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Performance Analysis of VFD Fed Aerial Ropeway System in Coal Handling Plant at CSTPS, Chandrapur-A Case Study

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ABSTRACT
Large rating drives required in coal handling plant for coal transportation. Smooth control with minimum power loss techniques must prefer for reliable operation. This paper presents the comparative studies of slip ring induction motor and squirrel cage induction motor with VFD technique for aerial rope way system in the view of good manageability, efficiency, and energy economy used at super thermal power station, Chandrapur, Maharashtra. Simulations are carried out in MATLAB environment.
Keywords: Energy saving, Variable frequency Drive (VFD), aerial ropeway, thermal power station, manageability.

I. INTRODUCTION

The Chandrapur power station is a giant in power plants has a total capacity of 3340MW. Out of 3340MW the 2340MW has been established from 1983 to1997 and remaining 1000 MW is under the construction. The ultimate coal requirement of the station is about 38000 Metric Tons per day and practically, all requirements is made from the various open cast collieries located within the radial distance of 50 Kms. from this power station. Durgapur and Padmapur Collieries of WCL is pit head mines from where the coal is transported by Ropeway and the unit train system with Wagons boxed of GENCO respectively. This aerial ropeway had been driven by Slip ring induction motor (SRIM) and now SRIM replaced by Variable frequency drive (VFD) fed Squirrel cage induction motor (SCIM) due to some benefits of the technique like saving of energy smooth operation , low maintenance etc.

Previously SRIM drives were used where control was not smooth, large power losses as the motors of large ratings, etc. Energy conservation is necessary losses in the large rating drives are more with the traditional technique and SRIM Drives. A major proportion of electrical power in a plant is consumed by electrical derives. Significant amount of electrical energy can be saved by the use of efficient and rigid type of electrical drives. VFD is one of the well-known technique where problems in SRIM are solved with observable energy saving.
SCIM driven by VFD. Before the SCIM the ropeway was driven by the SRIM, the main reason behind the up gradation of the system is the more maintenance, poor control and power loss in SRIM even it has the high starting torque. [6]

The growing popularity of variable frequency drives is due to its ability to control the speed of induction motors, which are the most commonly, used motors in industries.

Traditionally, an induction motor is used for constant speed and constant torque applications and when variable speed or torque is required, a DC motor or wound ac motor is used. But now AC induction motors with Variable Frequency Drives are used for variable speed applications. Such drives reduce the energy consumption of motors and increase the energy efficiency of plants. [2]

This paper deals with the comparative analysis of ropeway drive using SRIM and VFD fed SCIM for this simulations are carried out in MATLAB environment.

II. ROPEWAY SYSTEM

After railway maximum amount of coal brought to the plant through the aerial ropeway system. The ropeways feeding end is at 1Km from the motor operating point . There are total 47 trollies and each having capacity of 1.5 tone. This aerial ropeway system is driven by 150 HP

I. Slip ring Induction Motor

Slip Ring Induction Motor was used for aerial ropeway controlling. Slip Ring motor has a stator and a rotor with insulated windings brought out via slip rings and brushes. However, no power is applied to the slip rings. Their complete purpose is to allow resistance to be placed in series with the rotor windings while starting. This resistance is shorted out once the motor is started. Slip ring induction motor with external rotor resistances reported in Fig.1.

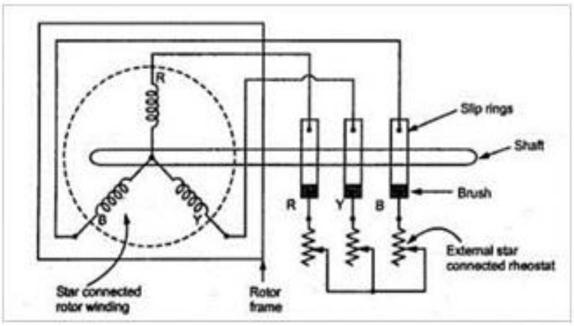

Fig.1 Slip ring induction motor with external rotor resistances

Placing resistance in series with the rotor windings not only decreases start current, locked rotor current (LRC), but also increases the starting torque, locked rotor torque (LRT). Fig.2 shows that by increasing the rotor resistance from R0 to R1 to R2, the breakdown torque peak is shifted left to zero speed. This torque peak is much higher than the starting torque available with no rotor resistance (R0) Slip is proportional to rotor resistance, and pullout torque is proportional to slip. Thus, high torque is produced while starting.

