Considerations for the selection of variable frequency drives for primary fans

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The operation of primary mine fans must be well configured, yet flexible, to provide the required airflow for underground production activities under changing mine resistance characteristics and surface air conditions and temperatures. Under certain conditions, a Variable Frequency Drive (VFD) may be successfully used to achieve and maintain the fan design operating requirements. A VFD controls the voltage and frequency supplied to a motor to vary the speed, power, and torque in order to meet load conditions. The motivation behind the use of a VFD is to increase energy efficiency and thus reduce energy costs. However, the decision to use VFDs in favor over Reduced Voltage Starters (RVS) is not straight forward. The justification must be made on an engineering and economic basis. The VFD must be carefully specified to match the specific motor otherwise it will destroy the motor. The larger capital costs of VFDs must be offset by savings in operating costs. This paper presents a case study in which main surface fresh air fans were sized for operation in a new ventilation raise under extreme environmental conditions in Northern climates. Ventilation costs for the remote mining operation are high and every opportunity for savings was carefully investigated during design of the fresh air system. Use of VFDs was considered as a potential alternative to increase system energy efficiency. The decision on the selection between RVS and VFD was based on detailed engineering and economic analysis.

Keywords: primary fans, variable frequency drives, reduced voltage starters, energy efficiency, cost savings

1. Introduction

In an operating mine, the system resistance and air density vary regularly and, as such, the fan operation needs to be routinely adjusted in order to achieve or maintain the required operating point of flow and pressure.

During the winter season in Northern climates, when extremely low air temperatures (below -45ºC) can persist for extended periods of time and when natural ventilation pressure is at its maximum, substantial savings in energy costs can be realized by reducing the fan operating pressure.

In order to regulate fan flow and pressure, inlet and outlet dampers can be used. However, this practice usually results in inefficient operation and energy loss because of the increased resistance.

Fan operation can also be adjusted by changing the fan blade setting. However the costs associated with production downtime sometimes makes the procedure prohibitive. An attractive alternative is to integrate a means of controlling the fan operating speed. One of the main justifications for selecting a VFD is if the load profile varies frequently.

Alternating current induction motors are constant speed machines. When the motor is started, the electrical system experiences a current surge and the mechanical system experiences a torque surge. With line voltage applied to the motor, the current can reach up to ten times the motor full-load current and the magnitude of the torque the fan could be in excess of 200% of the motor full-load torque [1]. RVS are used in induction motors to reduce the starting current draw of the motor and to reduce the starting torque provided by the motor. Their use results in smooth acceleration with gradually increasing torque and voltage. Reduced voltage starting minimizes the shock on the fan, and potential damage to shaft, bearings, couplings, etc., by reducing the starting torque of the motor. With RVS alone, one cannot regulate fan flow and pressure.

When the load profile varies frequently, it is desirable to have a fan motor with fully variable speed operation. This can be accomplished by incorporating variable speed operation using a VFD.

A VFD is a device that controls the voltage and frequency being supplied to a fan induction motor thus controlling the speed, power and torque of the motor and of the fan. Since the VFD is capable of adjusting the speed and torque of the fan motor it provides a continuous range fan speed control. By precisely meeting the specific system resistance the fan, efficiency can be maximized.

A number of benefits may be realized using VFDs. Because the brakepower varies with the cube of the speed, adjusting the fan operating speed will result in significant energy savings. Also, when a fan is operated at reduced speeds, significant maintenance savings are achieved due to reduced wear on shafts, bearings, seals, etc. The purpose of a VFD is thus to increase energy efficiency, reduce energy costs and reduce fan operating and maintenance costs.

The decision on use of VFDs in favor of RVSs is however not straight forward. The justification must be made on an engineering and economic basis. A case study in which main surface fresh air fans were sized for operation under variable load profiles is presented.

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Additionally, a decision on the selection between RVS and VFD is presented to demonstrate the decision-making process.

