Energy Saving with Variable Speed Drives in Industry Applications

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Abstract: - One of the major costs incurred by most industry worldwide is energy. Therefore in the competitive markets of today where reducing costs is an important part of surviving, any methods of reducing the amount of power used in the processes that industry performs will be advantageous. With induction motors so widely used they account for a significant part of the energy requirements of many companies. This paper examines the feasibility of adding ac variable speed drives to control the existing pumping applications in one of New Zealand industrial site. The aim is to identify the energy savings that were possible from the implementation of ac variable speed drives and determine the payback period. The first task was to identify which motors would benefit the company most by having variable speed drives controlling them. The next step was to build a small scale experimental pumping system to determine the energy saving a variable speed drive would give. Then, using the motors identified in the first stage and the data collected in the second stage, the payback periods could be calculated.

Key-Words: - Variable speed drive, Energy saving, Fan/Pump applications.

1 Introduction

Electric motors, and more specifically induction motors, play a large part in the conversion of electrical energy to mechanical energy to perform many varied operations in industry. With induction motors so widely used they account for a significant part of the energy requirements of many companies. Induction motors used in industrial applications invariably do not run at 100% capacity though over design for safety margins.

One of the major costs incurred by most industry worldwide is energy. Therefore in the competitive markets of today where reducing costs is an important part of surviving, any methods of reducing the amount of power used in the processes that industry performs will be advantageous.

There are currently two methods available for industry to minimise the energy usage of induction motors. The first method aims at increasing the efficiency of the conversion of electrical energy to mechanical energy using enhanced efficiency motors [1],[7]. This options tries to reduce the energy lost due to inefficient motors; it does not solve the problem of wasting energy due to a poor control method.

The other option uses a different method of controlling the motor and thereby supplying the motor with only the energy that is required for the application. This option uses a variable speed drive [2] to control the speed of the shaft of the motor and therefore also the amount of mechanical energy output to the load.

The variable speed drive concept uses an inverter to supply the motor with enough energy to turn the shaft at the speed and torque the application requires. This not only creates a very efficient system but can be used as an effective method of controlling the application. The aim of the study was to identify the energy savings that were possible from the implementation of variable speed drives and determine the pay-back period for each of the selected motors.

The first task was to identify which motors would benefit the company most by having variable speed drives controlling them. Some motors may not be operating often enough and others may be too small to justify the cost of a drive. The next step was to build a small scale experimental pumping system to determine the energy saving a variable speed drive would give. Then, using the motors identified in the first stage and the data collected in the second stage, the payback periods could be calculated.

2 Variable Speed Drives

Approximately one third of the electricity consumed for industrial purposes is transformed to mechanical energy by induction motors [3].

The induction motor's largest role is in the running of pumps, fans, conveyors, compressors and a host of other applications. Induction motors have dominated fixed speed applications for many years but with the help of reliable variable speed drives they are also establishing themselves in controlled speed applications. A general diagram for the control of motor drives is shown in Figure 1.

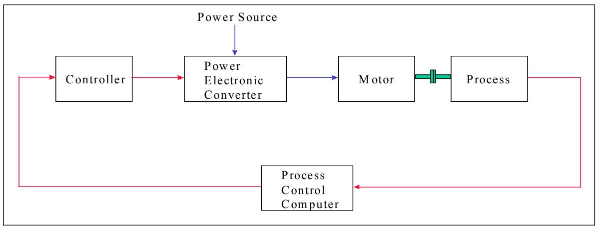

Figure 1 General motor drive control system layout

2.1 Converters

A converter, when used in variable speed drive applications, acts as an interface between the power supply and the induction motor [4]. For the drive to work effectively the converter must meet several requirements:

- It must have the ability to adjust the frequency to produce the required output speed.
- It must be able to adjust the output voltage to maintain a constant air-gap flux in the constant torque region.
- It must have the ability to supply the rated current at a given frequency.

Figure 2 shows a block diagram of a typical converter of this type.

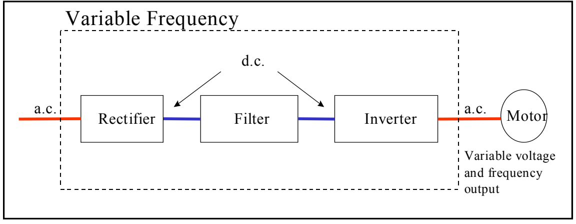

Figure 2 Variable frequency converter

2.2 Advantages of variable speed drives

This study is concentrating on the energy saving possible from the use of a variable speed drive. There are many other advantages to be gained by the use of a variable speed drive in pumping and fan applications that are not directly related to the energy savings. These advantages are listed below:

- Very wide extremes of pumping flow-rates achievable while maintaining acceptable levels of efficiency and control.
- Reduction of pump failure caused by pump cavitations.
- If abnormal pumping conditions occur that could result in motor overload, reduced rate pumping is possible. This protects the motor and keeps the process running.
- Low starting torque given by the variable speed drive will not generally exceed rated torque, thus extending the lifetime of the shaft, pump-seal, pump and motor components.
- Removal of the traditional form of control will reduce maintenance on piping and valves, thus reducing maintenance costs.