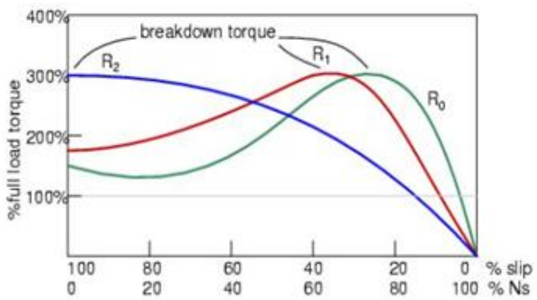

Fig.2 Speed torque characteristics of slip ring induction motor

The resistance decreases the torque available at full running speed. But that resistance is shorted out by the time the rotor is started. A shorted rotor operates like a squirrel cage rotor. Heat generated during starting is mostly dissipated external to the motor in the starting resistance. This motor is suited for starting high inertial loads. A high starting resistance makes the high pull out torque available at zero speed.

Disadvantages of aerial ropeway with Slip ring Induction Motor.

1. Speed variation is limited.
2. If different speed range is required then the range of resistances should be more.
3. Maintenance is more because of the presence of the slip rings, brushes, short circuiting devices etc.
4. Less efficiency compared to squirrel cage induction motor.
5. Starting torque is more compared to squirrel cage induction motor however it is not smooth.
6. Hence more Mechanical circuitry is required.
7. More power losses due to external resistances at rotor side.

II. Squirrel cage Induction motor with VFD:

Motor Speed - In order to use the polyphase AC Motor as an adjustable speed device, it is necessary to

Control and adjust the frequency of the 3 ph. Power applied to its terminals. The operating speed of the AC motor is determined by the following relationship:

$$shaft\ speed = \frac{120X\ supply\ frequency}{2X\ pole\ pair\ number} - slip$$

Where

Frequency is described in cycles per second (Hz) Speed and Slip are expressed in RPM.

Effect of change in supply voltage on starting torque

If

Substituting E2 = supply voltage V

$$T_{st} = \frac{k_1 E_2^2 R_2}{R_2^2 + X_2^2}$$

Then

$$T_{st} = \frac{k_1 V^2 R_2}{R_2^2 + X_2^2} = \frac{k_1 V^2\ R_2}{z_2^2}$$

(Substituting, K3= K1/ 2z_2^2, then Tst = k3V2 (The graph in Figure below Sample Torque & Current versus Speed Curve.)

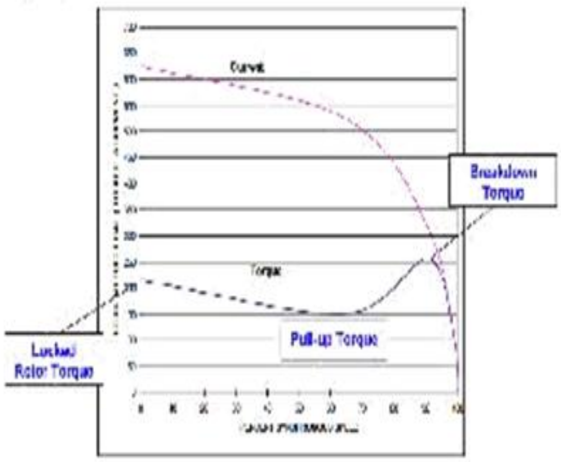

Fig 3. Sample Torque & Current versus Speed Curve

All Variable Frequency Drives maintain the output voltage – to – frequency (V/f) ratio constant at all speeds for the reason that follows. The phase voltage V, frequency f and the magnetic flux Φ of the motor are related by the
equation:

$V = 4.444\ f\ N\ \Phi m$ or $V/f = 4.444 N\Phi m$

Where
N = number of stator turns per phase.