2. Fan motor controller selection – A case study

An engineering design associated with commissioning of a new fresh air raise to supply 200 m^3/s and operation under extreme environmental conditions in Northern climates was completed [2]. Primary fans were sized and a detailed engineering and economic analysis was conducted for the selection of the fan motor controllers (RVSs versus VFDs).

2.1 Operational parameters

The following engineering and operational parameters were considered for sizing of the primary fans.

- The design flow rate is 200 m^3/s.
- The raise is a bored raise of diameter 4.5 m.
- The raise length is 610 m.
- The fresh air fans will be operated 24 hours/day, 365 days per year.
- The target availability of the fan system is to be 100% excluding scheduled outages.
- The fans will be exposed to ambient air temperatures ranging between +40°C and -50°C.
- Power cost is 9 cents per kWh.

2.2 Fan sizing

For the required airflow volume it is more economical to install multiple fans. The proposed main surface fresh air fan system consists of two fans operating in parallel configuration.

All fan assemblage components were designed for maximum efficiency (low shock resistance losses) and for lowest fan operating cost. Figure 1 presents a schematic of the fan assemblage design.

For the design flow, the raise resistance pressure was estimated at 0.65 kPa. The fan assemblage resistance pressure was estimated as 0.56 kPa based on system losses associated with the heater house, fan screen, inlet bell, backdraft damper, transition sections, fan cones, duct junction and elbow. The fan total pressure was estimated at 1.49 kPa.

Based on the design operating point a 2.13 m diameter axial flow fan, with a 0.8 m hub diameter hub was selected. A 225 kW motor, running at 1180 rpm was installed. Figure 2 shows the fan curve, the system curve and fan operating point.

2.3 Fan operation

Under extreme winter temperature conditions in Northern climates, natural ventilation pressures are so significant that, by adjusting the fan operating point, substantial savings in energy costs can be realized.

Based on the monthly temperature profile at the mine site and psychrometric surveys, the monthly variations of natural ventilation pressure were determined. The required fan operating point as a function of surface air temperatures was then determined, as presented in Figure 3. This allowed for the selection of the fan operating point during any time of the year.

If VFDs are used, the fan operation can be instantly adjusted under varying environmental conditions, thus maintaining its operation at the design requirements and guaranteeing the required airflow for underground production. The fan operating point and operating power was determined for each month of the year when using a VFD.

If using RVS, the surface fresh air fans will operate at full demand year round, with an estimated brake power of 200 kW. At extremely low temperatures, the fan blade setting would need to be changed in order to meet the design flow requirements. This would result in additional costs associated with downtime during blade setting changes.