3 Traditional Pumping Control Methods

The three most common options for controlling the flow-rate of a fluid out of a pump are on-off switching, throttling and recycling [5]. Each method is outlined below.

3.1 On-off switching

On-off switching involves continually stopping and starting the pump to reduce the overall flow-rate. This method has the right idea: by cutting the power to the motor it appears to be reducing the amount of power required but this is not the case as with high starting current, the peak demand electricity charges can be increased.

Direct online switching on and off of motors can cause serious problems for the pumping system. The high torque on starting can cause pressure waves and fluid surging.

3.2 Throttling

This uses an inline valve between the motor and the distribution system to restrict the flow. This is a cheap method in terms of capital cost. The increase in the costs of the power due to the increase in the load when trying to run at low flows has to be considered. Problems can also be caused by pressure build up while trying to control at low flows.

3.3 Recycle System

This allows the flow-rate to be altered by sending the unwanted fluid back to the pump via a bypass valve. This method does not increase the load on the motor but does allow effective control of the distribution flow.

None of the traditional methods can effectively reduce the power consumption while also controlling a reduced flow.

4 Traditional Fan Control Methods

The main use of fans at the Production Station is to supply airflow with which cooling is achieved. This is for the use of air-cooled heat exchangers. There are three traditional control methods for changing the output of cooling fans.

4.1 Gearing

This not so common method utilises a series of gears between the motor shaft and the driving shaft on the fan. The gearing is adjusted up and down depending upon the amount of cooling required.

The problem with this system is that there is a set number of settings, depending upon the number of gears. Gearing is also high maintenance compared to having one fixed belt.

4.2 Pitch control

The most common method of controlling the cooling fans is by controlling the angle of the blades. Changing the angle of the blades changes the amount of flow passing over the areas being cooled. This has an advantage over the other method where it can have many more cooling rates than the gearing method.

4.3 On-off switching

This is a very simple method of averaging out the amount of time the fans are required by continually turn them on and off.

Though it is a simple method, there are two problems with it. Continual switching on and off decreases the motor's lifetime considerably and it is not an accurate method of control. For these reasons it is not commonly used.

5 Energy Saving Estimation

5.1 Pumping experiments

A pumping system was set up to mimic a real system used at the Production Station. Water was pumped out of a reservoir, through the pump, across the flow meter, and back to the reservoir.

The variable speed drive was a PDL Microdrive-3, 3-phase, 380-480 Vac, output current 16 amps and output power of 7.5 kW [6]. A single unit pump-motor was used. The motor was a Doeer, 3Hp, 460/400 volts, 3500/3900 RPM, 60/50 Hz, 3-phase, 4.0/4.3 amps. The pump was a Corken Coroflo, Model C14ID. The power was measured using two FB Feed Back Wattmeters Model EW604.

The initial set-up used the traditional method of power supply and one of the traditional control methods. The motor was connected directly to the 3-phase power supply. The flow-rate was controlled by a valve that recycled the unwanted fluid back through the pump. In the experiment the unwanted fluid was passed back through to the reservoir without passing through the flow meter, this symbolises the fluid recycling and not passing down the pipe. The schematic of the experimental set-up is shown in the Figure 3.

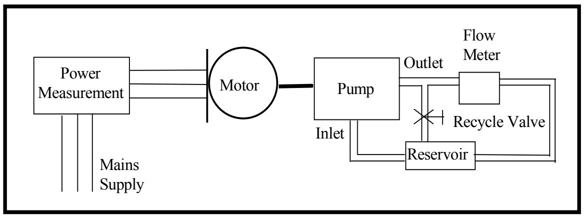

Figure 3 Pump schematic with traditional control

Flow across the flow meter was varied from maximum flow to minimum, using the flow valve. The flow across the pump and therefore the load on the motor remained constant at all times. At each point the power, the flow-rate and the temperature were measured.

For the second run a variable speed drive was added between the power measurement equipment and the motor. The flow valve and the recycle loop were removed allowing the variable speed drive to control the flow of fluid.

The speed of the motor shaft and the pumping speed were adjusted by the variable speed drive to control the flow-rate. The speed was stepped from the maximum rated speed to zero. The flow-rate, power, and temperature of the motor were recorded at each step. The schematic of the experimental set-up is shown in Figure 4.

