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Energy Conservation in centrifugal pump with variable frequency drive including SCADA, PLC and HMI

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Abstract : Pumping systems account for nearly 20% of the world's electrical energy demand and range from 25-50% of the energy usage in certain industrial plant operations .Pumping systems consume a significant portion of the electricity, Variable frequency drives (VFD's) are often recommended as a way to save pumping energy. Actual energy savings will vary greatly depending on how the discharge pressure of the constant speed pump is controlled and how it is operated after the VFD is installed.In the present work,the flow of pump has been controlled by two different methods, experimental work has been carried out and comparetive statement is given.

Keywords: Centrifugal pump, flow control, throttling, variable frequency drive,Energy saving.

I. INTRODUCTION

Pumps are used widely in industry to provide cooling and lubrication services, to transfer fluids for processing, and to provide the motive force in hydraulic systems. Pumping systems account for nearly 20% of the world's electrical energy demand and range from 25-50% of the energy usage in certain industrial plant operations[1]. With raising energy costs, process plants are increasing their focus on the amount of energy consumed by rotating equipment. An improperly sized or poorly performing pump consumes unnecessary money [2].

The performance curves for a pump are shown in figure1, which are some important characteristics used for the design, modification, selection and performance assessment.

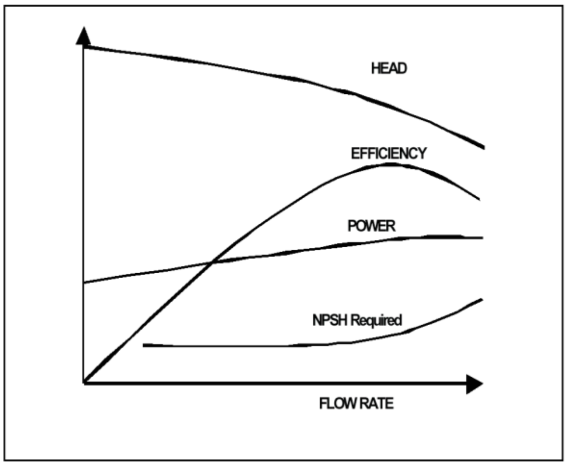

Figure 1 Pump Performance Characteristics

Basic criteria for selecting a pump are Head-Flow requirement and pump size. Pump efficiency varies with flow rate and head and it is highest at one point only, which is called best efficiency point. A pump is selected on the basis that pump curve and system head flow curve should be matched and pump is operated on the desired operating point.

An over-sized pump is derated by the various methods such as:

- Throttling
- Veriable speed drive
- Impeller trimming
- Bypass control.

Suppose consider a system having a system curve as shown in figure 2 by line SC_1. The pump curve is line PC_1 which intersect system curve at operating point A, where the flow rate is 700m^3/hr and head is 40 meter.

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Vol. 2, Issue 5, May 2013

But, the actual requirement of flow is 400m^3/hr. Hence the flow rate can be reduced by closing the throttle valve which inserts the artificial resistance to the system and system curve is lifted over the first one. The new operating point becomes B at which desired floe rate 400m^3/hr is achieved but at higher head. Hence, pump has to overcome additional head (BC) and for that pump consumes more electrical power. Thus by throttling valve operation to control flow rate is not efficient method.
The another best option is to reduce the speed form N_1 to N_2 hence pump curve is shifted below and intersect original system curve at point C, which is the best efficiency point (BEP) for the pump where desired flow and head are achieved and also the overall efficiency [2].

