STUDY OF APPLICATION OF VFD IN THERMAL POWER STATION FOR ENERGY CONSERVATION

1Prof. Nisha T.Sahu, 2Mr Tomesh .T.Sahu, 3Raksha Mahajan
1Assistant Prof, 2Network Engineer, 3Student
1Department of Electrical Engineering,
1Yeshwantrao Chavan College of Engineering (An Autonomous Institution Affiliated To Rashtrasant Tukadoji Maharaj Nagpur University), Nagpur, India

Abstract: The consumption of energy is faster than it can be produced. Energy resources are limited and India has approximately 1% of world’s energy resources but it has 16% of world population. Most of the energy sources we use cannot be reused and renewed. It is said that our energy resources may last only for another 40 years or so. We can save the country a lot of money when we save energy. Energy saving is energy generated.

Concerning the third focus point, relatively little attention has been paid to the efficiency of auxiliary processes in the thermal power plants, which account for about 5-8% of the gross generating capacity. Examples of auxiliary processes in the thermal power plants are conveying and preparing the fuel, moving the necessary air into the furnace, moving the necessary air into the furnace. Moving the fuel gases from the furnaces, returning the condensed water back to the steam generator, maintaining the necessary cooling effect in the condenser and operating various emission cleaning processes. A majority of these processes are run by centrifugal pumps, Fans and compressors driven by electrical motors.

This paper presents study and analysis of implementation of variable frequency drives for ID fan and HFO pump and calculation of energy conservation by using variable frequency drive at Thermal Power station, Nagpur.

I. INTRODUCTION

A variable frequency drive (VFD) is an electrical variable speed drive that is added to motor-driven systems to help save energy. Motor-driven systems are designed to handle peak loads. When these operating systems work for extended periods of time at a reduced load, it wastes energy. Adding a VFD allows you to adjust the motor-speed capability and match it with motor-output load. This is how it saves energy. The motor-driven system is connected to the VFD and allows us to have speed control by changing the frequency of the motor-supply voltage. Variable frequency drives allow reducing power consumption up to 30% or more and obtaining a payback time on the investments often lower than 1 – 2 years. Moreover, the quality of the equipment’s and the lower mechanical stress on the installed machinery guarantee it a longer life time and a substantial cut on its maintenance cost. In the present time, in most of the applications, alternating current (AC) machines are preferable to direct current (DC) machines due to their simple and most robust construction without any mechanical commutator. These motors have no brushes to wear out or magnets to add to the cost. The rotor assembly is a simple steel cage. Squirrel cage are rugged, cheaper, lighter, smaller, more efficient, requires less maintenance and can operate in dirty and explosive environment. With this induction motors are the most widely used motors for appliances, industrial control, fans, blowers, cranes, conveyors, traction, underground and 3 underwater installations and automation.

When power is supplied to an induction motor (IM) at the recommended specifications, it runs at its rated speed. However, many applications need variable speed operations. In industrial process there has always been a need for speed variation to meet the needs of flow or torque control. Driving and controlling the induction motor efficiently are prime concerns in today’s energy conscious world. In the 21st century the power electronics technology has gained significant maturity after several decades of dynamic evolution of power semiconductor devices, converters, PWM techniques, motor drives, advanced VLSI controls. With this both the size and the cost of semiconductors have gone down drastically over last couple of years and the motor user can replace an energy inefficient mechanical motor drive and control system with a variable frequency drive (VFD). In this speed and torque control are accomplished by supplying variable voltage and variable frequency via an adjustable frequency control to an IM. This change in approach has enabled the eliminations of gears, clutches, valves, throttles, dampers and other equipment from industrial systems.

These VFD not only control the motor’s speed but can improve the motor’s dynamic and steady state characteristics. In addition, they can reduce the system’s average power consumption and noise generation of the motor. Though, precise control of single-phase induction motor is less complex in comparison to the three phase induction motor, but where torque requirement is more than three phase induction motor is the best choice. For three phase motor control, six gate pulses are to be controlled independently unlike in the single-phase motor drive, where only two gate pulses are to be controlled. Induction machines are designed to operate at a constant input voltage and frequency. We can effectively control an induction machine in a closed loop speed application if the frequency of the motor input voltage is varied.

If the motor is not mechanically overloaded, the motor will operate at a speed that is roughly proportional to the input frequency. As you decrease the frequency of the drive voltage, you also need to decrease the amplitude by a proportional
amount. Otherwise, the motor will consume excessive current at low input frequencies. This control method is called “Volts-Hertz control”. In practice, a custom Volts-Hertz profile is developed that ensures the motor operates correctly at any speed setting. This profile can take the form of a look-up table or can be calculated during run time.

