ABSTRACT

The primary objective of this project was to determine the “best-fit” industrial grade wind energy unit currently available to convert residual air flow from coal mine exhaust fans to electrical energy. Additional objectives included documentation of actual residual air flow velocity from typical coal mine exhaust fans, determination of “turn-key” unit installation costs, and estimation of electrical energy output.

The “best-fit” unit, to date, is TMA’s Savonius-type vertical turbine at an installed cost of approximately $250,000. Two wind troughs, attached to a vertical shaft, capture residual air flow from the mine fan. This vertical shaft is attached to a generator. The unit is rated at 45% efficiency. It is ground-based for maintenance ease, and is designed for a twenty-plus year service life.

Residual air flow was measured from two mine exhaust fans at Peabody Energy’s Willow Lake Mine in Saline County, Illinois. Each 700 horsepower Jeffrey fan, model number 88U108-58, at nominal 500,000 cubic feet per minute, 885-rpm, and fifteen-foot diameter evase, produced sufficient air velocity to operate an industrial sized wind energy unit.

Air velocity at 20 feet beyond the fan evase averaged 36.5 mph. At 60 feet from the evase, air velocity averaged 13.9 mph. Thus, a 50-kw wind unit set approximately 25 feet from the evase would produce approximately 1,200 kw/day, or 438,000 kw/year of emission-free electrical energy. That is almost $22,000 in revenue a year at 95% availability and $0.05/kwh. Without any state or federal grants, tax incentives, renewable energy credits or carbon credits, the payback would be approximately 11.5 years.

A wind energy unit in the open air stream path beyond the fan discharge will create resistance. At issue is whether or not this resistance would cause back pressure at the exhaust fan. A wind unit placed immediately at the evase would cause the fan to draw more electrical energy to overcome this resistance. However, in the open atmosphere, 20 to 30 feet out from the evase, back pressure could easily release to the sides and overhead before stacking back to the fan. Additional research is needed to resolve this question.
EXECUTIVE SUMMARY

Sustained air velocities of 30+ mph from Illinois’ underground coal mine exhaust ventilation fan discharges are available for conversion to electrical energy. This residual energy source, a “by-product” of mine ventilation, can be efficiently harnessed with a carefully selected wind energy unit compatible with mine site environments. The “best-fit” unit found to date is TMA Global Wind Energy System’s vertical turbine unit. This industrial quality ground-level unit is very efficient (up to 45%) when the wind source is from one constant direction.

Air velocity measurements were taken 20 feet through 60 feet beyond the evase of an operating 700 hp Jeffrey exhaust fan at a southern Illinois underground mine. At 20 feet, and in the center of the exhaust air stream, 36.5 mph air flow was measured. Additional measurements were: at 30 ft – 27.1 mph, at 40 ft – 26.4 mph, at 50 ft – 20.3 mph, and at 60 ft – 13.9 mph. Measured wind speeds decline in a basically linear trend. This is “better” wind for electrical energy production than what is available almost anywhere in the country. It is of high uniform speed, sustained (24-7 x 365 days for the life of the mine), and heavy (high relative humidity). This wind source is also within immediate access to the electrical grid at most mines, and always located on an existing site permitted by the state.

A 50-kw wind energy unit could operate continuously at 25 feet from the fan’s evase. At $0.05/kwh and 95% availability, close to $22,000 of electrical energy could be generated each year from one unit. An installed wind energy unit of this size would cost between $220,000 and $300,000 with a payback between 10 and 14 years. With state and/or federal grants, tax incentives, renewable energy credits and carbon credits, the cost and payback would be considerably less.

The Illinois Department of Natural Resources’ Office of Mines and Mineral Land Reclamation Division would be the official permitting agency. An “Insignificant Mine Plan Change” request would be required to be approved. The request would include certain construction and operation details, a site location map, and a reclamation bond to cover full dismantling costs. Based on discussions with the U.S. Department of Labor’s Mine Safety and Health Administration (MSHA), they would not approve, or disapprove, the installation of a wind unit at a mine site. However, the unit would have to meet all of MSHA’s safety and health standards.

