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The application of Variable Frequency Drive as an efficient control element in cement industry

Amresh Kumar Ray, Kaushal Prasad and Nitish Kumar
[1]*Student, Department of Electrical and Electronics Engineering*
Maharaja Surajmal Institute of Technology, GGSIPU, New Delhi , India
Under guidance of Mrs. Nidhi Gupta, Assistant Professor,
Department of Electrical and Electronics Engineering

ABSTRACT
Variable Frequency Drives have been available to the cement industry for a number of years. Each step of the way from the quarry to the finished cement product, variable frequency drives are used to smoothly start large motors and continuously adjust the speed as required by the process. In cement industry many application machines such as excavators, induced draft fan, mills, conveyors, crushers and kilns which are driven by induction and synchronous motor are controlled by variable frequency drive. The control process through variable frequency drives leads to efficient speed control, low power losses, energy savings, low pollution and significant saving in economy. This paper reviews how variable frequency drive has emerged as a reliable control solution for the cement industry.

KEYWORDS: *variable frequency drive (VFD), induction motor, control, cement industry, power, energy and variable speed drive (VSD)*

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I. INTRODUCTION

It is interesting to know that historically the first A.C. drive (400hp) using the thyratron cycloconverter-fed wound-field synchronous machine(called thyratron motor), was installed in 1932 by F.E. Alexanderson of General electric in the Logan Power Station of Pacific Gas and Electric Company [3].From then industrial drives have evolved rapidly by dedicated effort of many scientists and engineers all over the world resulting in development of advanced drive technology such as VFD.VFD is power electronics based device which converts a basic fixed frequency, fixed voltage sine wave power (line power) to a variable frequency, variable output voltage used to control speed of induction motors [1]. It regulates the speed of a three phase A.C. electric motor by controlling the frequency and voltage of the power it delivers to the motor. Today, these devices are becoming prevalent in a wide range of applications throughout the cement industry, from motion control elements to ventilation systems, from waste water processing facilities to machining areas, and many more. The author's intention is only to provide a basic level introduction to the cement Industry professional with particular emphasis on controlling of different motors through VFD's .The block diagram of generalised motor control through VFD is shown in Fig. 1

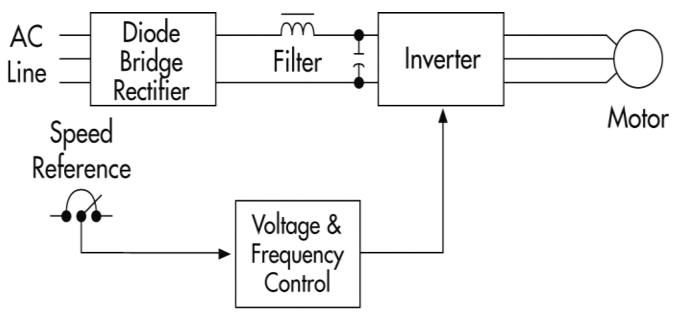

Fig. 1: Generalised motor control through VFD

II. Why Variable Frequency Drives?

Here are some of the reasons to use VFD's in cement industry:-

- **Increased Reliability:**

Adjustable speed motor-drive systems are more reliable than traditional mechanical approaches such as using louvers, valves, gears, or turbines to control speed and flow. Because electric drives have no moving parts they provide very high reliability [5].

- **Energy Saving:**

Primary function of VFD in cement industry is to provide energy savings .On an induced draft fan with a variable speed motor drive system, the flow control louver or valve is not required, avoiding large flow energy losses. In fact, the variable speed motor drive system is more efficient than all other flow control methods including turbines and hydraulic transmissions [1].For example Mexican cement plant is saving 5,300 MWh annually since replacing the existing damper fan control of two 735 kW fixed speed induced draft fans with ABB AC drives. Additional benefits included improved productivity, which has boosted revenues by about €574,000 per year, whilst giving a reduction in maintenance by 97 percent. The payback time has been estimated at six months [8].

