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OPTIMIZATION OF ENERGY EFFICIENCY AND ENERGY SAVING POTENTIAL ENERGY USE FOR MINE VENTILATION FAN WITH ADAPTABLE SPEED DRIVE

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ABSTRACT

This paper presents the issue of maximum energy consumption of mine ventilation fan and proposes an optimization technique based control system that enhances the savings of energy, operating performance providing a healthy atmosphere for the miners. It utilizes particle swarm optimization (PSO) algorithm for the feedback speed control facilitating with variable speed drives (VSD) based on current status of airflow and air pressure in underground coal mines. It also utilizes the overlapping hour format to control energy use. The system is developed in MATLAB environment and the both steady and dynamic behavior of the system are tested successfully.

INTRODUCTION

As the energy consumption to operate a ventilation system is 25 to 50% of the total energy requirements of an underground coal mine, proper planning, redesign, implementation and maintenance are necessary to achieve energy saving in this potentially viable area. Many researchers all over the world are therefore busy with solution for optimizing the consumption of energy in ventilation system. In this paper, the energy saving possibilities is discussed from different angles and a survey of current research is presented particularly on potential for electrical energy cost saving by implementation of various new technologies/methods. Ventilation demand in coal mines may vary throughout the year and by designing/developing a good ventilation system can not only minimize the cost of energy for the fan but also try to create healthy environment in mine. A number of recent commercially available systems are also reviewed in the paper to get the proper understanding.

It is known that the industrial sector consumes about 37% of the world's total delivered energy, and out of this, the mining industry contributes about 9%. Mine ventilation is crucial for safety reasons, because it is responsible for clearing out noxious and flammable gasses; and also provides a comfortable working environment underground. The rating of the fans that provide ventilation, depending on its use, can range from 100 kW to about 3000 kW. Thus, contribution by the ventilation fans towards the total power consumption is quite significant. Research suggests that, depending on the type of mine, up to 40% of the total electricity used, and up to 60% of mining operating cost can be attributed to ventilation underground.

Existing studies on mine ventilation networks vary in objectives. Some consider making use of computer programmes in conjunction with survey data to model the changes in the structures of the ventilation network to achieve safe and economic solutions. These cases do not consider LM or EE in any way. Other studies are performed with the objective of running the ventilation system more efficiently to reduce costs, e.g., in a review is done at the beginning of every week to determine which levels will be inactive for the next week, such that the auxiliary fans in those levels can be switched off. This study considers EE but not by application of VSDs. Optimization techniques are sometimes employed, e.g., discuss the use of nonlinear programming methods to find the optimal flow rates in the branches such that the the rating of the fan, required to supply the network, is minimized; shows the use of genetic algorithms (GA) to decide on the optimum number, location, and size of booster fans/regulators in the network; makes use of mixed integer programming (MIP) to find the optimal angles of the auxiliary fan blades, in order to match the varying flow rates throughout the different stages in a mine. These studies are all performed with the objective of minimizing energy consumption and/or related costs, but there is no consideration for the TOU or the application of VSDs. The only studies that consider using VSDs to vary ventilation fan speeds in underground mining are presented. These studies explore the concept of ventilation on demand (VOD). The idea is to allow variable air flow by adjusting the speed of the fan over time (based on the demand), as opposed to running them at full capacity at all times. These studies perform EE measures, but there is no consideration for shifting load from peak times and the TOU tariff. Another limitation to those researches is that only auxiliary fans, instead of the main fan, are selected. This is done because changing the speed of the main fan will affect the entire network and is more complicated to control than the auxiliary fans.

The Motor Challenge program promotes a “Systems Approach” rather than a “Component Approach” when evaluating projects for energy efficiency. A systems approach takes into account all the elements from the point the power is supplied to the motor to the actual process work done. Savings opportunities exist at all places in the system, but not all of them are cost-effective.

Depending on the application, these savings may be realized by properly sizing and streamlining the fan systems, using premium energy efficient motors, using speed control wherever applicable, defining a proper control strategy and implementing measures that reduce air wastage. Energy efficiency projects can also lead to significant non- energy benefits such as better equipment reliability, longer equipment life, reduction in maintenance costs and downtime, and an improved working environment. Another benefit is a corresponding reduction in environmental emissions.

The main components of a mine ventilation system are:

- Power Supply
- Motor
- Coupling
- Fan
- Flow Control Devices
- Ducts, Passageways & other System Hardware

Power Supply: High voltage wires, transformers, switchgear and starters comprise the electrical hardware components. Most of the mining facilities receive the standard 3-phase industrial electricity from a local utility company. Associated with the electrical supply are three different types of charges: consumption charge (in $/kWh), peak demand charge (in $/kW), and a power factor penalty. The utility companies may also offer several combinations of rate schedules. Some mining facilities also generate their own electrical supply on site.