A wind energy unit in the open air stream path beyond the fan discharge will create resistance. Although the “best fit” wind unit is a high flow-through unit, the question is whether or not some resistance would cause back pressure at the exhaust fan. If the wind unit was placed immediately at the evase, the fan would have to draw more electrical energy to overcome this resistance. However, in the open atmosphere, 20 to 30 feet out from the evase, most, if not all, back pressure would tend to release to the sides and overhead before stacking back to the fan. A wind unit would not likely add any more resistance than is created by soil berms, or walled structures, regularly used to reduce fan noise. Additional research is needed to resolve this question.
OBJECTIVES

The overall objective was to make a compelling case for energy conservation at Illinois coal mines by converting discharged coal mine exhaust air into useful/valuable emission-free electrical energy. Significant wind energy is present in the residual air flow immediately beyond the discharge of mine exhaust fans. This energy source is a by-product of the mine ventilation process, which maintains safe oxygen levels for underground miners and continually sweeps methane gas out of the mine. Once discharged at the mine fan evase, this by-product could be available for use.

The following efforts went in to accomplishing the above objective:

1. Determining wind energy installation costs and corresponding electrical energy production potential with an appropriately selected wind energy unit.

2. Measuring and documenting actual discharge air velocities at various distances from coal mine exhaust fans to provide a starting point for application consideration.

3. Regulatory review of the project concept to stay on a course that would avoid future approval issues. This included safety and environmental reviews.

4. Developing public acceptance of the project concept. “Good neighbor” issues regarding possible visual and noise concerns were considered in unit selection to minimize or avoid such concerns.

5. Developing mine operator acceptance of the project concept. Mine operations are typically single-purpose businesses focused on producing coal. Additional responsibilities to accommodate new and unique enterprises can be a distraction from regular production duties.

6. Developing private contractor interest in constructing and installing wind energy units at coal mine sites.

INTRODUCTION AND BACKGROUND

Wind energy technology has advanced at a tremendous rate over the last two decades. Electrical generation efficiencies now approach 50% in top-of-line units. Three additional essential elements must be available for a successful wind energy program: sufficient wind, accessible electrical grid (for inter-connect), and site approval.

All of these essential elements are available at underground coal mines. Large exhaust fans pull fresh air into the mine to provide clean air to miners and to remove methane gas. Air discharge velocities are sustained at high rates, the mine electrical grid is very accessible, and the site is already permitted. This tight composite of essential elements offers more than the sum of its individual parts – emission free electrical energy.
The air flow from underground mine exhaust fans contains residual energy beyond its immediate release to the natural atmosphere. Discharged air flow measured 36.5 mph at a distance of 20 feet from the evase of a 700 horsepower exhaust fan at an underground mine in southern Illinois. Air flow 60 feet out from that same evase was 13.6 mph. The principal investigator postulates that within that 40 foot distance (20-60 feet), a select wind energy unit would operate efficiently at little or no impact to the exhaust fan and mine ventilation. High efficiency, ground-level, vertical turbine wind units are ideally suited to convert this sustained wind energy source from mine exhaust fan discharges. TMA Global Wind Energy Systems offered the “best-fit” vertical turbine unit suitable for the Illinois underground mine environment. This particular unit is rated at 45% efficiency and is designed with industrial grade materials and components to provide a 20+ year service life with very low maintenance.

A special feature that sets the TMA unit even further above other vertical turbine units, for this application, is the airfoil-shaped support wall which sits in the air flow stream. Air flow increases through the unit, improving unit efficiency. The TMA vertical turbine is designed specifically for single direction air flow, another unique feature that matches well with mine exhaust fan discharge air flow.

Another special feature of the TMA unit is its high flow-through design. Air flow not only pushes the two wind troughs, but also pulls the backside of each trough for added efficiency. The high flow-through rate also reduces the concern of discharge resistance (back pressure).