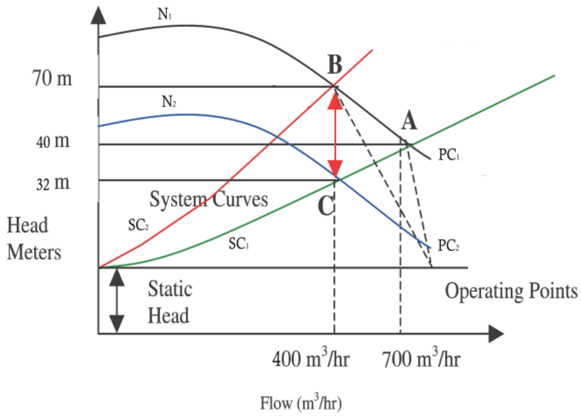

Figure 2 Flow control methods

II. VARIABLE FREQUENCY DRIVE

The variable frequency drive (VFD) converts the supply frequency and voltage to the required frequency and voltage to drive a motor. Hence, VFD converts the supply frequency and voltage to the frequency and voltage required to drive a motor at a desired speed other than its rated speed. The variable speed drive consists of rectifier, inverter and control components.
The majority of general purpose VFDs produced today has four fundamental sections. These are:
1. The input rectifier or converter.
2. The DC bus.
3. The output stack or VFD.
4. The controller.
The input rectifier or converter can be either three-phase or, in small machines, single phase. This input rectifier converts the Vac input into Vdc and charges the capacitors in this part of the circuit.
The DC bus acts as a small reservoir for power on which the output VFD draws. If any regenerated energy from the load remains, it is stored on the DC bus in the capacitors.
The output stack or VFD draws power from the DC bus and creates a synthesized Vac power supply, the frequency of which can be varied by the controller. The output of the converter is used to drive the electric motor [3].
The following factors/criteria should be considered for selection of appropriate VSD and its successful implementation.

A. CONSTANT TORQUE LOAD

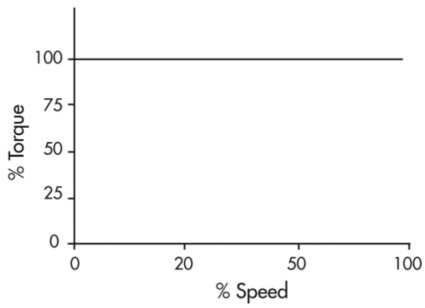

Figure 3 Constant Torque Load

A constant torque load is characterized as one in which the torque is constant regardless of speed. As a result the horsepower requirement is directly proportional to the operating speed of the application and varied directly with

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International Journal of Innovative Research in Science, Engineering and Technology
Vol. 2, Issue 5, May 2013

speed. Since torque is not a function of speed, it remains constant while the horsepower and speed vary proportionately. Typical examples of constant torque applications include: Conveyors, Extruders, Mixers, Positive displacement pumps and compressors. Some of the advantages VFDs offer in constant torque applications include precise speed control and starting and stopping with controlled acceleration/deceleration.

B. CONSTANT HORSEPOWER LOAD

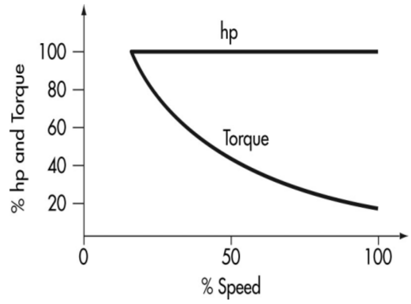

Figure 4 Constant Horsepower Load

The second type of load characteristic is constant power. In these applications the torque requirement varies inversely with speed. As the torque increases the speed must decrease to have a constant horsepower load. Examples of this type of load would be a lathe or drilling and milling machines where heavy cuts are made at low speed and light cuts are made at high speed. These applications do not offer energy savings at reduced speeds [4].

C. VARIABLE TORQUE LOAD

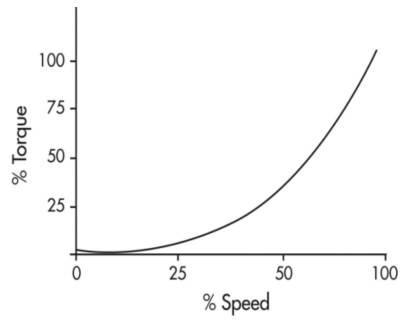

Figure 5 Variable Torque Load

The third type of load characteristic is a variable torque load. Examples include centrifugal fans, blowers and pumps. The use of a VFD with a variable torque load may return significant energy savings.
In these applications

- Torque varies directly with speed squared
- Power varies directly with speed cubed

This means that at half speed, the horsepower required is approximately one eighth of rated maximum. Throttling a system by using a valve or damper is an inefficient method of control because the throttling device dissipates energy which has been imparted to the fluid. A variable frequency drive simply reduces the total energy into the system when it is not needed.
The flows, pressures and power can be calculated along each constant efficiency line using the affinity laws. The affinity laws are as follows:

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2} \qquad \frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2$$

$$\frac{P_1}{P_2} = \left(\frac{N_1}{N_2}\right)^3 \qquad \frac{Q_1}{Q_2} = \sqrt{\frac{H_1}{H_2}}$$

Where Q is the flow rate (m^3/min), N is the speed (RPM), H is head (m), and P is power (Horsepower).
Once the flows and pressures are known, the pump's horsepower can be determined for a given efficiency η using the power equations shown below.

$$P = \frac{\rho\, g\, Q\, H}{\eta} \quad kW = \frac{P * 0.745\, kW/HP}{\eta_m}$$

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Vol. 2, Issue 5, May 2013

In this work, flowcontrol have been done by two methods(throtteling and VFD) and based on measured parameters graphs have been plotted [1].

III. TEST SETUP

The schematic diagram of test rig is shown in figure 3. It consists of a water tank, a centrifugal pump,magnetic flow meter, pressure gauges, ball valve.The specification of parts is listed below

- **Pump Description (Crompton Greaves minimaster III)**
  - KW/hp :- 0.75/1.00
  - Head :- 6/45 m
  - Discharge :- 4000/900 lps
  - Pump No :- KFPM06914
- **Flow meter**
  - Magnetic flow meter (ELMAG-200M)
- **HMI Panel (CVM-NRG96)**
  HMI panel is used for manual control of VFD drive.
- **PLC**
  - Siemens S7 200 PLC

  PLC is used to control the whole pumping system, measure input parameters and compare it and give feed back to the SCADA system.

- **Pressure Gauges**

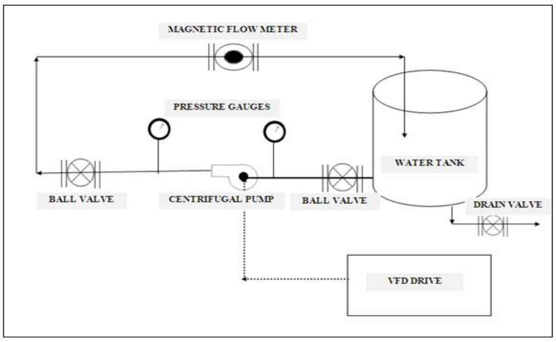

Figure 6 Schematic diagram of test rig

Figure 7 Photo of actual setup

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology
Vol. 2, Issue 5, May 2013

IV. EXPERIMENTAL WORK

The flow of centrifugal pump has been first controled by throttling. During test, different electrical and mechanical paremeter has been recorded which are shown in table 1.

Table 1 Observation Table (Throttling)

Flow	Head	Active Power	Reactive Power	Apparent Power	Power Factor	Pump Efficiency
m^3/hr	m	KW	KW	KW		η
3.81	4.23	0.134	0.232	0.26791	0.50	40.95
3.50	6.9523	0.155	0.2436	0.28878	0.53	53.47
3.20	10.1536	0.172	0.2456	0.29989	0.57	64.54
2.90	14.2547	0.18167	0.246	0.30580	0.59	77.23
2.50	20.3225	0.20567	0.2423	0.31784	0.64	84.14
2.12	25.2479	0.232	0.2406	0.33428	0.69	78.57
1.51	34.0963	0.256	0.2433	0.35319	0.72	68.49

Now, flow of centrifugal pump has been controled by VFD. During test, different electrical and mechanical paremeter has been recorded which are shown in table 2.

Table 2 Observation Table (VFD)

Flow	Head	Active Power	Reactive Power	Apparen t Power	Power Factor	RPM
m^3/hr	m	KW	KW	KW		
3.81	5.7791	0.1413	0.033	0.1451	0.97380	2919
3.50	5.1055	0.1183	0.02733	0.1214	0.97434	2703
3.20	4.8520	0.099	0.02266	0.1015	0.97477	2465
2.90	4.1120	0.082	0.01633	0.0836	0.98073	2235
2.50	3.8996	0.065	0.012	0.0661	0.98338	1933
2.12	3.5542	0.0526	0.01	0.0536	0.98244	1632
1.51	3.0254	0.039	0.006	0.0394	0.98837	1172