- **Speed Variations:**

Beyond energy uses, applications such as conveyors, crushers and grinding mills can use the motor and VFD's packages to provide optimal speed variations. In some cases, the operating speed range can be wide, which a motor applied with a constant frequency power source cannot provide. In the case of conveyors and mills, a VFD and motor system can even provide a "crawl" speed foe maintenance purposes eliminating the need for additional drives [2].

- **Soft starting of one or multiple mill motors:**

When electric drives soft start large motors, the problem associated with large inrush current (mechanical wiring stress, wiring overheating and voltage dip on connected bus) is eliminated. This removes limitations on motor frequency of starts, reduces insulation damage, and provides extended motor life. With synchronisation logic, one drive can start multiple motors.

- **Extended Equipment Life and Reduce Maintenance:**

The VFD's greatly reduce wear to the motor, extend life of the equipment and decrease maintenance costs. Due to optimal voltage and frequency control it offers better protection to the motor from issues such as electro thermal overloads, phase protection, under voltage, over voltage etc. When you start a load with a VFD you will not subject the motor or driven load to the "instant shock" of across the line starting, but can start smoothly, thereby eliminating belt, gear and bearing wear.

- **High Power Factor**

Power converted to motion, heat, sound, etc. is called active power and is measured in kilowatts (kW). Power that charges capacitors or builds magnetic fields is called reactive power and is measured in kVAR. The vector sum of the kW and the kVAR is the Apparent Power and is measured in KVA. Power factor is the ratio of kW/KVA. Typical AC motors may have a full load power factor ranging from 0.84 to 0.88. As the motor load is reduced, the power factor becomes low. The advantage of using VFD's is that it includes capacitors in the DC Bus itself which maintains high power factor on the line side of the VFD. This eliminates the need of additional expensive capacitor banks [6].

III. HOW A VARIABLE FREQUENCY DRIVES WORKS?

A VFD converts 50 Hz power, for example, to a new frequency in two stages: the rectifier stage and the inverter stage. The conversion process incorporates three functions:

Rectifier stage: A full-wave, solid-state rectifier converts three-phase 50 Hz power from a standard 220, 440 or higher utility supply to either fixed or adjustable DC voltage. The system may include transformers if higher supply voltages are used.

Inverter stage: Power electronic switches such as IGBT, GTO switch the rectified DC on and off, and produce a current or voltage waveform at the desired new frequency. Most currently available inverters use pulse width modulation (PWM) because the output current waveform closely approximates a sine wave. Power semiconductors switch DC voltage at high speed, producing a series of short-duration pulses of constant amplitude. Output voltage is varied by changing the width and polarity of the switched pulses. Output frequency is adjusted by changing the switching cycle time. The resulting current in an inductive motor simulates a sine

wave of the desired output frequency. The high-speed switching of a PWM inverter results in less waveform distortion and, therefore, lowers harmonic losses [3, 4].
Control system: An electronic circuit receives feedback information from the driven motor and adjusts the output voltage or frequency to the desired values. Usually the output voltage is regulated to produce a constant ratio of voltage to frequency (V/Hz).

IV. THE CEMENT MAKING PROCESS

Cement plants are usually located closely either to hot spots in the market or to areas with sufficient quantities of raw materials. The aim is to keep transportation costs low. Basic constituents for cement (limestone and clay) are taken from quarries in these areas. These raw materials are extracted from the quarry crushed to a very fine powder and then blended in the correct proportions. This blended raw material is called the 'raw feed' or 'kiln feed' and is heated in a rotary kiln where it reaches a temperature of about 1400 C to 1500 C. In its simplest form, the rotary kiln is a tube up to 200 metres long and perhaps 6 metres in diameter, with a long flame at one end. The raw feed enters the kiln at the cool end and gradually passes down to the hot end, then falls out of the kiln and cools down. The material formed in the kiln is described as 'clinker' and is typically composed of rounded nodules between 1mm and 25mm across. After cooling, the clinker may be stored temporarily in a clinker store, or it may pass directly to the cement mill. The cement mill grinds the clinker to a fine powder. A small amount of gypsum is normally ground up with the clinker. The gypsum controls the setting properties of the cement when water is added.