Motor: A motor converts the electrical input power into rotational mechanical output power; it has an efficiency associated with this conversion. The Energy Policy Act (EPACT) that came into effect in October 1997 requires most general purpose, polyphase, squirrel-cage, induction motors rated 0.75 kW (1 hp) through 150 kW (200hp) to meet minimum energy efficiency standards. Motors that have full load efficiency ratings higher than the prescribed EPACT standards are termed as energy efficient motors. The Consortium of Energy Efficiency (CEE) recognizes motors that meet a higher efficiency level than EPACT. These are termed as premium energy efficient motors. CEE works with its members, including a number of utility companies to provide incentives for purchasing these premium energy efficient motors.

Based on the load factor and the number of hours of operation, payback periods can vary significantly for replacement of standard motors by energy efficient models. Although the first cost of an energy efficient motor may be higher, the potential savings that can be gained accumulate rapidly over the life of the motor. On average, the initial cost of the motor operating in an industrial setting is probably 5- 10% of its overall life-cycle operating cost, so a decision based solely on first cost considerations is usually an expensive decision.

The DOE's Motor Challenge program has developed a software package called MotorMaster+ (DOE, 1998) that assists in motor systems management. The software has a built in database of over 17,500 motors manufactured in the US along with their load and efficiency characteristics, installation and rewind costs, etc. The software is menudriven, modular, and can be used for simple querying purposes as well as for more complicated batch analysis, etc. The software also includes tools for an economic analysis, an environmental energy accounting, conservation savings tracking, and greenhouse gas emissions reduction reporting.

Coupling: The coupling transmits the power from the drive shaft to the fan. For smaller sizes, a V-belt arrangement is frequently used. This has the advantage in that it is relatively easy to make fan speed changes if system requirements are different in the future. But belts have to be periodically tightened and adjusted to ensure proper alignment. Larger fans over 373 kW (500 hp) are almost always directly coupled with a gear or flexible disk type of coupling. For this arrangement, the fan speed is fixed to the motor speed. Other possible coupling arrangements are gearboxes and fluid couplings. Gearboxes have very little application to ventilation fans as they are more suited to high speed blowers. Fluid couplings are occasionally used on main ventilation fans and have the advantage of fan speed control.

Fan: Fans are classified into two main categories: centrifugal and axial-flow. Within each category there are many types, models, and arrangements. Centrifugal fans are further classified based on the curvature of the blades: radial, forward inclined, and backward inclined. Axial-flow fans can be further classified as tube-axial and vane-axial. Axial-flow fans are also classified by the impeller type: Fixed blades, Adjustable blades, and Variable-pitch-in-motion. Fan selection depends on the application and physical constraints of the site, and there are several handbooks and textbooks that provide this information (Bleier, 1998). Proper sizing and selection of a fan can lead to significant energy savings along with reduced maintenance costs and a longer life for the fan.

A mine can take years to be fully developed but the mine ventilation system is designed, built and installed up front. Clearly, the fan may be substantially oversized in the beginning, even if it is suitably matched to the fully developed mine requirements. For this scenario, the fan operating point may initially be far from its Best Efficiency Point (BEP).

Application - Main Exhaust Fan Cone Replacement

As part of an efficiency audit of a mine ventilation system, a main exhaust fan system was inspected and surveyed. The system consisted of two surface exhaust fans operating in parallel configuration. The fans were 2.1 m in diameter, with 0.8 m hub diameter. They had 261 kW motors installed operating at 1170 rpm. The fan assemblage was well designed, with acceptable resistance pressure losses. However, the fans were fitted with very inefficient cones. Figure 1 presents a simplified schematic of the fan installation. The fans were exhausting 189 m3 /s total. The cones were 1.5m long and 2.4 m in outlet diameter. The cone losses were estimated at 0.161 kPa. The fan velocity pressure including losses, was estimated at 0.41 kPa and the fan total pressure was estimated at 1.9 kPa. The operating power per fan was calculated at 230 kW. A simple retrofit, of just replacing the existing exhaust cones with more efficient cones was proposed. The proposed cones were 4.3 m long and 3.05 m in diameter. For the retrofit, and for the same flow, the cone losses were estimated at 0.149 kPa. The fan velocity pressure including losses, was estimated at 0.25 kPa and the fan total pressure was estimated at 1.74 kPa. The operating power per fan was determined at 211 kW. The total operating power savings are thus 38 kW and the annual savings in operating cost is $37,330 based on a power cost of $0.112/kWh. For an investment of $60,000 to construct and install the new cones, and with a discount rate of 10%, a Net Present Value analysis estimated a payback on year 2 and an Internal Rate of Return of 57.9%. This indicated a very attractive project, and it was successfully implemented by the mine.

