Variable Frequency Drives as Applied to Ventilation Systems

Cheryl L. Allen, P.Eng.
Chief Engineer - Ventilation
Vale Inco Ltd., Sudbury, Ontario, Canada

Robert Da Prat
Senior Account Manager
Rockwell Automation, North East Ontario

Abstract

The power required to operate a ventilation system can be 25% to 50% of the total energy requirements of the mine. In an effort to reduce energy consumption, initiatives are being introduced at Vale Inco to increase the efficiency of ventilation systems with the objectives of decreasing energy usage.

One energy conservation measure being introduced is the use of variable frequency drive (VFD) technology for fan motor control. Advancement in technology is making VFD applications more of a standard in industry. The benefits include improved operating performance and system control, reduction in current peak demand, and optimized power usage.

This paper describes the application of VFDs for main and auxiliary mine fans; and associated energy savings.

1 Introduction

Vale Inco Ltd. operates 6 base metal mines in the Sudbury, Ontario region; which vary in depth from 1200 meters to 2400 meters. Mining methods used are Sub-level Cave, Vertical Retreat Mining (VRM) and mechanized cut-and-fill. Costs associated with ventilating mines are increasing significantly as energy costs escalate and mines expand at depth. In an effort to reduce costs, various energy conservation projects are being carried out at Vale Inco mines. Developing a sustainable automation strategy that focuses on using minimal amounts of energy and resources falls within the Vale Inco values of endorsing the principle of sustainable development.

The purpose of a ventilation system in a mine is to provide a safe working environment by removing and diluting contaminants in the air. Mine fans, required to move the volumes of air, are normally controlled with across the line starters due to established standards, simplicity and low capital. These fans are commonly operated to supply the maximum airflow that would be required to an area at any time. The result is a large current draw from each motor at start-up and full time motor operation at 100% of rated speed. As there are hundreds of auxiliary fans and dozens of main fans in a typical system, managing the power of these two common occurrences can save energy. One initiative being implemented is Ventilation On Demand which requires the use of VFD starters on fans. This type of starter allows the electric motors to run at the speed necessary to supply the demand air volume; and maintain a smooth electrical current which allows control of peak demand charges. In summary, managing the demand results in energy savings.

2 VFD System Description

2.1 Motor

The motor used in a VFD application is normally a three-phase induction motor; which is more economical and suitable for most uses. Using the three-phase induction motor allows better performance in a VFD application.

2.2 Controller

A VFD converts 60 Hz power to a new frequency with a rectifier and inverter stage. The rectifier converts the 60 Hz power from standard (ie 575 volt) supply to DC voltage. The inverter stage is essentially electronic switches that turn the rectified DC on and off to produce a voltage waveform at the desired frequency; converting DC to variable frequency AC. The speed of an AC motor is controlled by varying the frequency supplied to the motor.

2.3 Operator Interface

The operator interface provides a means for diagnostic capability, to adjust the operating speed and start/ stop the device. The interface consists of key pads and display units for kW, Speed, status etc.

2.4 Operation

To start a device, the VFD applies a low frequency and voltage to the motor; which avoids a high inrush of current. From start to stop, the voltage applied to the motor is at a controlled rate through software features. In contrast, energy is wasted with an across the line controller as the initial start draws up to 600% of rated current while producing 50% of it's rated torque; and as the load accelerates, torque peaks while current stays very high until the motor gets to full speed. The ability of a VFD to balance, control and limit torque through software features reduces stress and wear on the motor (Rockwell, 2006).

3 Design

3.1 Rating

Units are classified as low or medium voltage drives. Low voltage is designed for use with motors rated at 0.2 kW (0.25 hp) to 375 kW (500 hp); medium voltage for greater than 600 kW (800 hp).

3.2 New Technology

Technology advances in variable frequency drive design have resulted in increased efficiency, reliability and decreased cost. With advanced computer technology, research has been allowed to focus on reducing drive system losses to gain these efficiency increases. Examples of this technology are Power optimizing features, Semi-conductor switches, Programmability, Communication software, regeneration and transformerless options. Semi-conductor technology has also allowed the drive design to be smaller and more reliable at a reduced cost (Ryerson University/Rockwell Automation).