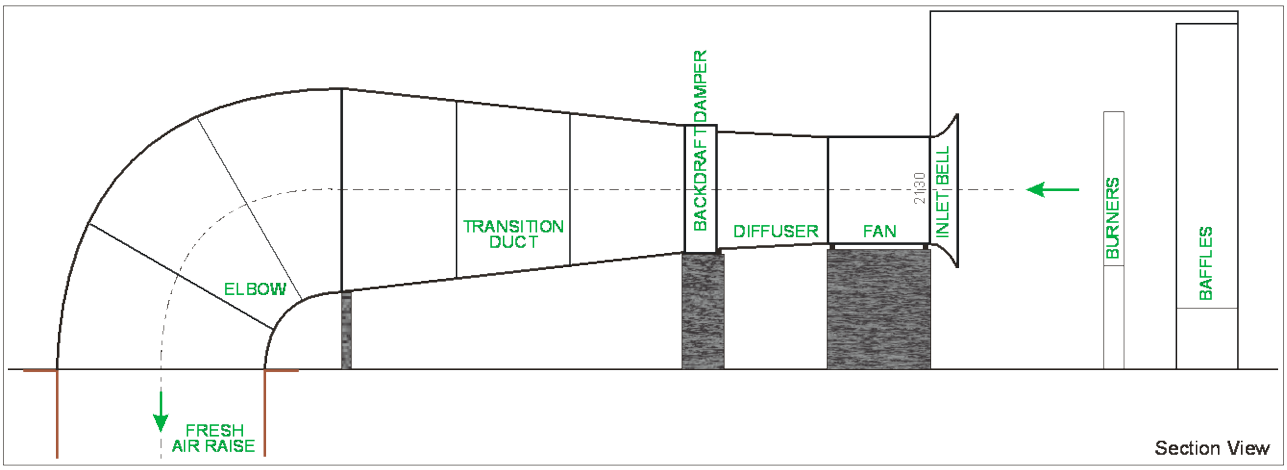

Fig. 1. Fan assemblage design schematic.

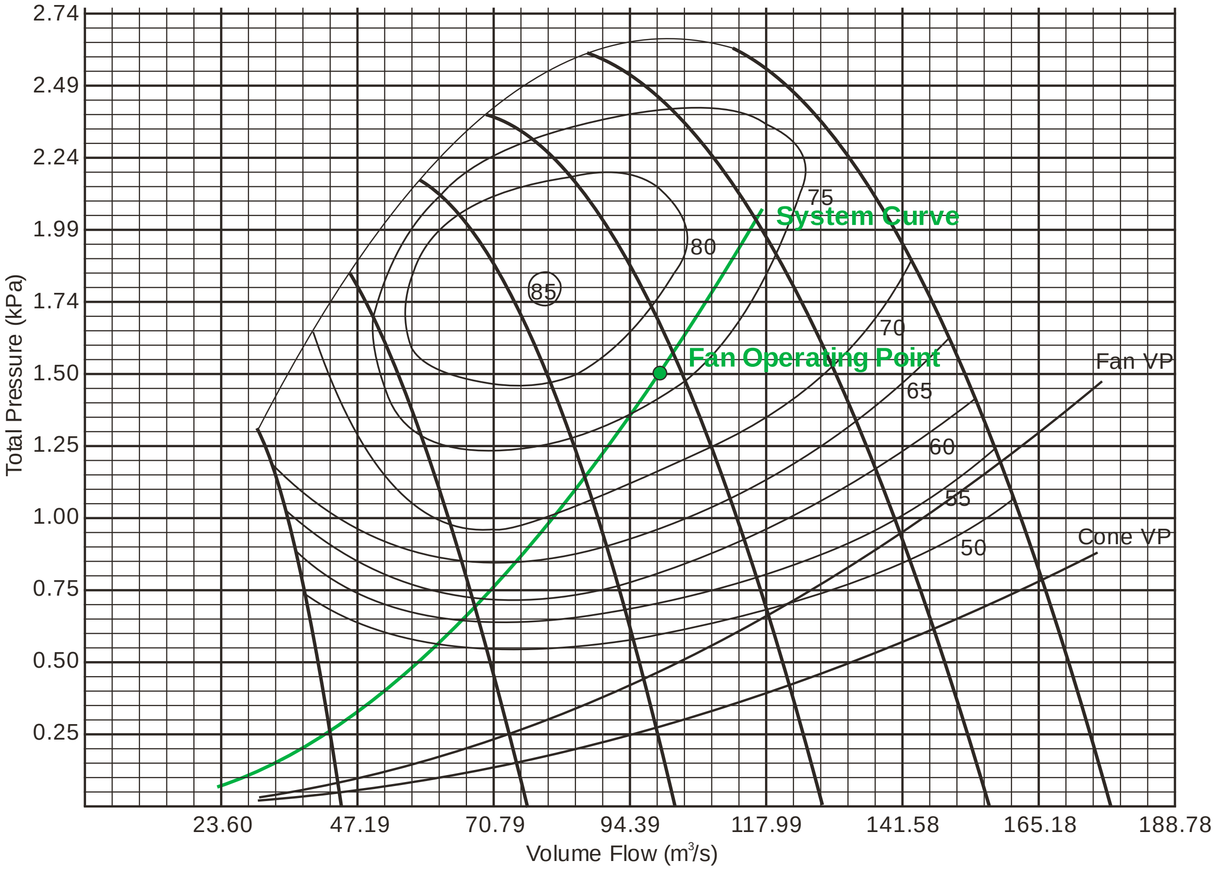

Fig. 2. Fan curve and design operating point.

