indicated by Rohn, (i.e. 10'7-5/8" on each side of the triangle). This created a concern as to whether the correct measurement had been used and if the towers would fit the bases after they were assembled.

The concrete contractor, Wagner Ready-mix of Browning, was required to not only meet the specs of the base design drawing but also to read, sign and adhere to the QA document included in **Appendix 5**.

Tower Assembly and erection

Peiter Hubner of Bergey Windpower arrived on site 11/8/99 and worked with Wilde, Boggs and two contract ironworkers, Lawrence Laplant and Dustin McLean, over the following 5 days to assemble and erect the towers and turbines.

Tower #4 was assembled first. The base section of the tower was assembled separately from the upper 80 feet allowing the workers to place it on the foundation to check the "fit" (*Note: all the towers fit to within 1/2" of the bolt patterns of the foundations*). Subsequently, towers #3, #2 and #1 were assembled, in that order, on the ground adjacent to their bases.

Duane Irvin (Irvin) was contracted to operate a 55-ton crane for use in tower erection. On 11/10/99 tower #1 was erected with no notable difficulty. As the sun began to go down, tower #2 was being hoisted up.

The placement of the hook of the side of tower #2 caused it to become hung up, with the blade of the turbine in danger of damage, being trapped between the weight of the tower and the cranes' boom. Eventually the blade swung free of the cable (due to some very skilled operation by Mr. Irvin) and the erection of tower #2 was completed just after dark.

On 11/11/99 tower #3 was ready to hoist, with the turbine attached, the wiring run and the blades attached, when the hitherto fore, moderate, 25 mph wind gusted up to 45-55 mph. The workers and the crane were well involved with the erection at this point and decided to attempt the job in the high wind. Although the high winds tossed the tower significantly, once again Mr. Irvin's substantial skills with the crane, and a bit of good luck allowed the tower to be erected and bolted down within 15 minutes. Over the next half hour the winds rose to 65-80 mph and any further erection work on turbine #4 became impractical.

Tower #4 was erected late morning on 11/12/99 after a night of drizzling rain. The 4" mud layer at the site made positioning the crane difficult due to poor traction. Tower #4 was 80' long with the 20' base section already bolted to the foundation. This meant that the workers had to join the tower sections together at a height of 20' in the air. This proved to be tricky and the erection took about 6 hours.

Over the next three days, each nut/bolt on the towers was torqued and capped with a "pal" nut, to prevent loosening from vibration. A single missing piece of angle iron and two incorrectly sized winch U-bolts were shipped to the site by Bergey and were in place by mid November.

Inverters

During the period that the towers were being torqued, the turbines were left in a "shorted" state to place reverse torque on the spinning rotors and keep them from free wheeling with no load. As the towers were readied the breakers were closed and the turbines were allowed to operate freely.

Initially, Siyeh received only one of four inverters from Trace Technologies in California. The remaining three inverters did not reach the site until January 19th, 2000. The single inverter was mounted on the wall and the wiring was completed in and around the building (see **Appendix 6**).

The working schematic of the wiring is shown as **Appendix 7**.

3. Performance

On December 10th Turbine #1 was put on-line. On January 21st, 2000 Turbines #2, #3 and #4 were on-line. The turbines have not actually accrued any significant run-time during the period of this report. They have, however, once or twice experienced winds over 100 mph and have been exposed to winds over 60 mph regularly. In the first month of operation there have been only three days when the rotors did not spin.

Problems Encountered

The furling mechanism for turbine #4 is not functioning correctly. It appears that the damper on the tail section boom is sticking and will not allow the tail to furl freely during high winds. Bergey has promised to help correct this problem. As an interim measure,

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the winch is tensioned to assist the tail in furling and consequently, the tail sits at a slight angle even in normal operation.

There have been a number of problems with the Trace inverters, which are being corrected by Trace at the time of this writing. Specifically, the inverters "fault" out and generation is halted until the units are reset. The most frequent of the faults is "GenFuseFault" Fault #60 or #61. There was one time when the inverter tripped due to "Line Over Voltage" fault, presumably due to the utility grid voltage exceeding the maximum of the inverters nominal margin.

