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ENERGY OPTIMIZATION IN A CEMENT PLANT: A CASE STUDY ON REPLACING GRR WITH MV DRIVE

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ABSTRACT

This paper presents a case study on energy conservation in a cement plant achieved by replacing the conventional Grid Rotor Resistance (GRR) starter with a Medium Voltage Variable Frequency Drive (MV VFD) for a high-power coal mill fan motor. The study involves collecting real-time operational data both before and after the VFD installation. The VFD integration enabled variable speed control, improved power factor, soft starting capability, smooth control of process, and a significant reduction in thermal and mechanical stress on the motor and fan system.

KEYWORDS: Coal Mill Fan, Energy Conservation, Grid Rotor Resistance (GRR), Medium Voltage Drive, Variable Frequency Drive (VFD).

I. INTRODUCTION

The cement industry is one of the most energy-intensive sectors, with electrical energy consumption contributing significantly to production costs. Among the major electrical loads in a cement plant, fans and large drive motors used in raw mills, coal mills, and clinker cooling systems account for a substantial share of the energy demand. Traditionally, many of these motors operate using conventional starting methods such as Direct-On-Line, Star-Delta, Grid Rotor Resistance or use dampers. While functional, these methods result in significant energy losses, limited speed control, and mechanical stress on equipment.

Purpose of the Coal Mill Fan in a Cement Plant:

The coal mill fan is used to extract hot gases through the coal mill it draws hot air from the kiln or preheater and passes it through the coal mill this hot air helps dry the raw coal while it is being ground. Maintain negative pressure inside the mill, the fan creates suction to keep the coal mill under slightly negative pressure, which ensures proper flow of material and prevents coal dust from escaping into the environment. It Transports pulverized coal to the separator or bag filter, after grinding the fine coal particles are lifted by the air stream and carried to the separator or directly to the kiln burner if part of a direct firing system. Assist in combustion process stable and controlled coal flow enabled by the fan supports uniform combustion in the kiln or calciner, critical for clinker production.

In Dalmia cement plant Before the implementation of the VFD, a GRR starter was used to operate this 850 kW slip ring induction motor driving the coal mill fan. While using with GRR during startup, dampers were used to block initial air flow on the fan to decrease the load on motor to avoid high inrush current but due to this there used to be a drop in pressure resulting in power loss. After the VFD implementation, the drive can now be started directly eliminating the need of damping mechanism. In this plant Coal mill fan drive is a slip ring type induction motor, to enable integration with a MV VFD, the motor's rotor end rings were shorted (as shown in Fig.1), effectively converting it into a squirrel cage induction motor, which is compatible with VFD operation.

Fig.1.1 Shorted End Ring of Rotor.

Variable Frequency Drives, especially medium voltage (MV) types, offer a modern and energy-efficient solution by enabling precise motor speed control, soft starting, improved power factor, and reduced system losses. VFD integration is gaining momentum in industrial environments due to its potential to deliver measurable energy savings, enhance process flexibility, and lower maintenance needs.

II. LITERATURE REVIEW

In Dalmia cement plant electric motors account for a substantial portion of total power consumption, large process fans such as coal mill fans(850 kW), preheater fans(2×1650 kW), and raw mill fans(3500 kW) often operate under varying load conditions. Traditionally, these motors were started and operated using Grid Rotor Resistance (GRR) starters. While GRR provides basic control for slip ring induction motors, it is associated with high rotor losses, low precision in speed control, poor power factor, and limited efficiency under partial loads and has frequent maintenance.

Several studies have highlighted the energy-saving potential of Variable Frequency Drives (VFDs) in industrial applications. Integrating MV VFDs in large fan systems can yield energy savings of 20–30%[3], along with improved control and system stability. VFDs offer features like overload protection and dynamic torque control, further enhancing motor longevity[1] While the benefits of VFDs are well-established, limited plant-level case studies exist specifically for coal mill fan applications. This paper addresses that gap by evaluating the technical and economic performance of an 850 KW coal mill fan motor converted from GRR to MV VFD at a cement plant.

III. METHODOLOGY

The MV VFD used in this project consists of three major sections: an input rectifier that converts 3-phase AC to DC a DC link with filter capacitors, and an inverter that synthesizes variable-frequency AC using pulse width modulation.[3] The drive operates under V/f control logic, maintaining a constant voltage-to- frequency ratio to ensure consistent magnetic flux and torque.[5] The VFD was configured to operate from 0 to 50 Hz, allowing the fan speed to be adjusted as per process demand while improving efficiency.

Energy consumption, power factor, and motor performance were analyzed under both GRR and VFD operation. Real-time operational data was obtained through SCADA logs and energy meters integrated into the plant's control system.[6] Nameplate details and electrical parameters were recorded for both motor and fan.