Φm = magnetic flux

If the same voltage is applied at the reduced frequency, the magnetic flux would increase and saturate the magnetic core, significantly distorting the motor performance. The magnetic saturation can be avoided by keeping the Φm constant. Moreover, the motor torque is the product of stator flux and rotor current. For maintaining the rated torque at all speeds the constant flux must be maintained at its rated value, which is basically done by keeping the voltage – to – frequency (V/f) ratio constant. That requires the lowering of the motor voltage in the same proportion as the frequency to avoid magnetic saturation due to high flux or lower than the rated torque due to low flux.

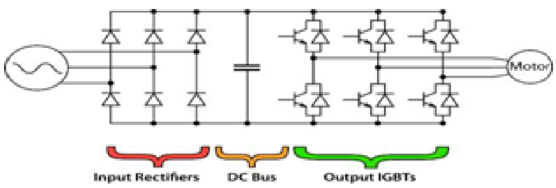

Fig 4. VFD Circuit

Rectifier stage:

A full-wave, solid-state rectifier convert three-phase 50 Hz power from a standard 208, 460, 575 or higher utility supply to either fixed or adjustable DC voltage. The system may include transformers if higher supply voltages are used.

Inverter stage:

Electronic switches - power transistors or thyristors - switch the rectified DC on and off, and produce a current or voltage waveform at the desired new frequency. The amount of distortion depends on the design of the inverter and filter.

Control system:

An electronic circuit receives feedback information from the driven motor and adjusts the output voltage or frequency to the selected values. Usually the output voltage is regulated to produce a constant ratio of voltage to frequency (V/Hz). Controllers may incorporate many complex control functions. Converting DC to variable frequency AC is accomplished using an inverter. Most currently available inverters use pulse width modulation (PWM) because the output current waveform closely approximates a sine waves.

III. SYSTEM DETAILS

Table 1. System specification for SRIM

Power Rating ,P	150HP/110KW
Speed ,N	740RPM
Frequency, f	50Hz
No. of Steps in Speed Control, n	3

Specifications of SCIM drives used in VFD scheme is as reported in table 2.

Table 2. System specification for SCIM

KW/HP	110/150
Rated Voltage (Volt)	415 V
Number of phases	3
Number of Poles p	4
Rated Frequency (Hz)	50
Moment of Inertia j kg.m2)	2.9
Power Factor	0.78
Efficiency	94.2
Speed	740rpm

For SRIM

The actual slip for the SRIM is given by,

$$slip = \frac{N_S - N_R}{N_S}$$

$$s = \frac{1000 - 740}{1000}$$

S=0.026

$$I_2 = \frac{SE_2}{\sqrt{(R_2^2 + SX_2^2)}}$$

and

$$s = \frac{R_2}{X_2}$$

Considering Rotor resistance only From above two equations R_2=0.1562ohms.

Therefore the total losses=3*208^2*0.1562 =20.27KW

If the ropeway is working for 8 hours/day Then power loss=8*20.27 =162.16Kwhr

For the SCIM
Rotor resistance is =0.1123ohms. Total power loss=3*208^2*0.1123 =14.57

If the ropeway is working for 8 hours/day Then power loss=8*14.57

=116.60 Kwhr

IV. ENERGY SAVING MECHANISM

Variable frequency drives (VFD) are becoming more common place and more widely used in applications. They are capable of varying the output speed of a motor without the need for mechanical pulleys, thus reducing the number of mechanical components and overall maintenance. But the biggest advantage that a VFD has is the ability to save the user money through its inherit nature to save energy by consuming only the power that's needed

A VFD is similar to the motor to which it's attached, they both convert power to a usable form. In the case of an induction motor, the electrical power supplied to it is converted to mechanical power through the rotation of the motor's rotor and the torque that it produces through motor slip. A VFD, on the other hand, will convert its incoming power, a fixed voltage and frequency, to a variable voltage and frequency. This same concept is also the basis to vary the speed of the motor without the need of adjustable pulleys or gearing changes. [1]

Electrical calculations
Electrical power is defined as the following:

Power (P) = √3 x Voltage (V) x Current (I) x Power Factor
(PF)

In an ideal VFD, the following would hold true: Powerin = Powerout

For this, we will assume that this extra power draw is negligible.