Often, a slope variable is used in the application that defines a linear relationship between drive frequency and voltage at any operating point. The Volts-Hertz control method can be used in conjunction with speed and current sensors to operate the motor in a closed loop fashion. The variable speed drive systems are classified in to electrical, hydraulic and mechanical drive system. Fig.1 shows the block diagram of a typical variable drive system. It consists of a rectifier unit, dc link filter, inverter power circuit feeding the motor and feedback control unit/system.

The energy analysis carried out in Thermal power plant contains information such as energy consumption pattern of the power plant and possible energy saving measure and cost benefit analysis using VFD. HFO, CT Fan and ID Fan were three systems we studied which were equipped with VFD.

II. VARIABLE FREQUENCY DRIVE

A variable frequency drive used for controlling the rotational speed of an AC induction motors by controlling the frequency of the electrical power supplied to the motor. Variable frequency drives are also known as AC drives or inverter drives.

Alternating current applied to the stator winding produces a magnetic field that rotates the motor at synchronous speed. This speed can be calculated by dividing the line frequency by the number of magnetic poles in the motor winding.

\[
\text{speed} = \frac{(120 \times \text{frequency})}{p}; \quad (1)
\]

where, \( p \) = number of poles per phase

![Figure: Block Diagram of VFD](image)

For 50 Hz frequency and 4 poles the speed or magnetic field will rotate with 1500 revolutions per second (rpm). The rotor of induction motor attempts to follow the rotating magnetic field and in under load condition the rotor speed slightly behind the rotating field called as slip. This small slip generates an induced current, and the resulting magnetic field in the rotor produces the torque. As an induction motor rotates near synchronous speed, the most effective and energy efficient way to change the motor speed is to change the frequency of the applied voltage. Variable frequency drive converts the fixed frequency supply to a variable frequency, therefore allowing the adjustable motor speed. Variable frequency drive consists of mainly three stages: Rectifier stage, filter stage and the inverter stage

- **Rectifier Stage**: A full wave rectifier section consist of solid state rectifier converts three phase 50/60Hz power either fixed DC voltage or variable DC voltage.
- **Filter Stage**: It consist of DC link choke or reactor and capacitor filter. DC link chopper removes unwanted signal harmonics and capacitor filter smoothen the rippled dc voltage.
- **Inverter Stage**: The inverter section uses the power electronic switches means power transistors or thyristors or IGBTs which switches the rectified DC voltage on and off, produces a current or voltage waveforms at the required frequency. And the distortion occurred are depends on the design of the inverter circuit and filter circuit.

Variable frequency drives are classified in three types:

1. Variable voltage source Inverter
2. Current source inverter
3. PWM inverter

The current source type inverter also face the same problem like variable voltage type inverter. Most currently available and due to emergence of advance power electronics Pulse width modulation (PWM) technology, Variable frequency drive (VFD) enclosure become more compact in size. It uses the IGBTs as a switching devices which have higher switching frequencies than that of bipolar transistors also it has high input impedance, reduces base driver power consumption.
III. Payback Period and Energy Saving Calculations of HFO pump

Table I: Data before VFD installation

<table>
<thead>
<tr>
<th>Motor RPM</th>
<th>1500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage Motor RPM</td>
<td>100</td>
</tr>
<tr>
<td>HORV Position(%age)</td>
<td>100</td>
</tr>
<tr>
<td>Voltage (V)</td>
<td>415</td>
</tr>
<tr>
<td>Current (Amp)</td>
<td>18</td>
</tr>
<tr>
<td>Power (Watts)</td>
<td>10997.334</td>
</tr>
<tr>
<td>Power Consumption in 1 hour(KWh)</td>
<td>10.997334</td>
</tr>
<tr>
<td>Power Consumption in 24 hour(KWh)</td>
<td>263.936016</td>
</tr>
<tr>
<td>Power Saving per Day (Units)</td>
<td>0</td>
</tr>
<tr>
<td>Rate Per unit (Rs.)</td>
<td>3</td>
</tr>
<tr>
<td>Saving Per Day (Rs.)</td>
<td>0</td>
</tr>
</tbody>
</table>