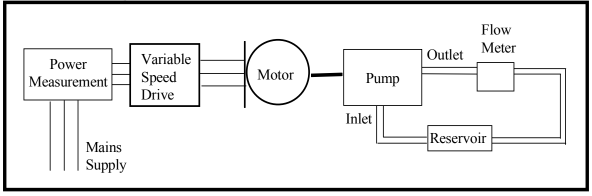

Figure 4 Pump schematic with variable speed drive

The temperature of the motor is monitored to ensure that at low speed (low flow-rates) the motor did not have a significant increase in temperature.

The two sets of results were analysed to determine the difference for the power usage between the two methods at different flow-rates. The data collected for the experiment using traditional controls was the motor shaft speed, the flow-rate and the power the motor was drawing from the mains. The plot of the power verses the flow-rate for the experiment using the traditional control is shown below in Figure 5.

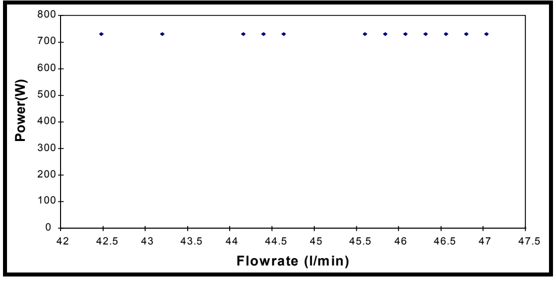

Figure 5 Plot of power vs. flow-rate for direct connection

The plot verifies that the power drawn is constant at all loads. This is because the flow-rate out of the pump is constant, as is shown by the shaft speed of the motor, but the excess flow is recycled prior to the flow measurement.

The plot of power versus the flow-rate with the variable speed drive is shown below in Figure 6. The graph does appear to approximate a square or cube law as the theory stated, although the long tail does suggest at the lower power levels power is also being drawn by the variable speed drive. This would infer that changes in flow-rates at low levels would not result in as large savings as the high flow-rates will bring.

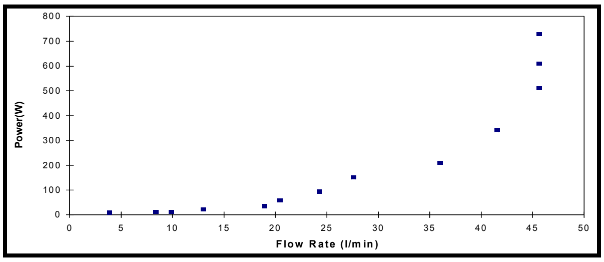

Figure 6 Plot of power vs. Flow-rate with drive connection

The steep curve shown at the high flow-rate levels shows that small decreases in flow-rate will give large energy savings. This is a very positive result, as pumps at the Production Station do not generally operate at 100% flow-rate, generally it is between 70% to 80% which will give a large power saving compared to current control methods.

To determine the actual power saving, the flow-rate and power data from the experiment is standardised. The difference in the power between the run with the drive and the run without the drive gives the standardised power savings over the range of flow-rates. The plot of this is shown below in Figure 7. The graph conclusively shows there are substantial power savings made when the load of the pump or fans drop from 100% to 90%, where the slope of the graph is the steepest. This standard curve can now be used to analyse the possible power saving for pumps at the site.

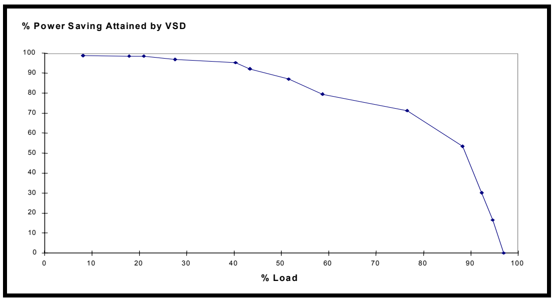

Figure 7 Percentage power savings vs. load

5.2 Fan Experiments

Due to the similarities of the torque curves for pumps and fans especially at the higher speeds, the results of the possible savings obtained from the pumping experiment will be true for the fan applications.

The aim of the fan experiment was to determine how accurate the experimental results of the pumping experiment were to the results obtained from actual operating motors and drives, also to verify the results would apply to fans.

This experiment was performed at the Production Station with a fin fan and drive used in their actual process. The fin fan is used for air-cooling heat exchangers connected to a variable speed drive that runs off 400 v 3-phase power supply. The variable speed drive is an ABB Drive Model No. ACS-601-0025-5. The motor's tag number is M0854A, it is 415V, 13.9A, 7.5kW, 50Hz, 1440rpm. The fan is belt driven by the motor.

The experiment ran in steps from the maximum set speed 1500 rpm to the minimum speed of 150 rpm. Values of speed current and power were recorded at each stage.