With these two equations, we can then define the relationship between the VFD's input and output:
Vin x Iin x PFin = Vout x Iout x PFout

Taking these equations into account, we use a 150-hp implemented motor with the following specifications:

Power=150HP
Speed=740rpm
Voltage=415V Power factor = 0.78
Full load current=208A

"A VFD will convert its incoming power, a fixed voltage and frequency, to a variable voltage and frequency."

Assume that the motor is running at 50 Hz on a VFD, drawing a no-load current of 73 A at the output of the VFD. With this, assume that the input current would also be the same, 73 A. The power factor causes this "discrepancy" in current, when a motor is running at no load, the motor's power factor can be assumed to be zero, not 0.78, 78 as stated on the nameplate. The reason the power factor isn't at 0.78 is because this is the motor power factor at full load. Alternatively, mechanical (friction) and electrical (resistive) losses in the motor prevent the power factor from being zero when running no load, but we'll assume these losses to be zero just like we did for the VFD. Therefore, you would have the following:

Pout=415Vx73Ax0
Pout = 0

Because the output power is zero, the input power also will be zero. With a fixed input voltage, the two variables would be current and power factor. Because current is needed for a power factor to exist, both current and power factor are zero, which means the low input current reading is indeed correct.

This explains why the input current to the VFD is so low when the motor is operating under no load conditions. But what about under load? The same concept still applies when the motor is under load. For example, assume the same motor is now operating at half speed, 25 Hz and producing full motor rated torque and drawing the motor's full-load amps (FLA).

In this example, the input current is less than half of the output, a result of having a higher power factor on the input side. The difference in power factor between the input and output side of the motor is what makes it possible to have a higher output current than input current. Assuming the motor is now running at full load and using the same power factor values, your input current now becomes:

Iin = (√3 x 415V x 208A x 0.75) / (√3 x 415V x 0.78) =
200A

Which is **8 A** lower than the output current.

As the current is reducing by 8A i.e. from 208A to 200 A. So losses because of VFD is again going to be less.

Power loss with VFD=3*200^2*0.1123=113.47kw
Therefore the energy saved because of VFD is 116-113=3kw.

For the 8hours it will be=3*8=24kwh.

From the above performance analysis it found that energy consumed by the VFD fed SCIM is very much less than SRIM.

Mechanical

The current a VFD draws on the input side also can be related to the mechanical power a motor is delivering. The basic relationship for motor power is:
Powermechanical ∝ Speed x Torque

This means that if the motor is operating at half the speed and producing full torque, the motor is outputting half of its rated power. Consequently, if the motor is running at full speed and producing half torque, the motor is also outputting half of its rated power.

Because of motor losses, the power relationship between the electrical power going into the motor and the mechanical power is:

PowerElectrical = (Powermechanical) / (EfficiencyMotor)

Revisiting the above example, if the motor is operating at

25Hz, half the motor's rated speed and producing full torque, then the mechanical power being produced is 75 hp. the motor is 78 % efficient, the electrical power that's required is:

Power $_{Electrica}$l = (75HP x 0.746) / 0.78 = 71.73kW

Which means that the current on the input side of the VFD will be approximately 91 A. This same current will also hold true even if the motor is operating at full speed and producing half torque.