Table II: Data after VFD installation

<table>
<thead>
<tr>
<th>Motor RPM</th>
<th>1470</th>
<th>1350</th>
<th>1200</th>
<th>1050</th>
<th>900</th>
<th>750</th>
<th>600</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage Motor RPM</td>
<td>98</td>
<td>90</td>
<td>80</td>
<td>70</td>
<td>60</td>
<td>50</td>
<td>40</td>
</tr>
<tr>
<td>HORV Position(%age)</td>
<td>80</td>
<td>55</td>
<td>40</td>
<td>30</td>
<td>20</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Voltage (V)</td>
<td>415</td>
<td>415</td>
<td>415</td>
<td>415</td>
<td>415</td>
<td>415</td>
<td>415</td>
</tr>
<tr>
<td>Current (Amp)</td>
<td>14</td>
<td>13.2</td>
<td>12.1</td>
<td>11.2</td>
<td>9.3</td>
<td>7.4</td>
<td>5</td>
</tr>
<tr>
<td>Power (Watts)</td>
<td>8553.4</td>
<td>8064.711</td>
<td>7392.652</td>
<td>6842.7856</td>
<td>5681.9559</td>
<td>4521.1262</td>
<td>3054.815</td>
</tr>
<tr>
<td>Power Consumption in 1 hour(KWh)</td>
<td>8.55348</td>
<td>8.064711</td>
<td>7.392652</td>
<td>6.842785</td>
<td>5.681955</td>
<td>4.521126</td>
<td>3.05481</td>
</tr>
<tr>
<td>Power Consumption in 24 hour(KWh)</td>
<td>205.283</td>
<td>193.5530</td>
<td>177.4236</td>
<td>164.2268</td>
<td>136.3669</td>
<td>108.507</td>
<td>73.3155</td>
</tr>
<tr>
<td>Power Saving per Day (Units)</td>
<td>58.6524</td>
<td>70.38293</td>
<td>86.51236</td>
<td>99.70916</td>
<td>127.5690</td>
<td>155.4289</td>
<td>190.620</td>
</tr>
<tr>
<td>Rate Per unit (Rs.)</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Saving Per Day (Rs.)</td>
<td>175.957</td>
<td>211.1488</td>
<td>259.5370</td>
<td>299.1274</td>
<td>382.7072</td>
<td>466.2869</td>
<td>571.861</td>
</tr>
</tbody>
</table>

Table III: Energy Saving Calculation on HFO pump

<table>
<thead>
<tr>
<th>Power consumption in KWh</th>
<th>Power saved with VFD in KWh</th>
<th>Cost savings in Lakhs per year</th>
<th>Cost of the drive in Lakhs</th>
<th>Pay back in years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without VFD</td>
<td>With VFD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>263.936016</td>
<td>205.28568</td>
<td>58.652448</td>
<td>0.52</td>
<td>3</td>
</tr>
</tbody>
</table>
Energy Savings Calculations:

The power consumed by the pump without variable frequency drive is given by:

\[ \text{Power consumed} = \sqrt{3} \times V_L \times I_L \times \cos \theta \]
\[ = \sqrt{3} \times 415 \times 18 \times 0.85 \]
\[ = 10997.334 \text{ W} \]

Power consumed in KWh = 10.997 KWh

Power consumed in 24 hours = 263.936016 KWh

The power consumed by the pump with the use of variable frequency drive is given by:

\[ \text{Power consumed} = \sqrt{3} \times V_L \times I_L \times \cos \theta \]
\[ = \sqrt{3} \times 415 \times 14 \times 0.85 \]
\[ = 8553.482 \text{ W} \]

Power consumed in KWh = 8.553 KWh

Power consumed in 24 hours = 205.283 KWh

So, the power savings obtained = 58.652 KWh

As Rs.3 per unit, saving per day = Rs.175.9

Table III: Energy Saving Calculations of HFO Pump Using VFD

Rating of VFD where it is installed = 22KW

Power saving with variable frequency drive per day = 58.652448 units

Operation of unit for 300 days in year

For 300 days net savings = 58.652448 x 3 x 300 = 0.52 lakhs per year based on the data

The extra capital expenditure towards installation of variable frequency drive will be approximately Rs 3 Lakh based on the present day cost.

Payback period = 3/0.52

= 5.7 years approximately.

The implementation of variable frequency drive for HFO pumps in a power plant reduces the power consumption approximately. The drive payback periods for the additional investments are quite attractive. From the above data and calculation we can get to final conclusion that variable frequency drive is the most efficient and economical solution for energy saving for HFO pump.
IV. Payback Period And Energy Saving Calculations Of ID Fan

Table IV: Test Result Obtained On ID Fan

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Speed (RPM)</th>
<th>Excitation panel</th>
<th>Contactor panel</th>
<th>Field current</th>
<th>Field voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>V (volts)</td>
<td>I (amps)</td>
<td>V (volts)</td>
<td>I (amps)</td>
</tr>
<tr>
<td>10</td>
<td>150</td>
<td>200</td>
<td>95</td>
<td>300</td>
<td>60</td>
</tr>
<tr>
<td>13.33</td>
<td>200</td>
<td>275</td>
<td>100</td>
<td>50</td>
<td>80</td>
</tr>
<tr>
<td>22</td>
<td>300</td>
<td>400</td>
<td>200</td>
<td>180</td>
<td>200</td>
</tr>
<tr>
<td>33.33</td>
<td>500</td>
<td>850</td>
<td>260</td>
<td>480</td>
<td>260</td>
</tr>
<tr>
<td>40</td>
<td>600</td>
<td>1200</td>
<td>300</td>
<td>810</td>
<td>310</td>
</tr>
<tr>
<td>46.66</td>
<td>700</td>
<td>1200</td>
<td>450</td>
<td>690</td>
<td>450</td>
</tr>
</tbody>
</table>