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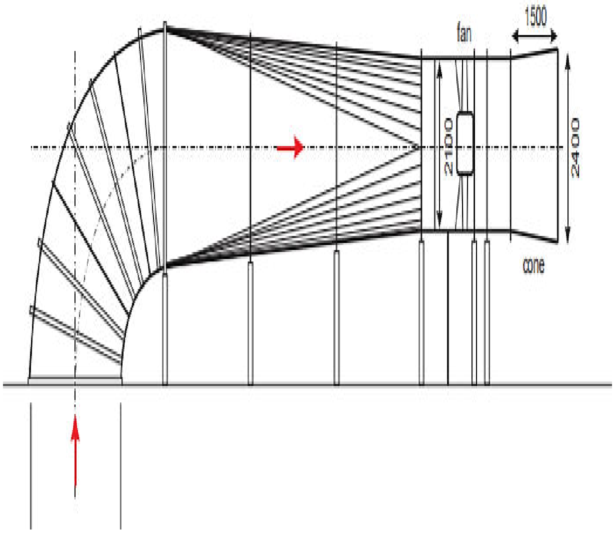

Main Exhaust Fan Installation Schematic

LITERATURE REVIEW

Mine ventilation systems have been designed, built and installed for years. The technology is well documented and textbooks and handbooks are readily available (Hartman, et al., 1997). The U.S. Bureau of Mines has also published bulletins on mine ventilating principles and practices (Kingery, 1960).

Since the energy cost in mines is a small fraction (less than 5%) of the overall production costs, less emphasis is given to energy efficiency than to production and maintenance. Also "pumping additional air than necessary doesn't hurt", has been the general mode of operation because mining has historically been an occupation with a relatively high-risk level to human health. However, recent energy trends and emission regulations have led the mining industry to look at more energy efficient technologies. Kumar, et al. (1995) discusses optimum fan selection in multiple fan networks to minimize power consumption. Ray (1995) highlights minimizing main mine fan duct pressure losses at a test site. With the advent of sophisticated computational capability, mine ventilation systems can now be modeled to determine optimum performance (Oberholzer & Meyer, 1995).

Internationally, energy consumption in the mining industry has been receiving renewed interest. A recent report showed that mining accounts for 22% of Canada's total industrial energy consumption (Jaccard & Willis, 1996). A study on Polish mines highlights monitoring and control of main fans for minimization of power consumption (Krzystanek & Wasilewski, 1995).

RESULTS AND DISCUSSION

In underground mine environment, the airflow and air pressure playa very important role. From the airflow and air pressure sensing signals, the motor speed can be selected with PSO program/algorithm. By considering this speed as a reference, the input power is optimized. On the way to show the optimum energy use ofthe motor /fan with optimal speeds effectively, the simulation was performed at different range of airflow and air pressure. Optimum speeds and power consumption at different air conditions are calculated and are shown in Table II. The

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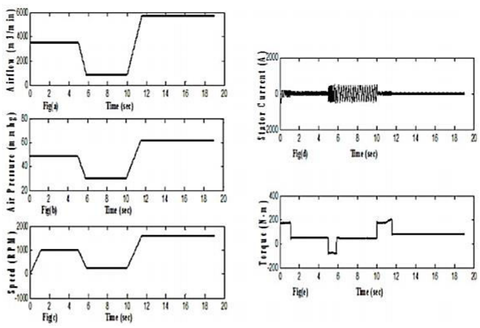
variable speed requirement can be catered through the use of suitable VSD.

Motor	Squirrel Cage Induction
Ventilation Fan	Auxiliary
Supply	3-phase
Voltage	400 V
Capacity	25 kW
Frequency	50 Hz
IGBT based VSI	300 V, 100 A
Speed	1500 rpm
No. of Poles	04

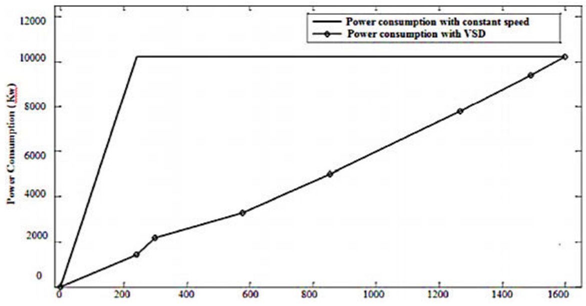
Motor specifications

Sl. No	Airflow (m^3/min)	Pressure (mmhg)	Optimal/ Reference Speed (RPM)	I/P power to the motor drive (W)
1	800	30	240	1432
2	900	35	269	1591
3	1000	40	299	2165
4	1500	43	439	2628
5	2000	45	578	3301
6	2500	47	716	4146
7	3000	48	855	5003
8	3500	49	999	5925
9	4000	50	1130	6806
10	4500	52	1268	7772
11	4700	54	1324	8200
12	5000	56	1407	8760
13	5300	58	1490	9407
14	5500	60	1545	9718
15	5700	62	1600	10219

Input power to the motor drive with optimum speed



Dynamic performance of mine ventilation fan/Motor



Power consumption of fan/motor in closed loop system with constant and variable speed

CONCLUSION

The study with the model proposed and developed in this paper can save a large amount of energy for the mine ventilation fan. The proposed system makes use of an adaptive control strategy for variable speed drive used for the fan through sensing of real-time parameters like airflow and airpressure and controlling the speed ofthe electric drive through PSG energy optimization technique. The use of overlapping hour speed control and online optimization control can make huge amount of energy savings in case of underground mines.

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