International Journal of Engineering and Technical Research (IJETR)
ISSN: 2321-0869, Volume-1, Issue-10, December 2013

Power Efficient Motor Driver - VFD

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***Abstract*— VFD is known as the variable frequency deriver. It is used to derive a motor at different speed. In the power plant commonly induction motors are used to run fans and pumps. In which fluid coupling, blade pitch control, damper, inlet guide vane control or any other type of mechanical method is used to reduce the speed of the motor to get desired output. In this way speed of the motor is controlled to maintain the output of motor according to load on the plant. But as the motor is giving the desired output but still it is running at full load i.e. it is giving the reduced output at same power consumption. So at this situation we can consider a part of power as loss. To improve this situation VFD is used. It is an electronic circuit that accurately control the speed of standard AC induction or synchronous motors. With VFDs, speed control with full torque is achieved from "0" rpm through the maximum rated speed and, if required, above the rated speed at reduced torque. VFDs manipulate the frequency of their output by rectifying an incoming AC current into DC, and then using voltage pulse-width modulation to recreate an AC current and voltage output waveform. In this way we get the desired output at reduced power but the torque remains constant. This method is very efficient for fans used in plants.**

In this paper working of VFD, its principal, circuit and how it saves power, the difficulties faced during implementation and their possible solution is discussed.

***Index Terms*— GBT (Insulated Gate Bipolar Transistors), pwm (Pulse Width Modulation), vfd (variable frequency drive)**

I. Introduction

VFD is known as the variable frequency deriver. It is used to derive a motor at different speed. Variable frequency drives (VFDs) accurately control the speed of standard AC induction or synchronous motors. With VFDs, speed control with full torque is achieved from "0" rpm through the maximum rated speed and, if required, above the rated speed at reduced torque. VFDs manipulate the frequency of their output by rectifying an incoming AC current into DC, and then using voltage pulse-width modulation to recreate an AC current and voltage output waveform. However, this frequency conversion process causes 2% to 3% loss as heat in the VFD caloric energy that must be dissipated. The process also yields over-voltage spikes and harmonic current distortions.

Adding a variable frequency drive (VFD) to a motor-driven system can offer potential energy savings in a system in which the loads vary with time. VFDs belong to a group of equipment called adjustable speed drives or variable speed drives. (Variable speed drives can be electrical or mechanical, whereas VFDs are electrical.) The operating speed of a motor connected to a VFD is varied by changing the frequency of the motor supply voltage. This allows continuous process speed control.

Manuscript received December 15, 2013.

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II. Need of VFD

Since there is many motor drives are presently available than why we need the VFD is the common question. This is described in the following points

A. Problem Statement

Now a day induction motor is most widely used in power plants to run the different type of fans and pumps. As we know that the load on the plant in not constant. It is varying with the time i.e. according to the need of the consumer. So as the load varies the production of plant is also adjusted according to that. Coal, water and air are the three main consistent which govern the capacity of the plant. So these three things must be varied to change the produced power. In order to change these, the motor and pump output is need to control and vary according to load. Today mechanical coupling is most widely used to control the motor output. Some of them are

- Hydraulic coupling
- Blade pitch control
- Guide vans controlling
- Mechanical coupling

All of this methods control the output of the motor directly or indirectly controlling the speed of the motor. So the power consumption of the motor is same but the output varies.

B. What VFD do?

Variable frequency derive also changes the output of the motor by varying the speed of the motor but the torque of the motor remains constant. Torque is the important factor which must be constant that's why the other speed control methods are not applicable in the industry.

III. Principal of VFD

The torque of an induction motor is given by the expression

$$T = \frac{KSRE^2}{R^2 + S^2X^2}$$

Where, K= constant
S= slip of the motor
R= Resistance of the secondary side of motor
E= Induced EMF in the secondary side
X= Reactance of the secondary side of the motor

The value of K is given by

$$K = \frac{3}{2\pi n}$$

And we know that n is given by

$$n = \frac{120f}{P}$$

Where P = number of pole
n = synchronous speed
f = operating frequency
so torque is given by

$$T = \frac{3P \times SRE^2}{(2\pi \times 120f)(R^2 + S^2X^2)}$$

Here P, S, R, f are constant. So the value of torque is directly depends upon the ratio of E and f.

In VFD speed is varied by maintaining the value of E2/f constant. So at variable speed we get the constant torque.

IV. Major Parts of VFD

There three major parts in a VFD system. These are

- Rectifier Bridge
- DC bus Circuit
- Inverter

The Ac supply coming to the motor is first converted in to DC and it is stored by the Dc bus. This dc is again converted in to variable voltage and variable frequency AC which is used to drive the motor.

A. Rectifier Bridge

A 3-phase fully-controlled bridge rectifier circuit is used to convert the 3 phase Ac supply in to Dc. A three-phase fully-controlled bridge rectifier can be constructed using six SCRs as shown below.

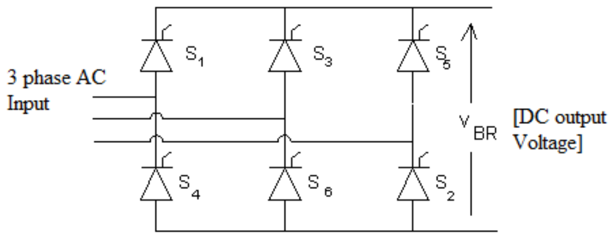

Fig.1 Rectifier Bridge

The three-phase bridge rectifier circuit has three-legs, each phase connected to one of the three phase voltages. Alternatively, it can be seen that the bridge circuit has two halves, the positive half consisting of the SCRs S1, S3 and S5 and the negative half consisting of the SCRs S2, S4 and S6. At any time, one SCR from each half conducts when there is current flow. If the phase sequence of the source be RYB, the SCRs are triggered in the sequence S1, S2 , S3 , S4, S5 , S6 and S1 and so on.

