Performance Analysis of VFD Operated Paddle Feeders used for Evacuation of Coal in A Coal Based thermal Power Station

Niraj Kumar Sahu1, Dr. V Balakrishna Reddy2

1Research Scholar, 2Research Supervisor, SVN University, Sagar (MP), India

Abstract— In a thermal power plant paddle feeders are used to evacuate coal from track hoppers for processing and to feed the processed coal to bunkers. Previously the paddle feeders were operated with eddy current couplings, which had various maintenance and operating problems, due to those problems the eddy current coupling had been replaced with the fluid couplings, but the fluid coupling has fixed speed and there was no possibilities of speed variation hence, the paddle feeders were operated at fixed speed and due to that the coal evacuation from a paddle feeder was fixed and conveyor utilization was also reduced as there was no possibilities to run two no. of paddle feeders at a time. To increase the coal evacuation from paddle feeders and to increase the conveyor utilization, now by the use of variable frequency drive(VFD) in the paddle feeders, in place of fluid couplings & eddy current couplings, resulted in reduction of the running current of paddle feeders (less power consumption at low speed by variation of frequency and voltage maintaining v/f constant) and also the conveyor utilization increased as two no. of paddle feeders are running simultaneously and hence, saving of considerable energy is there.

Keywords— Eddy current coupling, Energy saving, Fluid coupling, Paddle feeders, Thermal power plant, Track hopper, Variable frequency drive (VFD),

I. INTRODUCTION

Electricity is very much required for growth and development of the industries.

But there was a drawback with the fluid couplings of the fixed speed operation. As the speed variation was not there the utilization of conveyor was also poor.

To overcome the above problem and to reduce the power consumption in a paddle feeders at low speed variable frequency drives (VFDs) are now used for controlling the speed of paddle feeders to control the coal evacuation from track hopper. VFDs are now a days common for controlling the speed of induction motors by variation of frequency.
By use of the VFDs in paddle feeders the efficiency of the equipments increased very much.

II. OPERATION AND ADVANTAGES OF VFDs

The induction motors are the extensively used in the power plant for various auxiliaries which are operating at fixed speed as per the supply frequency. Alternating current given to the stator windings of an induction motor produces a magnetic field that rotates at synchronous speed. This speed may be calculated by dividing line frequency by the number of magnetic pole pairs in the motor winding i.e.

\[ \text{Speed (rpm)} = \frac{\text{frequency (hertz)} \times 120}{\text{no. of poles}}. \]

The rotor of an induction motor attempts to follow this rotating magnetic field, and, under load, the rotor speed slightly slips behind the rotating field. This slip speed generates an induced current, and the resulting magnetic field in the rotor produces torque.

The torque developed\(^{[12]}\) by the induction motor follows the equation below:

\[ T = k_1 \cdot m \cdot I_2 \]

where: \( m = k_2 \cdot \frac{V_1}{f_1} \)

\( T \): torque available on the shaft (Nm)

\( m \): magnetising flux (Wb)

\( I_2 \): rotor current (A) à depends on the load!

\( V_1 \): stator voltage (V)

\( k_1 \) & \( k_2 \) : constants à depend on the material and on the machine design.

To have the flux constant the ratio of voltage to frequency should be constant. Since an induction motor rotates nearer to synchronous speed, the most effective way to change the motor speed is to change the frequency of the applied voltage.

A variable frequency drive (VFD), as shown in Fig.3, is an electrical variable speed. When the system needs to work at reduced speed for long time at reduced load it wastes energy. A VFD allows us to adjust the motor-speed capability and match it with motor-output load. This is how it saves energy. Varying the frequency output of the VFD controls motor speed: Speed (rpm) = frequency (hertz) x 120 / no. of poles.

The VFD uses the IGBT\(^{[4]}\), the IGBT can switch on and off several thousand times per second and precisely control the power delivered to the motor. The IGBT uses a method named “pulse width modulation” (PWM)\(^{[1]}\)[4] to simulate a current sine wave at the desired frequency to the motor.

The utilisation of VFD in a system gives various advantages like\(^{[4]}\)[6]:

1. Soft starting features for a longer life of electrical and mechanical equipment
2. It reduces the power consumption of drives at reduced speed.
3. It improves the power factor of induction motor.
4. It improves the electrical efficiency of induction motor.
5. The operation of drive system is smooth.