V. COMPARATIVE GRAPHS

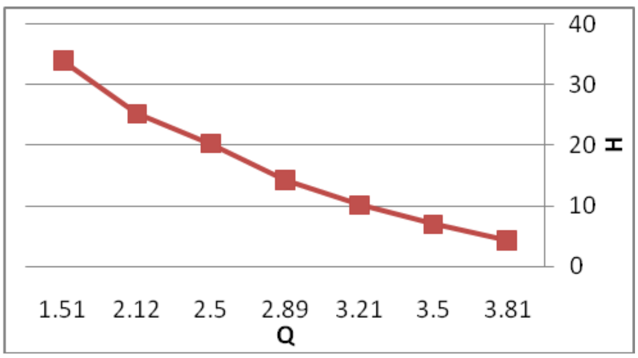

Figure 8 Head vs Flow for Throttling

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology
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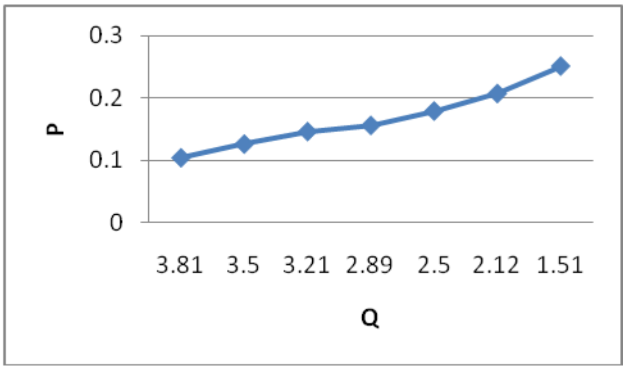

Figure 9 Power vs Flow for Throttling

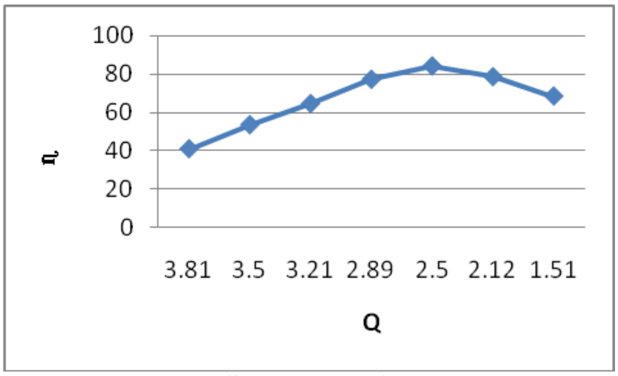

Figure 10 Efficiency vs Flow for Throttling

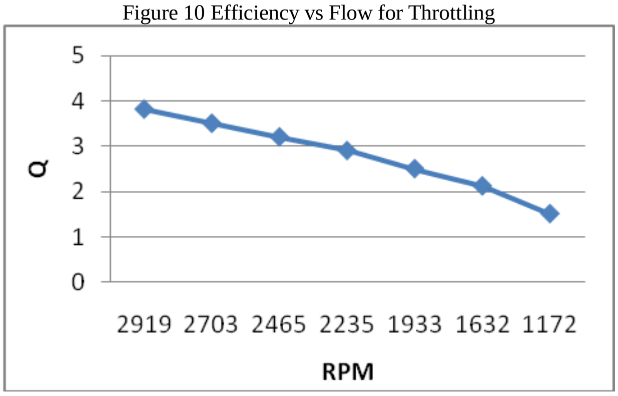

Figure 11 Flow vs RPM for VFD

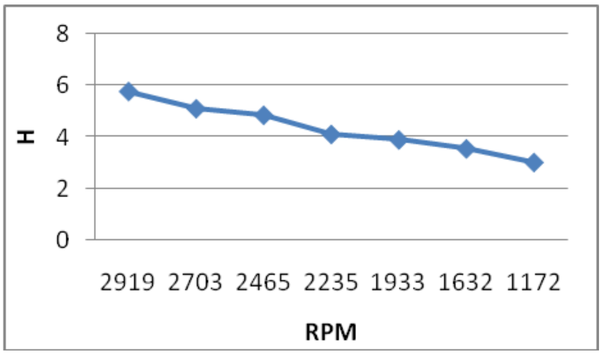

Figure 12 Head vs RPM for VFD

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology
Vol. 2, Issue 5, May 2013