The local utility manager was disturbed by the installation and ordered his engineer to check out the system and the hook-up to make sure there was no danger to line men working on their line in a power outage. The engineer reported back to his manager approving the installation and the hook-up. His report is included as **Appendix 8**.

4. Conclusion

The facility is up and running even in the face of the Montana winter. The project has been a source of great excitement around the local and statewide community and was the lead story on KRTV evening news shortly before Christmas 1999. Three newspaper articles were inspired as a result of the highly visible new project, two locally in the Glacier Reporter and one, which received statewide attention, in the Great Falls Tribune. These will be included in Quarterly Report #2.

At this point, Tasks I – VIII, of XII in the proposed statement-of-work (SOW) schedule have been completed, with the exception of the installation of the data acquisition system.

The next steps are:

- To design and install a data acquisition system which will efficiently monitor the site conditions and the generation system
- Work to refine the operation of the Trace inverters
- Work with Bergey to repair the furling mechanism on turbine #4

It is anticipated that these tasks will be accomplished by the time of the 2nd quarterly report.

Appendix 1 - MS Project 98 fold-out

1999-2002 DOE Field verification Supplemental power for the town of Bl

program for small wind turbines
owning Waste water treatment facility

Rolled Up Progress External Tasks Split Project Summary

Appendix 2 - Site layout drawing of Browning Sewer Lagoon

[illegible]

APPENDIX

Appendix 3 - Engineers Estimate for Electrical wiring

Engineers Estimate for Electrical wiring					
	Aerator Wiring				
Item	Description	Quantity	Unit	Unit Price	Total Price
1	#4, THWN Conductor (includes connectors)	29700	LF		
2	2-1/2", Schedule 40 Conduit	2200	LF		
3	2-1/2" Schedule 40 fittings	1	EA		
4	Misc. Connections	1	EA		
	Total Estimate				
	Wind Turbine Wiring				
Item	Description	Quantity	Unit	Unit Price	Total Price
1	#8 Bare Copper Wire	1600	LF		
2	#2/0 THWN Conductor	9500	LF		
3	#8 THWN Conductor	300	LF		
4	Misc. Electrical Connections	1	EA		
5	2-1/2" Schedule 40 Conduit	1200	LF		
6	2-1/2" Schedule 40 Fittings	1	EA		
7	3-1/2" Schedule 40 Conduit	750	LF		
8	3-1/2" Schedule 40 Fittings	1	EA		
	Total Estimate				

Appendix 4 – Rohn Tower Foundation Drawings.

GENERAL NOTES

TOWER LEG
 DRAIN HOLE
 DRAINAGE
 SECTION OF ALL TOWER
 ADJUSTING NUT
 CONCRETE
 GRAUT
 BASE
 ALLOW FOR DRAINAGE
 COUNTING DRAINAGE
 DETAILS

CONCRETE QUANTITIES SHOWN ARE FOR THREE PIERS

• THE STRESS AND SHEAR VALUES ARE FOR ONE LEG

Unarco-Rohn
ALTERNATE FOUNDATIONS
HEAVY DUTY S.S.V. WIND GEN. TOWERS

0830157

Appendix 5 - Quality Assurance Document for Concrete Work

Quality Assurance Document

The purpose of the following signed document is to assure that all specifications that are required in engineered systems are adhered to and given the highest level of attention by contractors working under SIYEH Corporation.

In the event of a failure of the contracted portion of the job, it may be determined that contractors who did not follow all engineering specifications, are responsible legally for damages.

CRITICAL SPECIFICATIONS: (from drawings)

- Re-bar: #7 bars on 12" center each way, with 16" laps staggered 180 degrees
- Concrete, 3,000 psi minimum, ultimate strength @ 28 dry
- Three (3) cores will be poured at time of foundation pour.
- Anchor bolts hung from level template, with base plates on each set of four (4), with one additional dry-day before template removal.

I understand the above stipulated engineering specifications and assure complete compliance in all work conducted in the four (4) Wind Turbine foundations at the Browning Sewer Lagoon.