Ultimately, a VFD is merely a power conversion device that converts the fixed voltage and frequency of incoming power to a variable voltage and frequency output to provide the variable speed capabilities for which it was designed. Keep in mind the variables associated with electrical power (voltage, current and power factor) and their relationships when comparing the VFD's input to its output. This also will hold true when using the motor's mechanical power (speed and torque) to determine the amount of input power/current to the VFD. Taking all the variables into consideration, one can be pleasantly surprised to find the input current lower than the output current,

V. SIMULINK IMPLEMENTATION OF VAIRIABLE FREQUENCY FOR SCIM

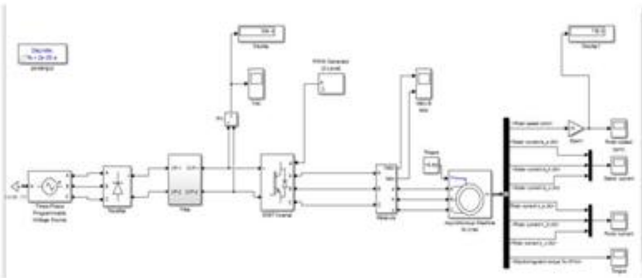

FIG 5. VARIABLE FREQUENCY DRIVE

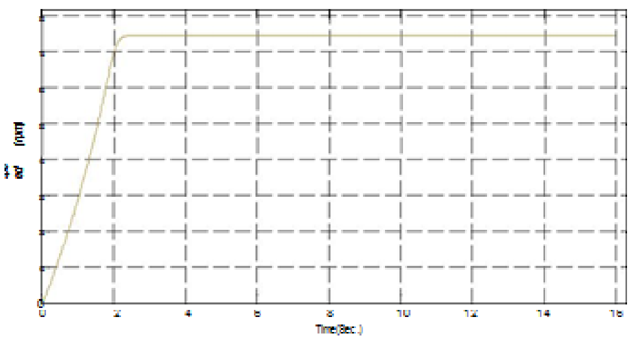

FIG 6. SPEED IN RPM FOR VFD DRIVE

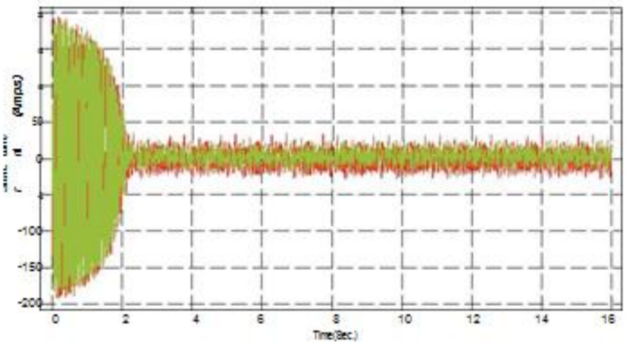

FIG 7. FIG.5 STATOR CURRENT FOR VFD DRIVE

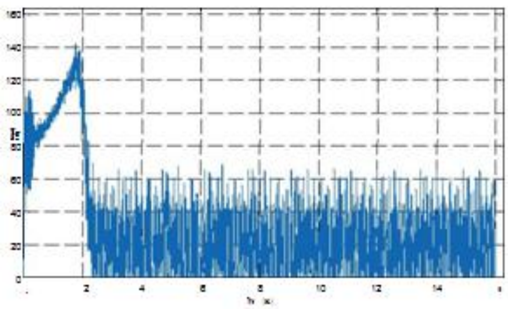

FIG 8. TORQUE FOR VFD DRIVE

The parameters are initially ramping in nature till they got settled at the peak value at 50Hz. Figure 13 shows the Rotor speed. It is seen that the VFD has succeeded in increasing the nominal speed of the motor from using the nominal frequency of 50Hz. Initially the speed of the motor rises from zero and increases up to the rated speed; it experiences some transients and then settles to a stable level within few milliseconds. Finally figure 15 shows the electromagnetic torque of the model. VFD provides the following advantages:

- Energy saving
- Low motor starting current
- Reduction of thermal and mechanical stresses on the motors and ropeway.
- Easy to install
- High power factor

Result:
The performance analysis of SRIM and SCIM with VFD is carried out. The simulation of the SCIM with VFD is carried out in MATLAB environment. The replacement of SRIM with VFD fed SCIM. The saving in energy is 49Kwhr obtained. Also the control is very smooth and the mechanical problems like's jerks have been solved.

VI. CONCLUSION

Energy saving and smooth control is obtained also the mechanical gearing system has been reduced with the replacement of SRIM by VFD fed SCIM

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