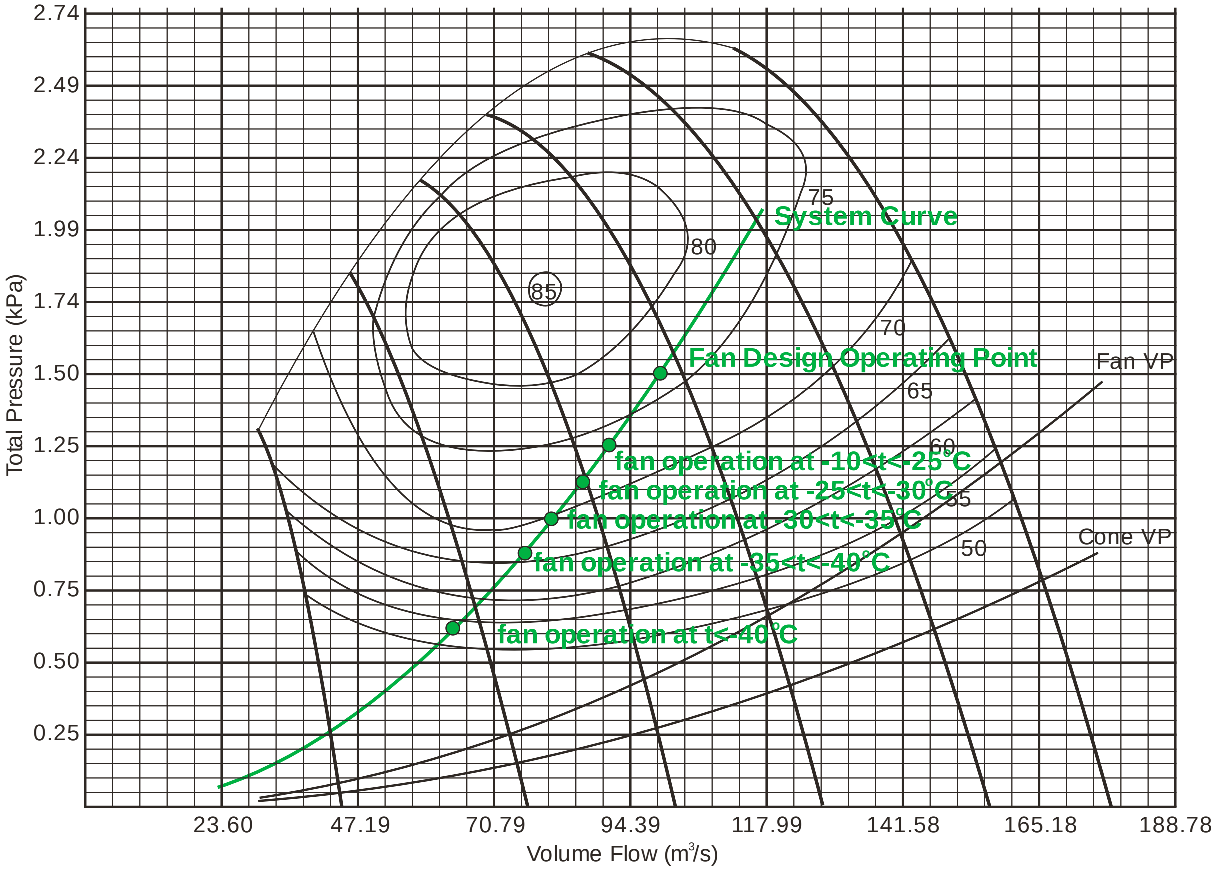

Fig. 3. Fan operating point as a function of surface air temperature.

