

Energy Efficient Speed Control Using Modern Variable Frequency Drives

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Introduction

Efficient speed control of equipment is a prerequisite in modern cement plants as a result of an ongoing thrust for process optimization.

Invariably, this calls for the need to accurately control gas flow rates, blending of materials and cooling water used during the manufacturing process, so that the most satisfactory operating conditions can be obtained against various process variables in the plant.

In the past, various control methods were employed to obtain flexibility and consistency during manufacturing of cement. These included one or more methods of limited control of the speed of the equipment, such as changing gear ratios or pulleys, or using hydraulic drives. Most often however, gas and liquid flow rates were controlled with dampers or throttled valves while the fan or the pump kept operating with a fixed speed motor.

The mechanical speed changing drives and some of the hydraulic drives are known to be hard wearing on the components, are often inefficient and have high operating costs. Very few of these types of drives remain in use today.

The electric motors with either direct current (DC) or alternating current (AC) drive controllers have been the most popular choice in many applications requiring speed control.

The DC motors have been for many years the real workhorses in many large drive applications requiring high output torque and smooth speed control. The main disadvantages of the DC motors rest with the commutator and brush design, which are the most sensitive components in the design of the motor. In order to ensure good commutation and uniform current distribution in the brushes, an inverse power versus speed relationship exists between those two requirements, which limit the design of the motor for a particular load application.

The AC motor drives with either stator or rotor resistance controller has also been in use reliably for many years. The main disadvantages of these drives are the limited speed control range and the large amounts of heat loss dissipated by the external resistance circuit.

Variable Frequency Drives

Whereas the above methods of speed control remain widely in use in the industry today, the variable frequency drives have slowly gained an equal status of acceptability in many speed control applications traditionally reserved only for the DC drives.

The slow introduction of these drives and their acceptance as the modern method of speed control has not been without merits. Earlier generations of drives were expensive and the switching devices were prone to failures. Individual switching devices had limited current and voltage ratings, and in order to achieve a given output many components had to be used in series and parallel combinations. The cost of the drive was high and reliability was poor. The additional cost to the power system for mitigating the

harmonic effects and the operating power factor were also deterrent issues.

However, recent technological advances in the design of electronic switching devices offer greater power handling capabilities and greater reliability than the earlier generations of these same devices and at a much lower cost. These features, combined with standardized components and more sophisticated digital control algorithms make the variable frequency drives today the norm rather than the exception in satisfying the speed control requirements in the cement industry.

HGRSC has developed a broad base of expertise for the design and application of variable frequency drives. In this article, HGRSC will present some of the important features to consider when applying modern variable frequency drives and will present some of the most recent drive applications.

Operating Efficiency

The variable frequency drives are very efficient electrical energy conversion devices. A typical variable frequency drive consists of a controller and an isolation transformer or a reactor, and a motor. The isolation transformers and reactors have efficiencies between 0.97 to 0.99. A typical drive with solid state switching devices will have an electrical efficiency of 0.98 to 0.99. Excluding the motor efficiency, the typical variable frequency drive efficiency is between 0.95 to 0.98.

Published motor efficiency figures are usually valid only for full speed at fundamental voltage and frequency. It is inferred however, that the higher

efficiency motor selected for the fundamental voltage and frequency will have a higher operating efficiency on the non-sinusoidal waveform. Premium efficiency motors have quoted figures of between 0.95 and 0.965 on the fundamental waveform.

For comparison purposes, hydraulic drives have typical starting efficiencies between 0.70 to 0.94 and vary inversely with the speed. In general, these types of drives are best suited in drive applications having space restrictions and requiring high output torque at low speed.

Speed changing gearboxes on the other hand have typical efficiencies of 0.85.

In most non-VFD speed control applications, the motor has to operate at fixed speed regardless of the load requirements. The difference in electrical energy wasted by the motor must also be included when comparing different methods of speed control.

Figure1 illustrates the relationship between power consumption and gas flow for a typical fan load. The diagonally shaded area shows the energy losses when operating under damper control. These damper losses are eliminated when the fan operates with a VFD.