Rockwell's Direct-to-Drive Technology (Rizzo, Wu. 2002), known as active front end technology has eliminated the need for isolation transformers in medium voltage drives. Transformers have windings making them less efficient, which carries into the drive system efficiency. This technology also allows savings on capital and site construction costs.

Typical component layouts for a surface and underground VFD are shown in figures 1 and 2 below.

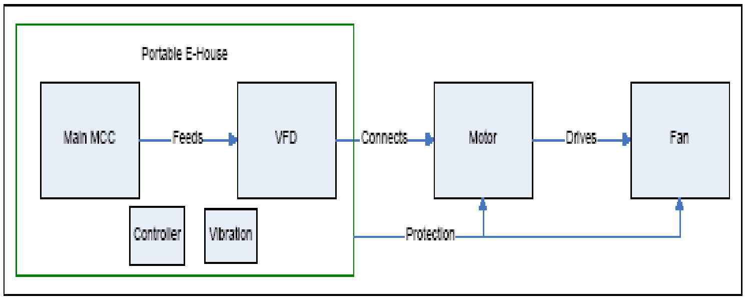

Figure 1. Surface Component Layout

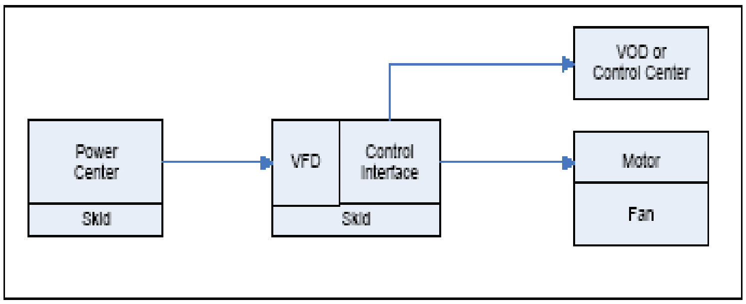

Figure 2. Underground Component Layout

4 Energy Saving Advantages

4.1 Peak Demand

When motors are started using across-the-line technology, an extreme peak of current draw, up to six times the Full Load Amps (FLA), is created. Using VFDs, the motor speed is gradually increased to reduce the current draw. As a result of reducing the spikes in current on fan start-up, the power usage is controlled; and events that create peak demand charges are averted.

Sites where connected loads are at feeder capacity would benefit from gradual ramping of motor speed by reducing power surges which cause brown out conditions.

4.2 Optimize Power Usage

It is common in hard rock mines that ventilation fans are controlled manually and operated 24 hours per day at maximum capacity. Opportunity exists for a decrease in energy consumption by managing the ventilation system to provide only the air required. For example, a diesel loader entering a particular area may require 100% of air volume, but a drill entering later in the cycle may require only 20% of the air volume.

Energy consumption in fan applications follows the fan laws which are a version of the similarity laws. These laws are used to predict the operating performance of a fan when variables are changed. The commonly used Fan Laws in equations 1, 2 and 3 (Howden Buffalo, 1999) demonstrate the relationship where flow is proportional to speed, pressure is proportional to the square of speed and horsepower is proportional to the cube of speed. For instance, reducing the speed of the fan motor 10 percent requires approximately 70 percent of the power; and reducing speed by 20 percent would require only 50 percent of the power.

$$\frac{Q_a}{Q_b} = \frac{N_a}{N_b} \qquad \text{where: } Q = \text{Flow},\ N = \text{Speed} \qquad (1)$$

$$\frac{p_a}{p_b} = \left[\frac{N_a}{N_b}\right]^2 \qquad \text{where: } p = \text{Pressure},\ N = \text{Speed} \qquad (2)$$

$$\frac{P_{ia}}{P_{ib}} = \left[\frac{N_a}{N_b}\right]^3 \qquad \text{where: } P = \text{Power},\ N = \text{Speed} \qquad (3)$$

With fixed speed motors, the power delivered does not decrease in proportion to the reduction in demand thus wasting energy when demand is reduced as demonstrated in Figure 3. In contrast, figure 4 shows the significant reduction in power requirement with reduced flow (Da Prat, 2006).