2.4 Cost analysis

The Net Present Value (NPV) method was used to compare the alternatives.

The capital cost, expressed in total dollars, and operating costs, expressed in dollars per unit time, for purchasing VFDs or RVSs was evaluated. The discount rate and growth rate of electrical costs were also determined.

The capital cost for two VFDs, including switch gear, was $500,000 and the capital cost for two RVSs was $122,000. The capital cost difference is thus $378,000.

The annual operating cost for the fans fitted with VFDs or with RVSs was determined based on the monthly operating cost for each alternative. The month operating cost was a function of the fan operating point, previously described, and cost of power.

The annual operating cost for the fans fitted with VFDs was $200,720 and the annual operating cost when fitted with RVSs was $321,771. The savings in operating cost when using VFDs approximate $121,051.

The economic analysis considered a 5 year period and a power increase rate of 7%. The cost of power in year 1 was $0.09/kWh.

The discount rate was determined using the weighted average cost of capital and cost of debt (WACC), which is a combination of the cost of equity and the after tax cost of debt.

The number of years was selected as a reasonable payback period.

2.4.1 Net Present Value

NPV allows one to consider the time value of money. It is defined as the present value of the expected future cash flows less the initial cost of the investment.

To evaluate the NPV of the project, the expected net present value of the future cash flows from the project was estimated, including the project's initial investment as a negative amount.

A comparison between VFDs and RVSs was made by using the relative difference between the two options for the cost factors and finding the NPV for each year in consideration. The time at which NPV = 0 would represent the payback period for the VFD project.

For the determination of the NPV, the initial capital outlay was $378,000 and a discount rate of 12% was considered.

The NPV analysis indicated a payback period of 3 years when the fans are operated with VFDs.

2.4.2 Internal Rate of Return

In evaluating this capital project, Internal Rate of Return (IRR) was used as a measure of the estimated percentage return from the project.

It uses the initial cost of the project and estimates of the future cash flows to figure out the interest rate. The IRR is the return rate that makes the NPV from a particular investment equal to zero. It is the discount rate at which the present value of all future cash flows is equal to the initial investment, that is, the rate at which an investment breaks even. In general, the project is accepted if the IRR exceeds the cost of capital.

Using the NPV method, the Internal Rate of Return was determined through trial and error and interpolation techniques; by trying different interest rates until finding the interest rate which delivered an NPV closest to zero.

For the project, the internal rate of return is 23.2%.

2.5 Final recommendation

Based on a 3 year payback period and IRR of 23.2%, and considering the guidelines previously presented, it was recommended that VFDs be installed with the surface fans.

In addition, VFDs offer the following advantages over RVSs: custom control is provided; provides controlled starting, stopping and acceleration; provides advanced overload protection; provides easily adjustable fan speed control; reduces peak energy demand; allows for power cost savings.

Table 1 presents a summary of the project economics.

Table 1. Project economics.

	VFD	RVS	Cost difference
Capital cost	$500,000	$122,000	$378,000
Operating cost	$200,720	$321,771	$121,051
NVP year 3	$3,306		
IRR	23.2%		

3. Conclusions

When deciding of the type the fan motor controller, the process is not straight forward. The justification must be made on an engineering and economic basis. On the engineering front, only under certain conditions, a VFD may be successfully used to achieve and maintain the fan design operating requirements. The VFD must be carefully specified to match the specific motor otherwise it will destroy the motor. On the economic front, the larger capital costs of VFDs must be offset by savings in operating costs. A case study has been presented to detail how these two aspects are applied for the selection of a fan motor controller.

References

[1] Schneider Electric. Reduced Voltage Starting of Low Voltage, Three-Phase Squirrel Cage Induction Motors. Technical Overview. Bulletin No. 8600PD9201. 16 (1992).

[2] AirFinders Inc. Surface Fresh Air Fan System Design. Technical report. 54 (2014).