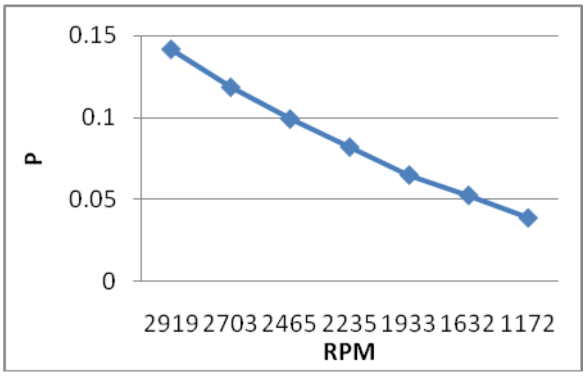

Figure 13 Power vs RPM for VFD

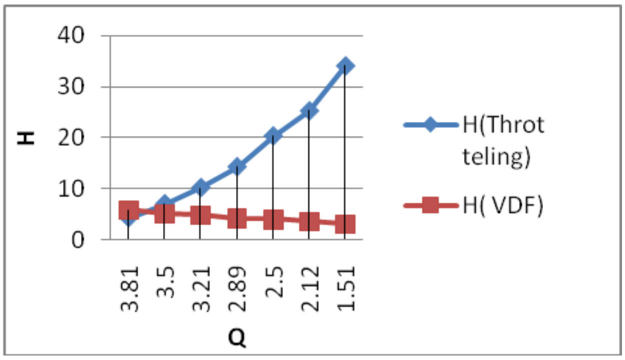

Figure 14 Head vs Flow for Throttling and VFD

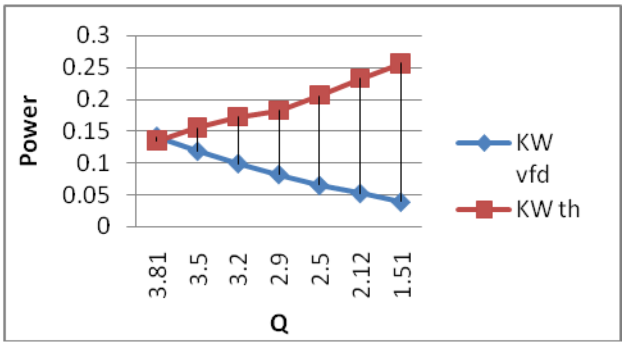

Figure 15 Power vs Flow for Throttling and VFD

VI. RESULTS AND DISCUSSION

Characteristics curves are plotted in Figure 8 to Figure 15. From figure 8, 9, 10, it can be seen that for throttling the head increases gradually with decrease in flow rate, power consumption increases with reducing the flow rate, efficiency of pump increase with reducing flow rate up to certain flow rate and reaches maximum, which is known as best efficiency point and after that it reduces.
From figure 11, 12, 13, it can be seen that reduces the RPM of pump, flow rate gradually decreases consequently head also decreases and power consumption also decreases.
Figure 14 and 15 shows the comparison of Throttling and VFD for Head and power consumption and it can be seen that reducing the flow with throttling, head gradually increases while for VFD head falls. From figure 15 it can be seen that reducing the flow with throttling, power consumption increase while for VFD power consumption reduces.

VII. CONCLUSION

As by control the flow of pump with throttling, net head increases and to overcome this extra head motor draw extra power. VFD offers a very good response to pumping system. Reduces the flow with VFD, motor consume very less power. So significant amount of power can be saved with the help of Variable Frequency Drive.

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology
Vol. 2, Issue 5, May 2013

VFD also serves as Soft Starter, during starting motor draws 6 times more current than rated current. While starting with VFD, motor draws very less current and also provide a smooth stopping of motor. So the losses occur in motor can be eliminated.

VFD also improve the Power Factor, Form the table it can be clearly seen that while controlling the flow with Throttling, Power Factor remains very low compared to VFD which maintain the Power Factor near to unity and because of this the losses regarding to low Power Factor like Increase the I^2R and I^2X losses, Increase thermal stresses, increase size of conductor, circuit breaker etc. reduces.

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