EXPERIMENTAL PROCEDURES

Measurements of actual wind speeds directly within the air stream exiting a typical underground mine exhaust fan were needed to establish that sufficient air velocities are present to operate a wind generation unit. Management at Peabody Energy’s Willow Lake Mine provided access to measure discharge air from two 700 hp Jeffery exhaust fans as shown in Figure 1.

Wind speed, relative humidity and air temperature were measured with a calibrated Kestrel anemometer, model 4500, as shown in Figure 2. The anemometer was elevated approximately 86 inches above ground level within the center of the air discharge path. Wind speed measurements were recorded beginning at 20 feet from the fan evase. Additional measurements were recorded in 10-ft intervals, stopping at 60 feet from the evase, within the downstream exhaust air flow path.
Figure 1. Data collection site at Willow Lake Mine’s South Jeffrey exhaust fan.

Figure 2. Kestrel model 4500 anemometer.
RESULTS AND DISCUSSION

Task 1: Measure and document available wind speeds and relative humidity at various distances from the mouth of different sized exhaust fan outlets typically used at Illinois underground coal mine operations.

Wind speed was measured with a Kestrel 4500 calibrated anemometer held at approximately 86 inches (7’2’’) above ground level in the direct path of air flow from two 700 horsepower Jeffrey mine exhaust fan at an underground mine in southern Illinois.

The first fan operated at a nominal 500,000 cubic feet/minute (cfm). Air flow at 20 feet from the fan’s evase was 36.5 mph, 27.1 mph at 30 feet, 26.4 mph at 40 feet, 20.3 mph at 50 feet, and 13.9 mph at 60 feet, as shown in Figure 3.

Air velocity measurements were also taken from a second identical fan with a nominal 425,000 cfm flow at the same distances. At 20 feet from the evase, 21.8 mph flow was measured, 17.3 mph at 30 feet, 9.9 mph at 40 feet, 7.2 mph at 50 feet, and 4.8 mph at 60 feet, as shown in Figure 4.

In both instances, the descent in measured wind speed was basically linear.

Figure 3. Air velocity measurements for Willow Lake Mine’s South Jeffrey exhaust fan.
Task 2: Review and select initial “best fit” vertical axis wind turbines for the underground coal mine environment.

An extensive review of ground-level wind energy units was conducted to find the “best-fit” unit for the Illinois underground coal mine environment. Efficiency, safety, durability, installation ease, maintenance, low noise, ground resonance, communications interference, bird kills, mid-range air flows design, and air flow-through rate, were all considered in the selection process for a “best-fit” unit. Misapplication of an otherwise good unit would seriously hurt, or even derail, this initial effort.

TMA Global Wind Energy Systems has recently developed a ground level wind generator that meets all desired parameters listed above. This particular unit is available at various rated capacities for various anticipated wind speeds. Figure 5 provides a comparison of the TMA Savonius-type vertical turbine with other conventional wind units. The TMA turbine offers substantial advantages over conventional propeller-style wind turbines as follows (TMA website):

- Greater efficiency provides a higher capacity factor at like prevailing wind speeds.
- Easier to operate and control in all aspects of operation and shut down procedures.
- Operates in high or gusting wind and icing conditions when prop turbines shut down the net result being a longer period of effective power production.
- Lower profile turbines that appear as buildings, creating less “visual pollution”.

Figure 4. Air velocity measurements for Willow Lake Mine’s North Jeffrey exhaust fan.
- No bird or bat kills resulting in better support from environmental groups and government agencies.
- Ease of maintenance and inspections at ground level on all major components as opposed to 250-300 feet in the air at the nacelle or hub height.
- Lower top speed ratio by almost seven times compared to props reducing speed, vibration, fatigue, static, flex and other load stress profiles.
- Reduced audible distortion (decibel rating) and audible resonance due to lower rotor speed and less cutting action of the turbine blades into the prevailing wind.
- No magnetic field interference at the hub height from the generators, therefore no interference with aircraft navigation or telecommunications.