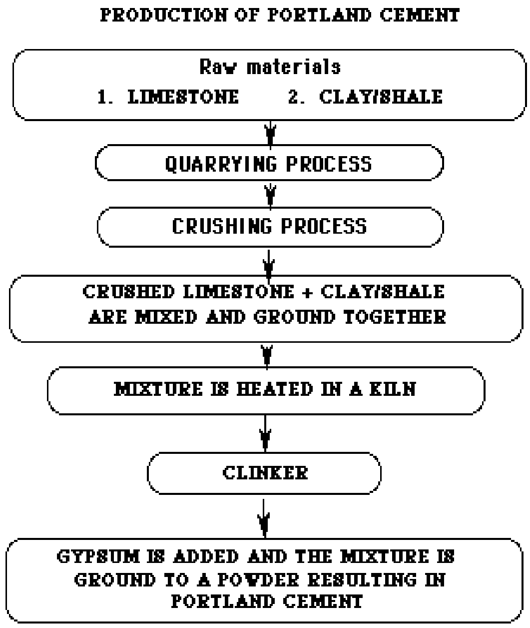

Fig. 2: Block diagram for cement manufacturing process

V. APPLICATIONS OF VFD'S IN CEMENT PLANT

Variable frequency drives are used to control the speed of fans, mills, conveyors and kilns in the cement industry. VFD's are also used to smoothly start large mill motors, synchronize, and connect them across the line.

➢ ***Induced Draft Fan for Cement Kiln***

The induced draft fan induces kiln air flow, which must be continuously controlled to match the process requirements. Because cement making is a thermal and a chemical process, both air volume and mass flow must be controlled. The process control system continuously monitors process conditions such as inlet air temperature, kiln feed, cement composition, and required fuel air ratio. The process control system then directs the blower and flow control system to provide the optimum air flow [5].

Traditional flow control methods use constant speed motors with mechanical flow reducing devices such as:
- Inlet louvers (dampers) in the ducting.
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- Flow guide vanes in the fan casing.
- Variable slip clutches in the fan drive shaft.

These traditional mechanical solutions have significant disadvantages:

- High energy consumption at reduced flow rates.
- Mechanical wear and required maintenance.
- Process interruptions due to mechanical problems.
- Limitations on motor starting duty.

Advantage of using VFD for induced draft fan of Cement Kiln:

- Maintenance of uniform working temperature, reduced fan noise and saving of valuable floor space in the plant.
- The ID fan power can be several thousand hp and using a drive to control air flow can result in considerable energy savings
- VFD optimises the fan RPM in such a manner that it precisely matches the system operating conditions.

- ***Cement Kiln Speed and Torque Control***

Variable speed drives are used to control the rotational speed of cement kilns. In addition to enhanced process control, the VFD increases the life of the mechanical equipment and reduces mechanical maintenance and operating costs. The drives also provide accurate torque and speed feedback signals, which are used by the distributed control system to improve kiln process control

Special requirements of kiln drives:

- High reliability. As cement making is a continuous process the kiln needs to operate 24 hours a day. As each kiln stop can cost several thousand dollars per hour, maximizing uptime is paramount.
- A wide range of speed control. During normal operation the rotary kiln is to be driven with the most suitable speed. This is decided by the condition of the material combinations and the combustion even if a load variation occurred.
- High control accuracy is required for an accurate load.
- Motor current limit protection during starting stage.
- High starting torque. A special design requirement is the starting torque. It is typically 250 percent of full load torque for the first three to five seconds before dropping to around 200 percent and gradually reducing further during the next 15 to 20 seconds at the end of which period the full speed is attained. This can be seen in figure 3.