III. OPERATION OF PADDLE FEEDERS WITH EDDY CURRENT COUPLING, FLUID COUPLING AND VFD

a) Eddy current coupling:

An eddy current coupling(as shown in Fig.4) consists of a loss drum and a field member. It operates on the same principles as an induction machine. The field member provides the magnetic flux, either using PMs or an electrically induced magnetic field. The loss drum rotates relative to the magnetic field, inducing eddy currents in the loss drum. The magnitude of the induced eddy currents depends on machine constants and the frequency of the magnetic field relative to the drum. Through action and reaction of the magnets and induced poles the same torque is common to both components, and power is transferred from the one to the other. In all eddy current couplings the loss drum consists of only a featureless ferromagnetic cylinder. The eddy currents are induced in the ferromagnetic material, which makes the current density distribution difficult to determine analytically, since iron saturation has to be taken into account. As The variation of speed in the eddy current coupling is possible by variation in the magnetic field of coupling no power saving is there.
The fluid couplings (as shown in Fig.5) are filled with oil and it starts the motor at no load and smoothly couples to the gearbox for operation of the equipments. The main components of the fluid are impeller & casing input side and runner & shaft output side. The impeller & runner both have a large no. of straight radial vanes. At the motor switch-on the fluid coupling has no torque capacity. The motor thus starts at no load and attains its full speed quickly. The motor then runs at constant speed and hence, no variation in speed is possible and the power consumed by the motor is also constant.

**Table-1**

<table>
<thead>
<tr>
<th>S.N.</th>
<th>Frequency (in Hz.)</th>
<th>Supply Voltage (V)</th>
<th>Voltage at Motor terminal (V)</th>
<th>Speed (in RPM) at 4% slip</th>
<th>Measured speed of motor (in RPM)</th>
<th>Current with VFD (in Amp.)</th>
<th>Power Factor (with use of VFD)</th>
<th>Feed Rate of coal (in MT per hour)</th>
</tr>
</thead>
<tbody>
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<td>1</td>
<td>30</td>
<td>415</td>
<td>249</td>
<td>432</td>
<td>435</td>
<td>17</td>
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<td>700</td>
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<td>461</td>
<td>465</td>
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<td>3</td>
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<td>415</td>
<td>315</td>
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<td>553</td>
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<td>0.85</td>
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<td>415</td>
<td>332</td>
<td>576</td>
<td>583</td>
<td>24</td>
<td>0.85</td>
<td>1000</td>
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<tr>
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<td>43</td>
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<td>357</td>
<td>619</td>
<td>627</td>
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<td>398</td>
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<td>50</td>
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<td>415</td>
<td>720</td>
<td>731</td>
<td>33</td>
<td>0.85</td>
<td>1350</td>
</tr>
</tbody>
</table>

**IV. CALCULATIONS**

Rating of Paddle Feeder Motor - 3 ph., 22kw, 415V, 720RPM

As per the observations of Table-1 following calculations done:-

(i) While operation of the Paddle Feeders is done with the eddy current coupling and fluid coupling the power factor measured is 0.7 and current taken by the drive is 45Amps at 415V supply. Hence, power consumption with these parameters:-
Power = 1.732xVoltage(V) x Current(I) x power factor

Po = 1.732x415x45x0.7 = 22.64 kw, say 22kw

(ii) As shown in Table-5, the current of the paddle feeder is less at reduced frequency and also the power factor improved to 0.85. Hence, power drawn by the motor with different frequencies is as calculated below:-

Power (P) = 1.732xVoltage(V) x Current(I) x power factor

% saving in power = (Pr-P)*100/Pr

where, Pr- power of motor at eddy current coupling and fluid coupling which is approx. 22kw as above, P-power drawn.

(1). at freq. 30Hz, P1 = 1.732x249x17x0.85
= 6.23 kw
% Saving of power = (22-6.23)*100/22
= 71.68%
(2). at freq. 32Hz, P2 = 1.732x265x18x0.85
= 7.02 kw
% Saving of power = (22-7.02)*100/22
= 68.09%
(3). at freq. 35Hz, P3 = 1.732x290x20x0.85
= 8.54 kw
% Saving of power = (22-8.54)*100/22
= 61.18%
(4). at freq. 38Hz, P4 = 1.732x315x22x0.85
= 10.20 kw
% Saving of power = (22-10.20)*100/22

= 53.63%

(5). at freq. 40Hz, P5 = 1.732x332x24x0.85
= 11.73 kw
% Saving of power = (22-11.73)*100/22
= 46.68%

(6). at freq. 43Hz, P6 = 1.732x357x27x0.85
= 14.19 kw
% Saving of power = (22-14.19)*100/22
= 35.50%

(7). at freq. 45Hz, P7 = 1.732x374x30x0.85
= 16.52 kw
% Saving of power = (22-16.52)*100/22
= 24.90%