Figure 5. Comparison of wind turbine performances (TMA website).

Various TMA turbines have been in operation for over eight years without causing any avian deaths. Pictures of the TMA turbine are not available due to patent issues but a construction site is shown in Figure 6. The design of the unit consists of three concrete support walls that direct air flow to the “sweet spot” of its two blades. Air speed increases as it moves around the primary air-foil shaped concrete wall. This creates an additional “pulling” effect on the back side of each blade, boosting efficiency. The high “flow-through” rate of the two-blade Savonius type unit produces more energy than the same unit with three or more blades. This may also diminish some of the anxiety of “back pressure” issues near the exhaust outlet of mine fans.

TMA wind turbine units for 25- through 75-kw generators use the same turbine and structural frame. This generator range fits the 10 to 35 mph air velocity range measured at 20 to 40 feet beyond the evase of the two mine exhaust fans. Larger framed turbine units and generators are available, in stages, for air velocities that exceed 50 mph air flow. The option to install the appropriate sized turbine/generator, for the various exhaust fans, was critical in the selection of the “best fit” vertical turbine unit.
Figure 6. TMA vertical wind turbine construction site (TMA website).

At the 20-foot distance from the evase of the first fan, a 50-kw TMA wind unit would generate approximately 1,200 kw/day. With an expected 95% availability, and a $0.05kwh rate, the unit would generate approximately $57,000/day rate equivalent, or $21,805.00/year. Unit installation cost would be approximately $250,000 for an 11.5 year payback, without any state or federal energy incentives, including tax incentives.

Task 3: Regulatory acceptance/recommendations.

The United States Department of Labor’s Mine Safety and Health Administration (MSHA) management personnel were advised of the project concept. Discussions were conducted from their West Virginia and Pennsylvania offices. They were open to the concept; however, approval would have to be on a case-by-case basis. Basically, installed wind energy units must meet all of MSHA’s safety standards.

Illinois Department of Natural Resources (IDNR), Office of Mines and Minerals, Division of Land Reclamation would be the official permitting agency. A wind energy unit at an Illinois mine site would be approved as an Insignificant Mine Plan Change, subject to standard reclamation bonding requirements. The IDNR was not aware of any other state agency that would be involved in the permitting process.

Task 4: Commitment of interested parties for future Illinois coal mine site demonstration project.

The president of Southeastern Illinois Electrical Cooperative reviewed the concept and was very interested, and the discussion was positive. Three coal mining executives, representing two companies with multiple operations in Illinois, indicated a strong interest in the concept of generating electrical energy from the residual air flow from mine exhaust fans.
CONCLUSIONS AND RECOMMENDATIONS

Sufficient residual air flow energy is available at a short distance beyond the typical mine exhaust fan discharge, at Illinois underground mines, to generate significant electrical energy. Commonly used soil berms and walled structures for mine exhaust fan noise control constitute similar resistances that a wind energy unit would exhibit. Subsequently, and especially for new mine construction, a wind energy unit could be installed with sound suppression walls to reduce fan noise and to produce emission free electrical energy.

Alternate/renewable energy incentives require additional research due to the tremendous changes now taking place in this area. State and federal incentives and funds for grants, and low-interest loans for such special projects, are in flux as these programs are being refined, consolidated and funded. Tax incentives and energy credits are also in the process of being modified and extended. Consequently, actual costs were used in this study with the tentative assumption that final costs, including the selected incentives, would likely be much less.

Additional research is needed to determine if air flow resistance through the selected high flow-through wind unit would create back pressure at the exhaust fan at various distances from the fan evase. Walls associated with the selected wind generating unit will dampen fan noise to some extent without modification. Additional research may be appropriate to determine how best to maximize noise dampening effects that could be incorporated in the wind generating unit to add more value to the installation.

REFERENCES

DISCLAIMER STATEMENT

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