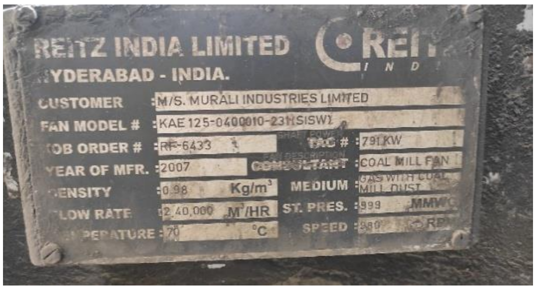

Fig.3.1 Nameplate of 850kW Slip Ring Induction Motor.

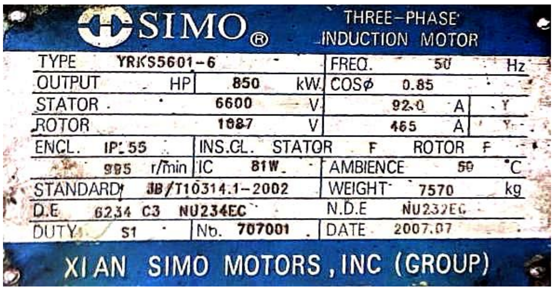

Fig.3.2 Nameplate of Coal Mill Fan.

Power consumption (kW), energy used (kWh), current, voltage, and power factor were monitored before and after the conversion.

Data analysis was performed using Microsoft Excel for trend plotting and comparison. Graphs were created to represent daily energy usage and power factor trends. Cost savings were evaluated using the average unit energy cost provided by the plant, and payback period was calculated based on the initial investment in the VFD system.

This methodology enabled a reliable comparison between the two systems and established a clear correlation between VFD integration and energy efficiency improvements.

IV. WORKING PRINCIPLE

4.1 GRR

In a slip ring induction motor, the rotor windings are connected externally through slip rings and brushes.

A three-phase resistor bank (GRR) is connected to the rotor terminals.

At motor startup, high resistance is inserted into the rotor circuit. This increases the rotor impedance and limits starting current while boosting starting torque.

As the motor picks up speed, the external resistance is gradually reduced in steps (manually or automatically), eventually shorting the rotor windings directly (i.e., bypassing the GRR).

Once the motor reaches near-rated speed, the motor behaves almost like a squirrel cage motor (with low rotor resistance).

4.2 VFD

A Variable Frequency Drive (VFD) controls the speed of an AC motor by varying the frequency and voltage of the power supplied to the motor.[5] The basic operation involves three main stages.

4.2.1 Rectifier Stage: Converts the incoming 3-phase AC supply into DC using diodes or thyristors.

4.2.2 DC Link: Filters and smooths the DC power using capacitors and inductors to provide a stable DC voltage.[3]

4.2.3 Inverter Stage: Converts the DC back to AC with variable frequency and voltage using Insulated Gate Bipolar Transistors (IGBTs) through Pulse Width Modulation (PWM) technique.[7],

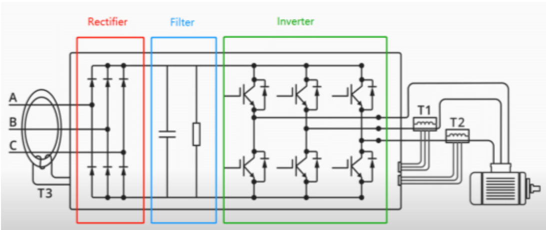

Fig. 4.2.1 Circuit diagram of VFD.

By changing the frequency (f) of the output, the motor speed can be controlled, since motor speed (N) is given by the formula.

$N = 120 \times f / P$

Where:

N = Speed in RPM

f = Frequency (Hz)

P = Number of poles of the motor

This enables precise speed control, improved efficiency, and energy savings in industrial applications.

V. CALCULATIONS

This section presents the observed data collected before and after the implementation of the MV VFD on the 850 kW coal mill fan motor. The performance was evaluated based on power consumption, energy savings, power factor, and operational behavior.

5.1 Power Consumption

Before VFD installation, the motor operated via a GRR starter with an average load of approximately 402 kW. After installing the MV VFD, the average load reduced to 286 kW due to optimized speed control and improved efficiency.

5.2 Energy Savings

Based on continuous 24-hour operation:

Daily Energy Saving = (402 KW – 286 KW) × 24 i.e. 116×24 = 2784 kWh/day

This corresponds to an annual saving of over 2784 × (330 Days) = 918,720 kWh/year

5.3 Cost Savings

An average energy cost of ₹4.86/unit (Power generation cost per unit at captive power plant at Dalmia cement plant)

Daily Cost Saving = 2784/kWh × ₹4.86/Unit = ₹13,530 per day.