SIGNED: _____

DATE: _____

TITLE: _____

WITNESS: _____, SIYEH CORPORATION

Appendix 6 – Site Drawing Blow-up of Building and Wiring

Appendix 7 – Schematic of inverter-to-grid wiring

480/277 Service

**Appendix 8 – Glacier Electric Coop Engineers Review and Report of
the Project**

*The Interconnection
Of
Wind Generating Facilities
To
The Utility Grid*

*By:
Jasen R. Bronec
Glacier Electric Cooperative*

The Interconnection of Wind Generating Facilities to the Utility Grid

A. Overview

This is an investigation into equipment and functionality of the wind turbines installed at the Browning Lagoon by Siyeh Development Corporation. The report will cover concerns that regard personnel safety, power quality, equipment protection, and the interconnection to the utility grid. The equipment being used consists of wind turbine generators and power inverters. Bergey Windpower Company and Trace Technologies are the manufactures of the equipment. All equipment is designed to meet all IEEE standards and have been tested according to Underwriters Laboratories UL1741.

B. Purpose

The purpose of this Document is to produce valuable information about grid connected wind generating facilities of less than 50 kW. The recommended practices discussed in this article will help everyone understand operational issues and overall safety.

C. References

UL Subject 1741, May, 1999, Standard for Static Inverters and Charge Controllers for use in Photovoltaic Power Systems.

IEEE std P929, Draft 11, Recommended Practices for Utility Interface of PV Systems.

Bergey Windpower Company, BWC Excel-S Windpower Generator, Owner's Manual and Parts List.

Trace Technologies, Model BWT-10240, Operation and Maintenance Manual for the 10 kW Grid-Tied Wind Turbine Inverter.

D. Main Report

1. Equipment

Siyeh Development Corporation is using equipment that is produced by Trace Technologies and Bergey Windpower Company. The wind turbine is a product of Bergey Windpower Company. The Model BWC Excel-S is a permanent magnetic alternating wind power generator. The wind turbine has a rated power output of 10 kW and will withstand a maximum wind speed of 120 mph. The electrical output is in the form of 240 VAC at 60 Hz single phase.

The inverter is supplied by Trace Technologies. The Model BWT-10240 is a 10 kW grid tied inverter. It utilizes advanced power electronics to allow the interface of a BWC-Excel-S wind turbine with a utility grid. The inverter is a highly integrated assembly, consisting of an inverter bridge and associated control electronics all on a single board. The control software provides for complete overall system control with a variety of protective and safety features.

The inverter controls the output of the wind turbine through the use of electromechanical components, electronic DC choppers, converters, digital filters, and transformers. The wind turbine generator ties directly to the input fuses, which then connect to the input AC contactor. The three phase variable voltage, variable frequency power, is then converted to DC by the bridge rectifier. A DC chopper circuit controls the current level through the DC bus. The output DC bus voltage is maintained at a constant level with the grid voltage through the inverter IGBT's, or high frequency power switches. The inverter controller then manages the transfer of power between the DC bus and the utility grid.

2. Safety

Abnormal conditions can arise on the utility system that require a response from the connected generation system. This response is to insure the safety of utility line personnel and the system operators. Also, considerations must be made for the protection of the existing equipment and the generation system. This section will address the functionality of the protective equipment as well as the hardware recommended for personnel safety. It also must be noted, the Model BWT-10240 has met the standards of the UL 1741. The UL 1741 is a document prepared by Underwriters Laboratories that contains safety tests that confirm the existence of an anti-islanding scheme.

Islanding is a condition in which a portion of the utility system, which contains both load and distributed resources, is isolated from the remainder of the utility system and continues to operate. The Model BWT-10240 has anti-islanding features that insure that the inverter ceases to energize the utility line when the inverter is subject to islanding conditions. The vast majority of potential

islanding situations are protected against by voltage and frequency detection schemes. However, circumstances may exist on a line section which has been isolated from the utility and which contains a balance of load and generation that would allow continued operation. This would require a load to generation balance such that both frequency and voltage remain inside the trip limits. Although such a load balance is perceived as a low possibility, the potential impact is great enough that this islanding effect has been the subject of numerous studies. For this reason, developments have been made in active control techniques that have proven to be reliable in detecting potential islanding, as well as a method to determine if an adequate anti-islanding scheme is operational in an inverter. It is recommended that a utility wishing to ensure against islanding effects should require the use of a non-islanding inverter.