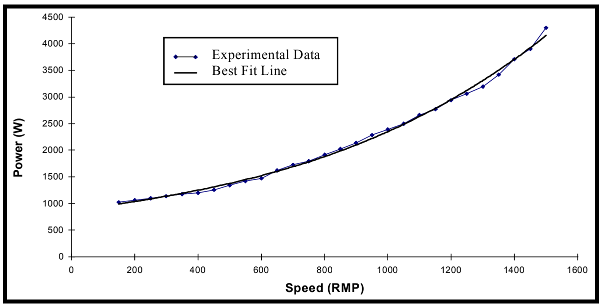

Figure 8 Plot of power vs. speed of the fan experiment

The power was plotted against the shaft speed of the motor, as is shown in Figure 8. The data shows that the experimental data is a very good approximation to the normal operating trends. This validates the correctness of the pay-back periods calculated in the next section as being a good approximation to the real pay-back periods.

6 Determining Pay-back Periods

The Production Station has in excess of eighty pumps operating and forty fans. It would not be cost-effective to control all of these with variable speed drives. The section outlines how the motors that are likely to give a fast payback period were selected.

There are three main factors that affect the length of the payback period: running periods, power rating of the motor, and its actual loading.

6.1 Running periods

The energy saved over a period of a year would be greatly increased if a motor were running continuously. A motor running for ten hours per day may not use enough energy for the possible savings to warrant the cost of a variable speed drive.

The data available only noted whether or not the motor was running continuously and did not give what period the motors were not continuous did run for. Of all the pumps operating only thirty-five of them run continuously.

6.2 Power rating

Although the cost of a variable speed drive does increase as the size of the motor increases, there is an initial fixed cost that is several thousands of dollars. A motor that was only a few kilowatts would never save enough energy to give a reasonable payback period for a variable speed drive.

In general variable speed drives have to be specially designed if they are coupled with motors that are rated at less than 0.75 kW. The cost of purchasing a drive to run very small motors may not be regained, as the motor power savings are so small. It was decided for this experimental stage to only choose motors that were rated at 7.5 kW or higher.

6.3 Actual loading

Using traditional control methods, the motor is loaded to full rating. This is a false impression of what the process loading is. The process loading is generally around 70-80%. If the normal process load is 70% then the use of a variable speed drive will have a shorter payback than if the loading is 95%. The motor's process loading was taken into account when choosing the motors for evaluation.

6.4 Pay-back periods

This section gives a brief description of how the values were calculated and the significance of the results.

1) The information of the average load on the chosen motors was supplied by the industrial site.
2) The graph of power savings vs. percentage flow-rate is used to predict the percentage power savings.
3) Multiplying this value with the rated power for each motor gives the amount of power saved in kW/hour.
4) This figure is then multiplied by the price the company pays for it powers giving the amount of money saved per hour.

5) Multiplying by 24 will give the money saved per hour and the multiplying again by 365 will give the money saved per year.
6) To calculate the payback period the cost of the drives is divided by the savings made per year.

The brief results showing the motor size, cost of a drive for that motor and the payback period in days is shown below in table1.

The drives chosen for calculating the payback period are the 'Microflo' and 'Microflo-i' variable speed drives. These a.c. controllers are especially designed for the control of pumps and fans. The drives are made by PDL Electronics-New Zealand.

In general, a company considers a payback period of less than two years to be a worthwhile investment. In this case, for some of the larger motors the period is less than a year. The pay-back period can be seen to be increasing as the motors get smaller due to the underlying fixed cost for the drives although they are all less than a two year pay-back period.

Power Rating (kW)	*Money Saved per year(NZ$)*	*Drive Cost (NZ$)*	*Pay-back Period (days)*
132	$28,015	$27,000	352
132	$28,015	$27,000	352
132	$28,015	$27,000	352
132	$28,015	$27,000	352
75	$18,233	$16,500	330
37	$9,423	$8,000	310
37	$9,423	$8,000	310
30	$7,409	$7,000	345
18.5	$4,497	$6,000	487
15	$3,704	$4,900	483
15	$3,704	$4,900	483
11	$2,717	$4,300	578
11	$2,717	$4,300	578
11	$3,099	$4,300	507
11	$3,099	$4,300	507
11	$3,099	$4,300	507
7.5	$1,997	$3,500	640
7.5	$1,997	$3,500	640

Table 1 Payback periods for chosen motors

7 Conclusions

The aim of this study was to see if variable speed drives are a viable option for reducing the industrial site's production costs. The first task was to identify which motors would benefit the company most by having variable speed drives controlling them. The next step was to build a small scale experimental pumping system to determine the energy saving a variable speed drive would give. Then, using the motors identified in the first stage and the data collected in the second stage, the payback periods were calculated.

The pay-back periods ranged from 310 days to 640 days: some less than a one year pay-back period, all of them well inside two years. This data does show that the boasts about variable speed drives are not all a fallacy. The paper verified that the implementation of variable speed drives at the Production Station to control large a.c. motors, 7.5kW and more, is a viable option.

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