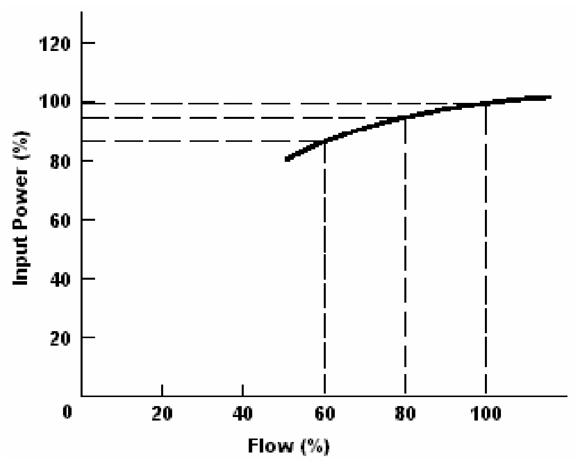

Figure 3. Fixed Speed Damper Control

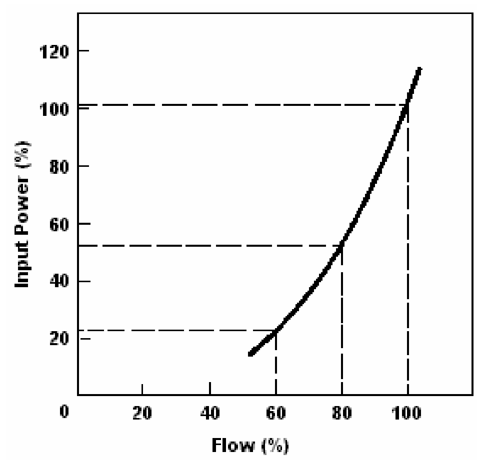

Figure 4. VFD Control

In 2001, Creighton Mine installed new centrifugal fans (3 in parallel) with variable frequency drives as part of a ventilation system upgrade. To prevent interruption of mine production, two fans carried the load while the third fan was being replaced. This situation allowed an opportunity to measure the performance of a VFD controlled fan to that of a fixed speed, damper controlled fan. All fans were controlled to produce the same volume and pressure. Table 1 shows the comparison between the two methods of fan control and the resultant energy savings (O'Connor, Da Prat. 2001); while Table 2 provides recorded performance data from the completed installation.

Table 1. VFD vs damper control

	Damper Control	Variable Speed
CFM	400,000	400,000
Motor HP & % Speed	2250 HP / 100%	3250 HP /80%
KWh per hour	2012	1556
Hours per month	X 720	X 720
Total kWh / month	1,448,640	1,120,320
KWh X $.07	$ 101,404	$ 78,422

Table 2. Actual kWh - VFD control

Vale Inco Creighton Mine 3250 HP Motor 717 RPM			
Centrifugal Fan 4160 V			
Speed %	100%	72%	50%
Speed RPM	717	516	400
AMPS	414	175	80
kW per Hour	2423	1025	485
Hours per month	720	720	720
Total kWH / month	1744560	738000	349200
kWH/ $.07	$ 122,119.20	$ 51,660.00	$ 24,444.00

Energy savings can be realized from simply using a VFD starter in place of an across-the-line starter. The fan blades can be set such that full performance requirements are met at 5% to 10% reduced motor speed; which equates to a 90% to 70% power reduction. Studies have shown that the demand profile for Creighton mine's primary system requires maximum capacity for only 56% of the time leaving 44% for reduced output levels. The auxiliary ventilation system was also shown to require maximum flow for 20% of the time with 80% for reduced output (Hardcastle, O'Connor. 2005).

5 Selecting a Drive

5.1 Packaged Systems

One option for installation of a VFD system is a portable packaged solution. These systems are fabricated off-site, made to suite the customer requirements and are ready for operation once input and output power connections are made. Figures 7, 8 and 9 show recent installations and designs of portable packaged solutions installed in Sudbury.