A non-islanding inverter will cease to energize the utility line in 10 cycles, 0.1667 seconds, or less when subject to a typical islanded load in either of the following two cases. First, there is at least 50% mismatch in real power load to inverter output. Second, the islanded load power factor is less than 0.95 leading or lagging. If the real power generation to load match is within 50% and the islanding load power factor is greater than .95, then a non-islanding inverter will cease to energize the utility line within 2 seconds whenever the connected line has a quality factor of 2.5 or less.

Disconnect switches are an integral part of any grid connected generation facility. These switches provide isolation points commonly required for safe work practices. The National Electrical Code dictates the requirements for disconnect devices that allow for safe operation and maintenance of the electrical power system within buildings and structures. The following will deal with disconnect switches that can be required to ensure safe work practices for the portion of the electrical power system associated with the electrical utility to which the wind generation system is interconnected. These following issues are not addressed in the National Electrical Code.

As in the National Electrical Code, all utilities have established practices and procedures that have ensured safe operation of the electrical power system under all conditions. All of these procedures should identify methods that ensure that the electrical system has been properly configured to provide safe working conditions for utility line and service personnel.

To uphold the utility safety procedures it is a general practice that a lockable, visible isolating load break device be provided for each source of electrical energy which is electrically connected to the utility's electrical system. These isolation devices are used to provide visible isolation of the electrical power source from the utility's electrical system. Two situations exist where utilities may choose not to require a utility interface disconnect switch. First, if a utility has operating procedures that do not require such a switch for utility interconnected generation systems, or second, if a certified non-islanding inverter is used.

There may be other non-technical or business related reasons to install a disconnect switch. For example, a utility might have contract requirements that specify a lockable, outdoor accessible, load break disconnect switch to allow the generation system to be locked out of service in the case of default on contract requirements.

3. Power Quality

Power Quality is a major issue. The quality of power provided by the wind generation system for the on-site loads and for delivery to the utility is governed by practices and standards addressing voltage, flicker, frequency and wave distortion. Deviation from these standards represents abnormal conditions and may require that the inverter cease to energize the utility line. Underwriters Laboratories, UL Subject 1741, contains tests to confirm that the Model BWT-10240 inverter meets recommended conditions for power quality. All power quality parameters (voltage, frequency, wave distortion) are specified at the point of common coupling unless otherwise stated.

Utility interconnected wind generation systems do not regulate voltage, they inject current onto the utility's line. Therefore, the voltage operating range for the inverter is selected as a protection function that responds to abnormal utility conditions, not as a voltage regulation function. It should be noted that a large quantity of this current injection has the potential for impacting utility voltage. As long as the magnitude of current injection on a utility line remains less than the load on that line, the utility's voltage regulation devices will continue to operate normally. If a situation arises where the current injection by a wind generator on a utility line exceeds the load on that line, then corrective action is required. The reason for this is that the voltage regulation devices do not normally have directional current sensing capability.

Generation systems of 10 kW capacity or less should be capable of operating within the voltage limits normally experienced on utility distribution lines. It is in the interest of the utility and the system owner that the voltage operating window be selected in a manner that minimizes nuisance tripping. The recommended operating window is 106 to 132 volts on a 120 volt base. That is, 88% to 110% of nominal voltage. This results in trip points at 105 volts and 133 volts. This recommended operating window states that the inverter ceases to energize the utility lines whenever the voltage at the point of common coupling deviates from the allowable voltage operating range.

The issue of the amount of voltage flicker is subjective to the generation owner and the utility's standards. Any voltage flicker resulting from the connection of the inverter to the utility at the point of common coupling should not exceed the limits defined by the Maximum Borderline of Irritation Curve identified in IEEE 519. This requirement is necessary to minimize the adverse effects to other customers on the utility system.

The power grid controls system frequency, and the wind generation system shall operate in synchronism with the grid. Small generation systems installed in North America should have a fixed operating range of 59.3 to 60.5 Hz. The Model BWT-10240 has a nominal line frequency of 59.5 to 60.5 Hz. Utilities may require adjustable operating frequency settings for systems larger than 10 kW.