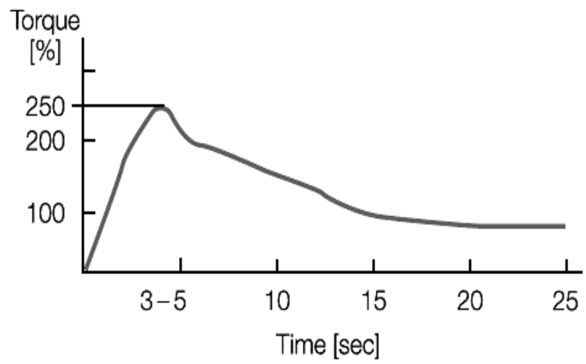

Fig. 3: Typical starting characteristic for a kiln

- **Conveyors**

Conveyors are found in almost every cement plant. It is used to handle raw as well as finished materials simultaneously between the cement plant and the harbour. Due to continuous operation there is always a risk of damaging the belt by overstretching, slipping or breaking. To reduce operational costs, it is important to extend the belt lifetime and availability. Variable speed drives provide accurate torque and speed control of conveyors. This reduces the stress on mechanical equipment such as gearboxes, pulley and belts, especially during start-up and stopping, but also during operation and maintenance [8].With the use of VFD it is possible to control the speed of the conveyors to match the production capacity and as such reduce wear and save energy. For maintenance inspection, belt changes or repairs or avoidance of ice build-up it is possible to run the conveyor belt at slow speed [8].

➢ **Mills**

In cement production, mills are process critical. Reliable and precise control has a high impact on production throughput and operating costs. Controlling them with VSD's results in the following benefits:

- **Optimized plant production:** By controlling a mill with a VFD, the speed of the mill is tuned for optimal grinding and maximum throughput, resulting in a more efficient use of the grinding power. If up and downstream processes require a lower grinding throughput, the mill can be operated at partial load without having to stop the process. VFD's can adjust the speed according to charge volume.

- **Less wear and higher reliability:** Grinding raw material and clinker causes considerable wear to the grinding mill. Starting the mill direct-on-line stresses the mill and the gearbox, increasing the risk of gearbox failure and shortens the lifetime of mechanical equipment. VFD's optimizes the mill speed to match the material flow, thus minimizing the wear of the grinding mill.
- **Energy savings:** Grinding mills can consume more than 60 percent of the plant's total electrical energy. Controlling them with VFD's results in significant energy savings.
- **Smooth ramp up:** Torque pulsations and peak torques, generated by mills during the starting phase, creates high stresses on network and mechanical equipment. VFD's provide a smooth ramp up of the mill. They deliver high starting torque for the current drawn from the power plant system and have a programmed upper limit to reduce peak current during the start of the mill. The low starting currents and high starting torque enable a smooth start-up of the mill, even when fully loaded [8].

➢ **Slip power Recovery**

Wound rotor induction motors have been popular in some industries, particularly cement, for decades. Until about 1985, a wound rotor induction motor (WRIM) was the only large ac motor that allowed controlled starting characteristics and adjustable speed capability. A WRIM is a machine with a 3-phase wound stator that is usually connected directly to the power system. The rotor also has a 3-phase winding, usually connected in a star circuit. The three terminals of the rotor winding are connected to separate slip rings, which are normally connected to a liquid rheostat or resistor bank. Changing rotor resistance changes the motor speed. In the past the power dissipated in the rheostat was lost as heat; however, using a variable speed drive as shown in figure 4 in place of the rheostat, the slip power can be recovered and returned to the utility supply, thus saving energy. The is achieved by rectifying slip-frequency power, inverting this to line frequency, and injecting it back into the supply through coupling transformer [5,7].