Another advantage when applying variable frequency drives in combination with squirrel cage motors is that the drive will operate between 1% to 2% variation on the output efficiency, from light load to full load over a predetermined speed range.

Other methods of speed control will experience variation in output efficiency

of between 3% to 6% on the average, over a comparable speed range. This difference could add up to considerable energy savings over the life of the drive.

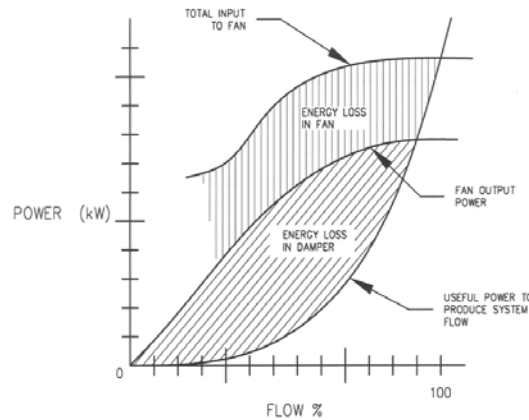


Figure 1- Power vs flow relationship with damper control for a fan load.

Motor Design Considerations

The motors employed with AC variable frequency drives are exclusively squirrel cage (SC) induction motors, which are more reliable and less expensive motors to build and maintain than the DC motors or the slip ring motors. A variable frequency drive with a squirrel cage motor requires little maintenance, which is typically limited to the cooling blowers and motor lubrication.

The squirrel cage motor can be designed to develop a high breakdown torque required by a specific load application. A high torque requirement in the past would have been an incentive for applying only DC motors. Today this requirement can be satisfied by a SC motor designed with a larger frame to produce the equivalent torque.

This is an important consideration in applications such as kiln drives. The power developed at the shaft of the motor is important for achieving production

rates, but the torque capability is what determines the selection of the motor frame.

The starting torque requirements and load inertia are very important features to consider if by-pass operation is required. For VFD applications the motor manufacturer will normally supply a motor, which will not be capable to develop the starting torque required to accelerate the load. All VFD duty motors fall under this category. Therefore, the motor must be specifically designed and be capable to accelerate the inertia of the load on by-pass operation.

Cooling is also a very important issue when motors are used in applications requiring wide speed control ranges. In applications requiring constant load torque over a speed range of no more than four to one, most manufacturers design a motor with sufficient thermal capacity to dissipate the heat generated by the motor's current. For wider speed turn down ratios, separate blowers must be provided to satisfy the cooling requirements.

Modern drive controllers turn on and off the power devices at very high frequencies. The switching gives rise to very fast rates of change of the voltage, which cannot be absorbed by standard motor insulation. In the past there have been numerous dielectric failures attributed to build up of voltages in the supply conductors and in the motor insulation. Consequently when an AC motor is used with a VFD, the insulation level must be usually upgraded, and the motor manufacturer must be made aware of the application.

Most motors are designed today with higher ground wall insulation to account for the proliferation of the variable frequency drives. However, not all of the motor manufacturers or cable suppliers are aware of the higher insulation requirements for VFD applications. Therefore, some drive manufacturers also recommend motor lead filters to be installed at the motor terminations in the field. This is an added degree of safety and must be included by the drive supplier.

Other drive manufacturers will install voltage filters in the output of their drives as a standard feature and will claim that their drives do not impose restrictions on the motor feeder length. This is a more desirable option, which is usually available only for the larger drives.

Each design, however, must be considered on its own merits to determine the most effective solution for the particular drive application.

All drives generate harmonics. In addition to the fundamental current, the harmonic currents from the drive also circulate in the windings and iron of the motor and give rise to additional heating.

The amount of harmonic current generated is a function of the design topology of the drive and switching method of the inverter. A drive designed for six pulses operation in general will deliver a higher (RMS) harmonic current than a twelve or higher pulses drive.