The inverter waveform output should have low current distortion levels to insure that no adverse effects are caused to other equipment connected to the utility system. The IEEE 519 Standard should be used to define the acceptable distortion levels. The basic requirements of this standard are that the total harmonic current distortion shall be less than 5% of the fundamental frequency current at rated inverter output. In the case of the Model BWT-10240 the harmonic distortion is rated at 2.1%.

The wind generation system should operate at a power factor greater than 0.85 lagging or leading when output is greater than 10% of rating. The Model BWT-10240 operates at a power factor of 0.98 to 1 lagging or leading. Like the Model BWT-10240 most inverters designed for utility interconnected service operate close to unity power factor. Inverters may have small deviations from a unity power factor due to output filters, transformers, and other components used in the inverter.

4. Equipment Protection

The response of an inverter and its controls to fault conditions on the system of the interconnected utility depends on what the inverter sees as terminal voltage and apparent load impedance during the fault. The voltage and apparent impedance, in turn, depend on the type of fault and which phase or phases are involved. The voltage and impedance seen may change drastically when the utility's substation breaker or feeder recloser opens to clear the fault. When the fault initially occurs, the voltage of the faulted phase or phases drops to a low value at the location of the fault. The utility substation delivers high levels of fault current down the feeder to the fault. Any current contribution to the fault by the inverter is negligible compared to the utility short circuit current. The detection of faults by the inverter is a function of the inverters control response to undervoltage conditions. Depending on the settings of the inverter controls, the unit will disconnect either before or shortly after the utility substation breaker opens.

The most difficult faults to detect from the secondary side with three phase inverters are primary single phase to ground faults when the distribution transformers serving the inverter is not a wye-ground/wye-ground connection.

However, detection of these faults is more positive than detection of faults on the non-involved phases of single phase inverters because there is some voltage drop for any faulted primary phase. For any ground fault which cannot be detected by under or over voltage protection, reliance must be placed on the inverter anti-islanding scheme.

A final safety note is that when a utility interconnected inverter shuts down or trips, what actually happens is the inverter ceases to energize the utility line. The inverter does not completely disconnect from the utility, nor does it completely turn off. The inverter controls remain active and a connection to the utility is maintained so that the inverter may continue sensing utility conditions. The power producing wires may or may not be disconnected, but there is always some connection maintained to allow the inverter to monitor utility conditions for the reconnect feature. This maintained connection and continued sensing of the utility is necessary to allow the inverter to return to normal operation once the utility service has been restored to normal operating conditions for a minimum of five minutes.

The use of protection controls in inverters is used to reduce cost and increase the reliability of protection systems. With these controls, any failures will result in an inoperative inverter, rather than an inverter which continues to operate without protection.

E. Conclusion

In conclusion, it must be noted that the Model BWT-10240 inverter and the BWC Excel-S wind turbine have satisfied the requirements of the Underwriters Laboratories testing. The UL standard to which the inverter was tested is UL1741, which includes certification to IEEE 519 and IEEE 929 standards. The safety standards include automatic disconnect and shutdown during grid outage, and during periods of low or high grid voltage or frequency. The inverter requires grid power to operate and is not power by the wind turbine.

Even though the situation exists that a utility disconnect switch is not required because the inverter is a non-islanding inverter, it is recommended that a manual, lockable disconnect switch is installed where it can be accessible to utility workers. This recommended standard would serve as a second line of defense against the wind turbine energizing the utility line.

Another issue is the injection of current onto the utility line. As long as the current injection is less than the load the voltage regulation device will remain operating normal. It is recommended that regulating devices be monitored for abnormal operation. If abnormal regulator operation is observed then alternative methods need to be used to limit current injection.

APPENDIX

It is also recommended that the transformer bank be connected in a wye-ground/wye-ground configuration for easier detection of faults on the line.

The final recommendation is to use a power quality monitor to monitor the output of the power system. The use of a power quality monitor will allow the utility to verify that the generation system is operating within the allowable standards.