Table V: Energy Saving Calculation on ID Fan

<table>
<thead>
<tr>
<th>Power consumption in KWh</th>
<th>Power saved with VFD in KWh</th>
<th>Cost savings in Lakhs per year</th>
<th>Cost of the drive in Lakhs</th>
<th>Pay back in years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without VFD</td>
<td>2319</td>
<td></td>
<td>43</td>
<td>165</td>
</tr>
<tr>
<td>With VFD</td>
<td>1845</td>
<td>474</td>
<td>43</td>
<td>165</td>
</tr>
</tbody>
</table>

**Energy saving calculations:**

Power saving with VFD = 297KWh

Operation of system is considered for 300 days in year.

Average generation cost of Rs. 1.25/KWh

For one day total cost= 1.25×24 hr = 30Rs

For 300 days net saving= 30×300×474 = 42.66 lakhs per year

The extra capital expenditure towards installation of VFD will be approximately Rs 165 lakhs based on the present day cost.

Payback period=165/43
The implementation of variable frequency drive for ID fan in a power plant reduces the power consumption. The drive pay back periods for the additional investment are quite attractive. From the above we can arrive at decision that the VFD is most suitable and economical solution for energy savings for ID fan.

From the results, the use of variable frequency drive for cooling tower fan in power plant reduces the power consumption. If the motor has to run without variable frequency drive then the motor will consume more power and cannot be controlled and regulated as per the load demand and requirement.

V. Simulation and Result

The above simulation model is based on a system with ID Fan which is without variable frequency drive. Variable load is supplied to the asynchronous motor by the use of step input of different frequency, for different time interval. The output of the motor, i.e. its stator and rotor current is measured by the current measurement and voltage measurement block. Further for the measurement of motor torque and the speed, measurements block are added, so as to get the required graphical output.

The above simulation model is based on a system with ID Fan which is equipped with variable frequency drive. Variable load is supplied to the asynchronous motor by the PWM Generator (2 level). The VFD is created by using inverter stage, which converts the input into required arc. output of suitable frequency. The fan system is connected in a close loop with the motor to
minimize the error. The output of the motor, i.e. its stator and rotor current is measured by the multimeter block. Further for the measurement of motor torque and the speed, measurements block are added, so as to get the required graphical output.

Figure: Graph of ID Fan without VFD

Graph no.1 shows variation of stator current w.r.t. time. As in the system the load is changes after 3 seconds of interval due to which fluctuations are seen in the graph hence due to variation of load the stator current also changes.

Graph no.2 shows the variation of electromagnetic torque w.r.t time. We can see after 3 seconds there is sudden increase in the torque which has further become steady this increase in the torque is due to variation of load.

Graph no.3 shows the speed of the motor w.r.t. time. As seen from the graph, with the increase of load the speed is decreasing.

Graph no.4 shows the variation of rotor current w.r.t. time. After 3 seconds there is sudden increase in the current as the load is increasing.

Figure: Graph of ID Fan with VFD

Graph no.1 shows the variation of stator current w.r.t. time. In this graph with the variation of load there are not much fluctuation in the stator current.

Graph no.2 shows the variation of stator speed w.r.t time. With the increase in the load the speed f the motor also increasing.
Graph no.3 shows the variation of electromagnetic torque w.r.t. time. There are not much variation on the torque with the varying load.

Graph no.4 shows the variation of voltage w.r.t. time.

VI. Conclusion

After the detailed study of Variable Frequency Drive, it becomes possible to control the speed of electric motor as well as to conserve the electrical energy, as we know that the energy conservation has become an important subject to all over the world. Increase in efficient energy use, decrease in energy consumption and/or consumption from conventional energy sources is reduced that leads to the conservation of energy.

For high performance provided by the Variable Frequency Drive for maximum process productivity always required a complex engineering consideration. However rapid improvements in AC control technology combined with ready availability of standard fixed frequency of AC motor have increased the number of possible solution. With the process of pulse width modulation, the frequency given to the induction motor can be set in order to control the speed of the induction motor. Thus the consumption of electrical energy is depends on the load requirement. However the variation of frequency leads to the harmonics distortion which can be mitigate by several techniques of harmonics mitigation.

At last the conservation of energy may result in increase in financial, capital, environment quality, national security, personal security and human comfort. The individual and commercial user can increase energy use efficiency to maximum profit which leads to help for the individual and organization that are direct consumer of energy security.

VII. Acknowledgement

We sincerely express our thanks to Amol Bhalerao of khaperkheda thermal power plant for discussion and support. We are grateful to the management and maintenance personnel for kind assistance during the visit.

VIII. References