Suppliers often claim that their drives have been designed to operate with ordinary non-VFD duty motors. However, very often it is not an entirely true statement.

A standard motor may be selected for a particular VFD application, but it will be current de-rated. This usually implies a larger motor frame with a larger iron cross section and a larger cooling fan.

Most motor manufacturers however, offer VFD duty motors, which are specifically designed to operate on non-sinusoidal waveform.

VF Drive Controller

A drive controller incorporates one or more of the currently available solid state power electronic devices, such as diodes, silicon control rectifiers (SCRs), insulate gate bipolar transistors (IGBTs), gate turn-off thyristors (GTOs) and integrated gate controlled transistors (IGCTs). The diodes and SCRs are common elements of either an AC or a DC controller. The other devices are used exclusively with variable frequency drives.

All of these devices are designed to electronically convert the input frequency of the power supply (50/60 Hz), to a variable frequency at the output.

An electrical circuit topology for a VFD is shown in Figure2. The drive has three major identifiable component sections:

The first section is called the converter section. Its main purpose is to rectify naturally (diode rectifier) or in a controlled fashion (SCR or IGBT), the input supply voltage and frequency into a fixed DC voltage.

The second section is called the DC link bus, which may include a reactor or a capacitor bank. The primary function of this section is to maintain a fixed reference voltage to be switched by the inverter section.

The third section is called the inverter section and is designed to switch in a controlled fashion the fixed DC link bus voltage into a variable frequency output. Depending on the current ratings this section may contain GTOs, IGBTs, or more recently IGCTs.

The type of converter switching device and DC link voltage defines the operating principle of the inverter: voltage source or current source.

The latest available drive technology employs a voltage source inverter for switching IGBT or IGCT devices.

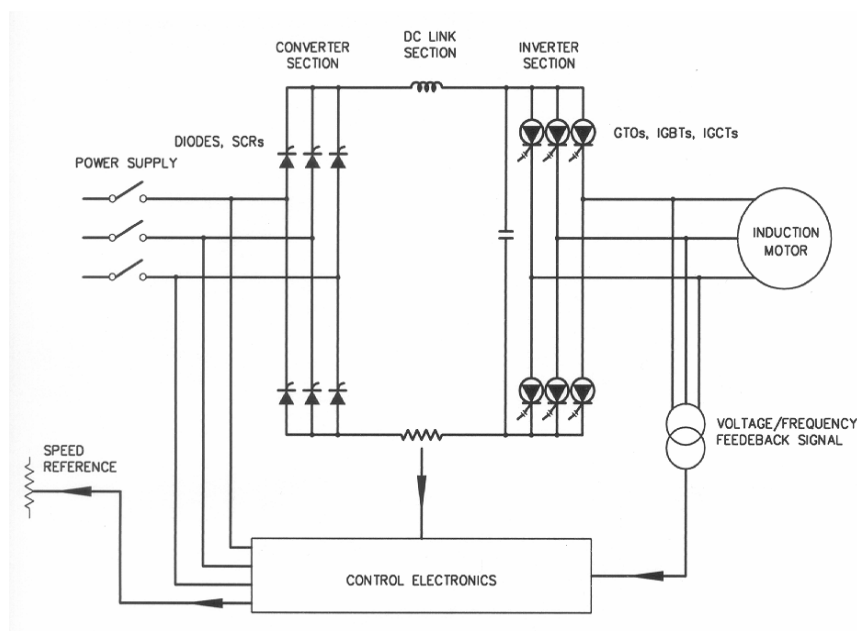
The switching of these devices is controlled by state of the art digital controllers, which contain the algorithms for firing and protecting the solid state devices and the motor.

The digital controller also maintains and displays an accurate log of drive faults, which are essential in troubleshooting drive problems.

The type of algorithm employed by the digital controller determines the accuracy of the speed and torque output requirements of the drive. It also determines if there is a requirement for a speed encoder or not. Most of the modern digital controllers will include algorithms referred to as constant volts per Hertz, (V/Hz) and Flux Vector control.