(8). at freq. 48Hz, P8 = 1.732x398x32x0.85
= 18.75 kw
% Saving of power = (22-18.75)*100/22
= 14.77%

(9). at freq. 50Hz, P9 = 1.732x415x33x0.85
= 20.16 kw
% Saving of power = (22-20.16)*100/22
= 6%

The above observation is shown in Table-2 & graph no.7.
Table-2

<table>
<thead>
<tr>
<th>S.N.</th>
<th>Frequency (in Hz.)</th>
<th>Supply Voltage (V)</th>
<th>Voltage at motor terminal (V)</th>
<th>Current with VFD (in Amp.)</th>
<th>Power Factor (with use of VFD)</th>
<th>Power drawn P in kw</th>
<th>% saving of Power</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.85</td>
<td>20.16</td>
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</tr>
</tbody>
</table>

Fig.7 graph between freq. & % saving in power

(iii) The speed of an Induction motor, \( n = 120 \times f \times (1-s)/p \).
Where \( n \) = motor speed, \( f \) = frequency, \( p \) = no. of poles, \( s \) = slip.

Hence, by variation in any of the above three parameters the speed of the motor can be changed.

As shown in Table-1 the measured speeds of the Induction motor at different frequency is higher than the speed at 4% slip as given on motor nameplate.

% Slip of motor \((s) = (Ns-N)*100/Ns\).

where \( Ns \)-synchronous speed, \( N \)-actual motor speed.
The slip at different frequency and measured speed is shown in Table-3.

Taking loss in the motor as slip power then the electrical efficiency of the motor will be:-

\[
\text{electrical efficiency} = \frac{P \times (1-s) \times 100}{P}
\]
Where \( P \) = power drawn, \( s \) = slip of motor with VFD.

1. at freq. 30Hz, eff. = 10.38*(1-0.0333)*100/10.38 = 96.67%
2. at freq. 32Hz, eff. = 10.99*(1-0.0313)*100/10.99 = 96.88%
3. at freq. 35Hz, eff. = 12.22*(1-0.0305)*100/12.22 = 96.95%
4. at freq. 38Hz, eff. = 13.44*(1-0.0298)*100/13.44 = 97.02%
5. at freq. 40Hz, eff. = 14.66*(1-0.0283)*100/14.66 = 97.17%
(6). at freq. 43Hz, eff. = 16.49*(1-0.0279)*100/16.49 = 97.36%

(7). at freq. 45Hz, eff. = 18.33*(1-0.0267)*100/18.33 = 97.47%

(8). at freq. 48Hz, eff. = 19.55*(1-0.0264)*100/19.55 = 97.36%

(9). at freq. 50Hz, eff. = 20.16*(1-0.0253)*100/20.16 = 97.47%

The above observation is shown in Table-3 & graph no.8 & 9

Table-3

<table>
<thead>
<tr>
<th>S.N.</th>
<th>Frequency (in Hz.)</th>
<th>Speed at 4% slip (in RPM)</th>
<th>Speed of motor (in RPM)</th>
<th>Slip (s) at measured speed (in %)</th>
<th>Power drawn P (in kw)</th>
<th>Efficiency (in %)</th>
</tr>
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<td>2.79</td>
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<td>720</td>
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<td>2.53</td>
<td>20.16</td>
<td>97.47</td>
</tr>
</tbody>
</table>

Fig.8 graph shows comparison between speed at 4% slip & measured speed at different frequencies
V. CONCLUSIONS

As shown in the Tables-1,2 & 3 and Fig.7, 8 & 9 by the use of VFDs in paddle feeders the current consumption at reduced speed is reduced very much and hence, energy saving. The operation of the paddle feeder become easier and needs less maintenance. The slip of the Induction motor also reduced by use of VFD as shown in the Table-1 measured value of the speed is more compared to 4% slip speed of the motor and hence, the electrical efficiency of the motor has increased. From the above observation we can say that by use of VFDs in auxiliary equipments of thermal power plant will be helpful in reduction of auxiliary power consumption, smooth operation of equipments and easy to control, and at the same time cost of generation of electricity will also be reduced.

Acknowledgement

Kind co-operation of the management as well as employees of NTPC Ltd. Korba for this academic work is highly acknowledged.

NTPC Limited (Formerly National Thermal Power Corporation) is the largest power generation company in India. The total installed capacity of the company is 42,454 MW including Coal, Gas, and Solar plants located across the country, NTPC Ltd. Korba being one of them.

REFERENCES

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