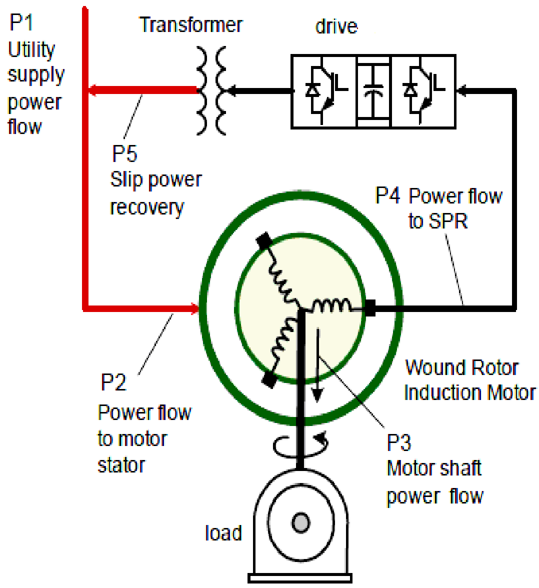

Fig. 4: Slip power recovery scheme for WRIM

VI. SIMULATION

➢ MATLAB *block diagram for Variable Frequency control of induction motor :*

Asynchronous Machine parameters and specifications are as follows:-
Nominal power, voltage (line-line), and frequency - [3*746 VA, 220 Vrms, 60 Hz]
Stator resistance and inductance - [1.115Ω 0.005974H]
Rotor resistance and inductance - [1.083Ω 0.005974H]
Mutual inductance - 0.2037H
Inertia constant, friction factor, and pole pairs - [0.02kg.m^2 0.005752N.m.s 2]
Rotor type - Squirrel Cage
Rated Power - 3 HP

Three-Phase PWM Generator parameters are as follows:-
Type - 2 levels
Mode of operation - Un-synchronized
Carrier frequency - 18*60Hz (1080 Hz)
Internal generation of modulating signals - selected
Modulation index m - 0.9
Output voltage frequency - 60 Hz
Output voltage phase - 0 degrees
Sample time - 10e-6 s

Scope properties:-
Number of axes - 4
Time range - 0.05 s
Tick labels - bottom axis only

Universal Bridge Parameters are as follows:-
Power electronic device - IGBT/Diodes
Snubber: Rs - 1e5 Ω; Cs - inf; Ron - 1e-3 Ω
Forward voltages: Vf - 0 V; Vfd - 0 V
Tail: Tf - 1e-6 s; Tt - 1e-6 s