Figure 7. Vale Inco Coleman #2 Shaft 2x3500 hp

Figure 8. Xstrata Nickel Rim 3x5000 hp

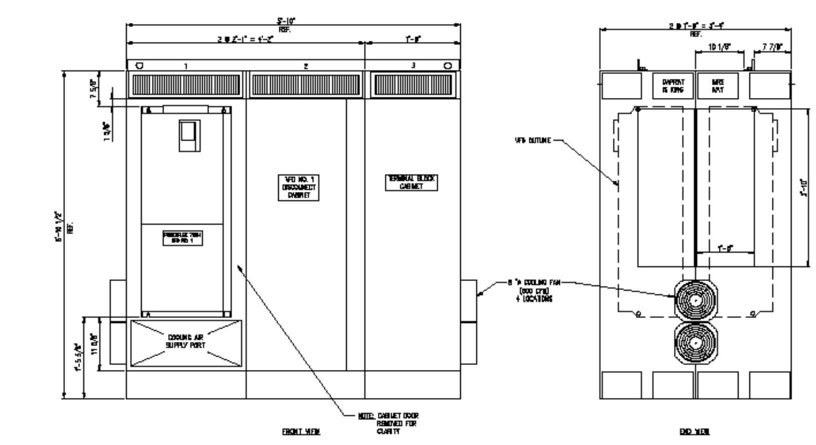

Figure 9. Underground Modular Skid for Auxiliary Fans

5.2 New or Retro-fit

The VFD solution varies per application; and has many considerations before selection. The peak torque requirements and operating speed range based on the required operating points of the fan must be known. The operating location of the system (ie surface, underground) and operating ambient temperatures must also be identified. Motor selection is critical to the successful operation of a VFD drive; and must be based on load calculations of the fan. Once this information is identified, a VFD can be selected to properly power the motor (B Da Prat 2006). It is considered best practice to select a drive that is 150% of FLA. Capital savings can be realized with retro fit installations by taking advantage of existing equipment rooms, motors, switches and communication systems.

5.3 Maintenance

Lower operating speeds mean longer motor bearing life. Reduced inrush current and voltage drop put less stress on the motor resulting in longer motor life. To demonstrate the stress that is induced to motor windings with across-the-line starts, the limit of start/stops is 2 times for cold and one time per hour for hot; while with VFD there can be infinite start/stops per hour.

6 Applications

6.1 Ventilation On Demand (VOD)

Mining companies are currently faced with challenges of economic downturn and volatile commodity prices. Despite these challenges, the most innovative mining companies are looking at implementing strategies which can accomplish the following goals:

- Increase productivity
- Increase profitability
- Reduce operating costs
- Ensure overall health and safety in the workplace

In order to achieve these results, companies must invest wisely in products which will have a significant impact on these key business metrics. In the pursuit of reducing operating costs, Vale Inco has been the industry leader in the application of VFD drives to control main surface fans, underground booster fans and auxiliary vent fans. VFDs are key components to the Ventilation On Demand (VOD) System being designed by the BESTECH lead consortium for which Vale Inco is the founding mining host consortium member.

BESTECH's approach to VOD is based on providing the mining industry with five distinct control strategies:

1) Time of Day Scheduling
2) Real Time Control
3) Event Based Control
4) Asset Monitoring and Control
5) Environmental Monitoring and Control

To date, BESTECH has been providing strategies 1 to 3 via its NRG-1 V2 product. Strategies 4 and 5 form the basis of the NRG1-ECO solution. BESTECH believes that each strategy represents a piece of the energy conservation pie (figure 10) and that the portion that each strategy contributes will vary greatly based on the characteristics of the mining operation. These characteristics include: the level and type of automation installed at the mine site, the mining method used to mine the ore body, the commodity prices, the power system feeding the mine workings, the communications and networking infrastructure in place, the applicable regulations, the cooling and heating requirements, and the overall buy-in by the various user communities and process owners (corporate, mine management, engineering, operations, and maintenance).