Estimated annual savings exceed ₹44 lakhs.

Per unit generation might vary according to generation cost, CCW plant have its own captive power plant.

If the plant uses grid as power source, per unit cost will be around (₹7- ₹8) /UNIT

5.4 Pay Back Period

VFD Total installed cost = ₹1,06,30,000

Payback years = 1,06,30000/44,64,499 ≈ 2.38 years

Payback months = 2.38 × 12 ≈ 28.5 months

Power Consumption Comparison Table

Parameter	GRR Starter	MV VFD System
Average Load (kW)	402	286
Power Factor	~ 0.80	> 0.92
Daily Energy Use (kWh)	9648	6864
Daily Energy Saved	NO	₹ 2784
Cost/Day Saved (₹)	NO	₹ 13530

VI. TECHNICAL AND OPERATIONAL BENEFITS ON REPLACING GRR WITH VFD

6.1 Technical Benefits

6.1.1 Elimination of Rotor Power Losses

GRR systems dissipate energy as heat through external resistors. VFDs eliminate this by using direct rotor shorting, improving overall electrical efficiency.[9]

6.1.2 Improved Power Factor

The power factor increased from ~0.80 (GRR) to above 0.92 with VFD operation, reducing reactive power demand and avoiding penalties.[4],[8]

6.1.3 Reduced Starting Current

VFDs allow soft starting, limiting inrush current to 1.2–2.0 times full-load current, compared to 5–6 times in GRR systems, reducing electrical stress.[3]

6.1.4 Better Voltage and Load Regulation

The VFD maintains consistent voltage and current levels under varying load, improving stability and reducing supply-side disturbances.[8]

6.1.5 Dynamic Speed Control

VFDs offer precise variable-speed operation, enabling better airflow control and energy optimization, which is not possible with fixed-speed GRR systems.[8]

6.1.6 Lower Harmonic Disturbance (with filters)

MV VFDs with input/output filters maintain acceptable harmonic levels, preserving system power quality.[3]

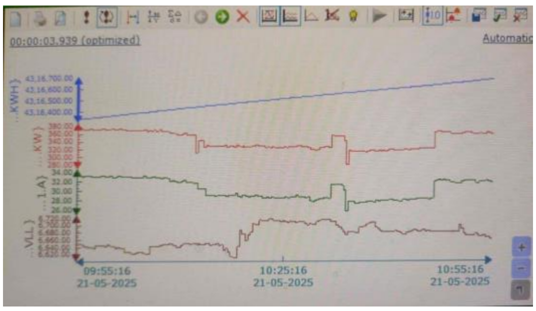

Fig. 5 Electrical Parameter Trends of VFD Motor Operation from SCADA (21-05-2025).

Figure 5 represents the real-time monitoring of a slip ring induction motor operated using a VFD. The graph shows voltage (VLL), current (A), active power (kW), and energy consumption (kWh) over a 1-hour duration on 21st May 2025. Compared to the previously used GRR control, the VFD operation demonstrates more stable voltage and smoother power consumption with reduced current spikes. The cumulative energy trend confirms efficient energy utilization. This validates the effectiveness of VFD in minimizing losses and enhancing motor performance under varying load conditions.

6.2 Operational Benefits

6.2.1 Enhanced Process Flexibility

The ability to vary fan speed based on process demand improves system responsiveness and clinker/coal handling performance.[8]

6.2.2 Reduced Mechanical Stress

Smooth motor acceleration and deceleration reduce stress on fan shafts, couplings, and bearings, increasing equipment life.[8]

6.2.3 Lower Maintenance Requirements

Eliminating rotor resistors reduces routine inspection and resistor failure risk, leading to fewer breakdown.[9]

6.2.4 Reduced Motor Heating and Vibration

The motor runs cooler and with less mechanical noise, improving efficiency and reducing lubrication frequency.[9]

6.2.5 Real-Time Monitoring and Control via SCADA

VFD parameters like current, voltage, power, and speed are monitored live, enabling better diagnostics and remote fault detection.[9]

6.2.6 Energy Savings and Cost Reduction

With optimized speed and reduced losses, daily savings of over 2784 kWh are achieved, translating to significant annual cost savings and a short payback period.

VII. CONCLUSION

Replacing the GRR starter with an MV VFD for the 850 kW coal mill fan motor significantly improved system efficiency, reduced energy consumption by over 30%, and enhanced power factor. The upgrade resulted in daily savings of 2784 kWh and reduced operational stress on equipment. With a payback period of under 28 months, the VFD implementation proves to be a technically and economically viable solution for energy optimization in cement plants.

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