The Flux Vector is a sophisticated algorithm providing 100:1 speed control range with 0.01 percent accuracy and without the requirement of a speed encoder.

In most fan drive and pump applications with a square function relationship between torque and speed, a simple V/Hz algorithm, of 1.0 percentage accuracy is normally sufficient.



2 Figure - Electric circuit topology for a VFD

For a kiln drive, which normally requires a 250% torque at zero speed, for up to 60

seconds, a speed encoder is always recommended to prevent motor overheating at standstill.

More importantly, however, is the selection of the drive, which must be designed to deliver sufficient current to the motor to satisfy the torque requirements of the specific application.

Operating Power Factor

The power factor of a typical modern VFD is 0.95 lagging and is maintained constant over the speed range. This is due to the diode inverter front-end and capacitor DC link. These drives use the IGBT and IGCT devices.

For the current source inverters and other regenerative drivers, the power factor varies with speed. To maintain good power factor, at or above 0.95 lagging, the VFD suppliers will correct the power factor and install additional capacitors and filter reactors in the drive enclosure. These drives include the SCR and GTO devices.

Voltage and Power Ratings

The selection of the operating voltage level is a matter of economics and that of the power distribution system. Modern variable frequency drives are available to operate at voltages up to 7200 V three phase, 50/60 Hz and can handle large loads.

In general for drives rated 750 kW and lower, 380V to 720V provide the most economical solution. Larger drives and

motors are best operated at medium voltage of 2.3kV to 7.2 kV.

Earlier generations of drives could operate only at low voltages 380V to 720 V. To satisfy the load requirements for operation at medium voltage, a second transformer was used to step up the output of the drive to the desired voltage for the motor.

Modern drives are designed to operate with power cells rated for 690 V or 3300V per cell with fewer components and without the need of a second step up transformer.

Recent Applications

Variable frequency drives in a modern cement plant can be found in several applications as shown in Table 1:

Drive Application	Controlled Parameter
Process ID Fans	Gas flow and pressure
Raw Grinding Feed conveyors	Mill feed rate
High Efficiency Separators	Fineness of cement
Process Water Pumps	Water flow
Kiln Drive	Clinker production

Table1
Variable speed drives for process control

Table2 represents some of HGRSC most recent applications using medium and low-voltage variable frequency drives.

The drive shown in Figure 3 is for a cement mill baghouse, installed at the Juan Minetti Group, Planta Campana in Argentina. The drive assembly includes an indoors dry type transformer, the cooling fan, the inverter, the converter and the microprocessor controller sections. The drive has been installed in an electrical room supplied with an adequately designed ventilation system.

Drive Application	Year	kW hp	Voltage frequency	Company Plant Location
Kiln ID Fan	2000	3750 4500	4000 60	HOLNAM Portland
Kiln drive	2000	850 1200	4000 60	HOLNAM Portland
Separator	2000	450 600	460 60	HOLNAM Portland
Baghouse Fan	1999	2000 2800	6000 50	Juan Minetti Campana
Kiln ID Fan	1999	1120 1500	4000 50	CSR Rinker Miami
Kiln Drive	1998	2x260 350	460 60	Progreso San Miguel
Baghouse Fan	1996	3000 4025	4000 60	Boyaca Nobsa
Coal Mill	1998	522 700	4000 60	Apasco Tecoman

Table2
Recent Applications of VFDs in Cement Plants Projects



Figure 4 -Converter power section showing modern IGBT devices installed in a drawer, for quick replacement.



Figure 3 – 2000kW VFD, 6000V/50Hz, on the test bay



Figure 5 - Test assembly for a 2000kW 6000V, 50Hz VFD, showing controller section and the converter section with air filters

Conclusions

In the foregoing sections of this article, we have illustrated some the important features, which need to be considered for the selection and application of VFDs.

Based on our application experience, the variable frequency 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 an adequate ventilation system, which sometimes 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.

Modern VFDs are also ideally suited for speed control applications in most retrofit situations making use of existing motors.

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