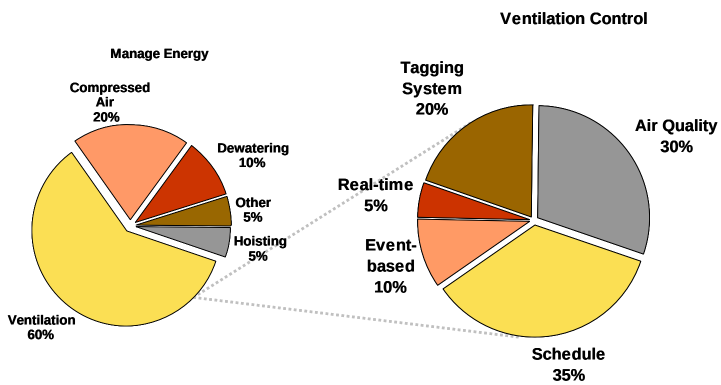

Figure 10. Energy Control Strategy Distribution

The integration of VFDs within the overall control strategy ensures that all opportunities for ventilation optimization can be realized thereby providing maximum energy cost savings. NRG1-ECO will be deployed within several mining horizons at Coleman Mine. One of the key deliverables of the project will be to measure the effectiveness of VFD's in relation to dual speed and single speed auxiliary fans. Each type of fan control will be uniquely tested by integrating a single type of control within a dedicated mining horizon. NRG1-ECO's unique adaptability to the fan control type will be leveraged to provide the necessary solution for energy optimization.

Without the technology application of using motor speed to control fan output, the VOD design would not be as efficient or have the flexibility required for a safe and robust system.

6.2 Coleman Mine #2 Shaft

Coleman Mine has recently commissioned a new ventilation exhaust system (figure 11). The project consisted of installing two Robinson 2800 kW (3750 hp) centrifugal fans in parallel. Rockwell Automation was hired by Robinson to supply VFD motor control for this application.

Figure 11. Vale Inco Coleman #2 Shaft Motor House

The Allen Bradley PowerFlex 7000L Liquid Cooled , MV Drives (liquid cooled drives with liquid to air heat exchangers) that were selected reduced HVAC and ventilation costs. Traditional cooling would have required 24 tons of cooling. The Direct-to-Drive technology saved $500,000 and increased system efficiency. Recorded fan power consumption is listed in Table 3.

Table 3. Actual kWh - VFD control

Vale Inco Coleman	Mine 3750 HP Motor 714 RPM			March 31-09
Centrifugal Fan	4160V			Reading
Speed %	100%	75%	50%	
Speed RPM	714	540	364	315
AMPS	434	295	167	158
kW per Hour	2613	1040	323	210
Hours per month	720	720	720	720
Total kWH / month	1881360	748800	232560	151200
kWH/ $.07	$ 131,695.20	$ 52,416.00	$ 16,279.20	$ 10,584.00

In the pursuit to reduce operating costs, VFD control should be considered as an integral part of an energy control strategy based on the opportunity to optimize energy usage through accurate control of a process and increased system efficiency.

7 References

ASHRAE (2008) *HVAC Systems and Equipment Handbook*, Chapter 44, pp. 8-11, American Society for Heating, Refrigeration and Air-Conditioning Engineers.

Da Prat, B., 2006. *Application Considerations in the Use of Variable Frequency Drives in the Pulp and Paper Industry*.

Fink, D.G. and Beatty, H.W., l987. *Standard Handbook for Electrical Engineers 12th Edition*, (McGraw Hill Book Co: New York).

Hardcastle, S. and O'Connor, D., 2005. *Justifying Ventilation-On-Demand in a Canadian Mine and The Need for Process Based Simulations*.

Howden Buffalo, Inc., l999. *Fan Engineering 12,15,17* (Quebecor World Book Services: Kingsport, Tennessee).

Natural Resources Canada, 2006 *http://oee.nrcan.gc.ca/industrial/equipment/vfdsavings.cfm?attr=24* Variable Frequency Drives

Ontario Hydro 1997. *Adjustable Speed Drive, Reference Guide 4th Edition*, (Canada).

Rockwell Automation, December 2007. *Energy Savings with Variable Frequency Drives*, (Publication 7000-AP002-EN-P)

Rockwell Automation, May 2006. *Vattenfall Europe Mining AG modernizes conveyor with variable frequency drive*, (Publication Mining AP010B-EN-D)