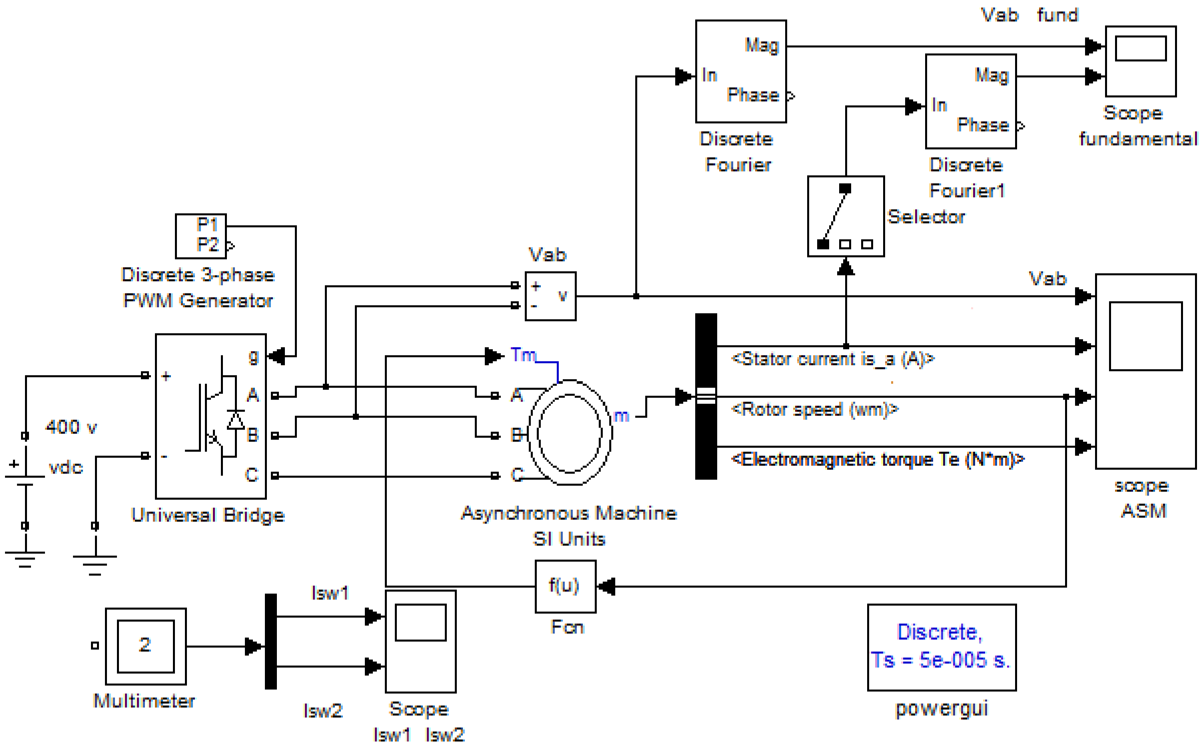

Fig. 5: The simulink model for VFD technique

➢ *Simulation Results for Motor Starting at Full Voltage:*

The motor starts and reaches its steady-state speed of 181 rad/s (1728 rpm) after 0.5 s. At starting, the magnitude of the 60 Hz current reaches 90 A peak (64 A RMS) whereas its steady-state value is 10.5 A . Strong oscillations of the electromagnetic torque at starting are observed. On zooming onto response, we observe a noisy signal with a mean value of 11.9 N.m, corresponding to the load torque at nominal speed. For the three motor currents, we can see that all the harmonics (multiples of the 1080 Hz switching frequency) are filtered by the stator inductance, so that the 60 Hz component is dominant.

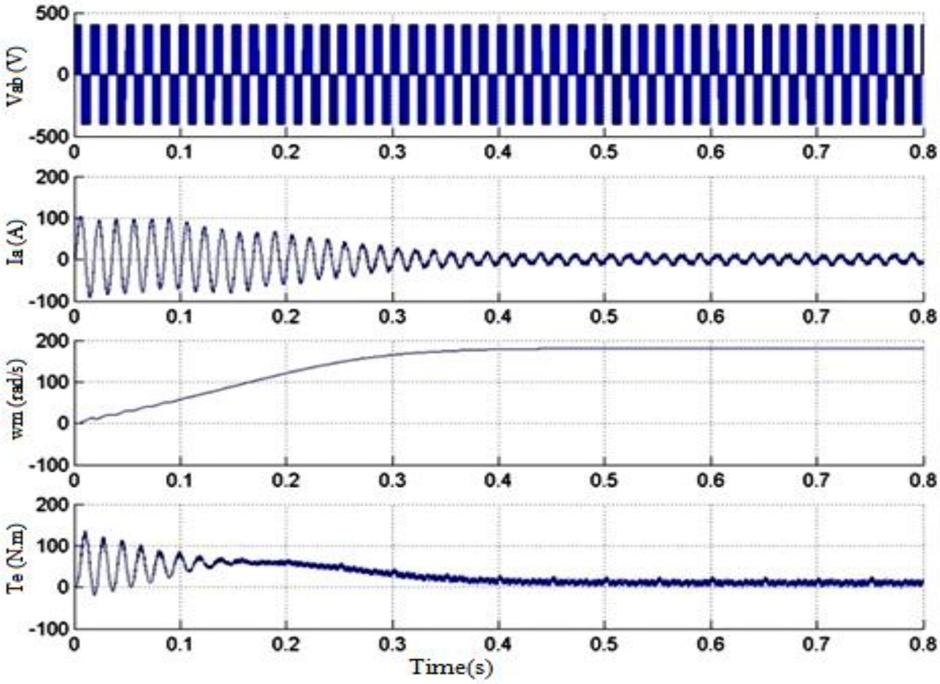

Fig. 6: Response for motor starting at full Voltage in VFD technique

VII. CONCLUSION

The number of VFD drives in the cement industry is increasing day by day. These drives have been proven to be reliable and cost effective for satisfying the requirements for speed control in the cement industry. However, the electrical rooms housing the equipment must be designed with a sufficient ventilation system, which must also include cooling, in order to ensure the satisfactory operation of the drives. When properly designed and applied, these drives operate efficiently and require very little maintenance.

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