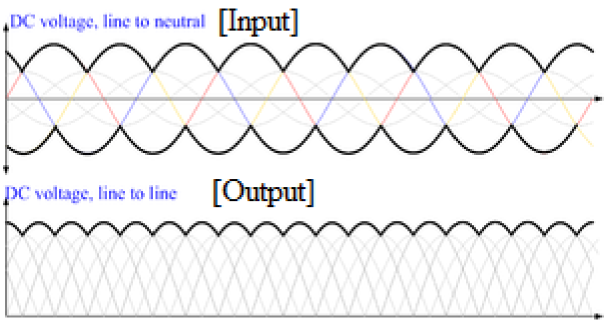

Figure 1. Voltage waveform

The wave shape of input and output is as shown in the fig. Ripples are present in this output. In this type of circuit, the DC voltage is 1.35 times the AC line voltage.

B. DC bus Circuit

A LC filter circuit is used for the storage of the rectified DC power. It also acts as a filter and removes the ripples.

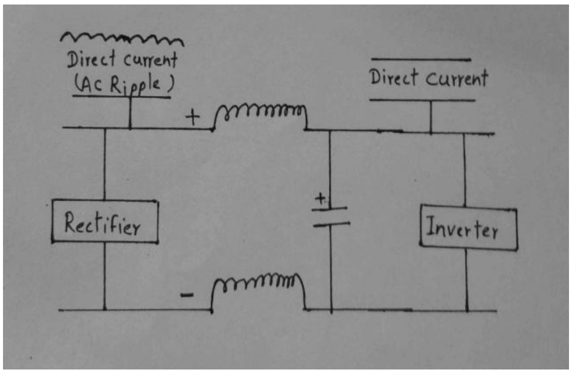

Fig.2 DC bus Circuit

The Intermediate Circuit also known as a DC Link, can be seen as a power storage facility for the next section, the inverter section. There are two major components to the DC Link section, capacitors and coils. In the diagram only one capacitor is shown but it is always a series of capacitors. With VFDs, this intermediate section always uses DC coils also known as DC Line Reactors or DC chokes. These coils as essential for two main reasons; one is the ability to reduce harmonic noise (interference) by 40% and the other is the ability to ride through a temporary loss of power. This allows this drive to avoid numerous nuisance shut downs. This DC Link Voltage is 1.35 times the input voltage.

C. Inverter

The next part of the VFD is the Inverter section. This section takes the DC voltage from the intermediate section and, with the help of the control section, fires each set of IGBT (Insulated Gate Bipolar Transistors) to the U, V and W terminals of the motor. This firing of the IGBTs is known as Pulse Width Modulation (PWM) and is described in the next section. The IGBTs are mounted on the heat sinks.

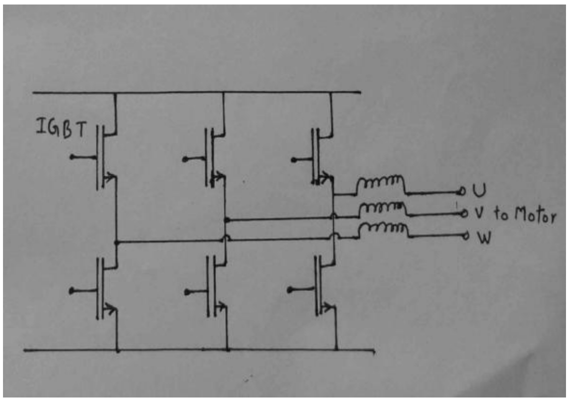

Fig. 3 Circuit for inverter

D. Pulse Width Modulation

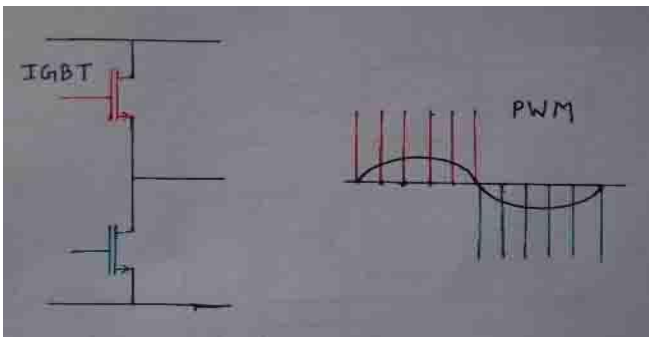

Fig. 4 Pulse Width Modulation

In the diagram above, a close up view of the waveform that goes to the motor shows the switching frequency of the IGBTs. The switching-pattern shown above is known as pulse width modulation or PWM. As the length of time is increased for the IGBT to be ON and then OFF, the motor responds to it as a sinusoidal waveform. The positive IGBT fires first in the diagram followed by its negative counterpart. Only one motor terminal (U) is shown but the same type of activity would appear on V and W.

Typical control for a variable frequency drive is between 0 and 120 % of its rated rpm. In reality the motor is generally adjusted from 60% to 130%of rated rpm, which provides sufficient control for the system being adjusted. It is important to note that the VFD can only rule the motor for a short period of time at RPMs above 100% because the motor will overheat.

E. Soft Charge Circuit

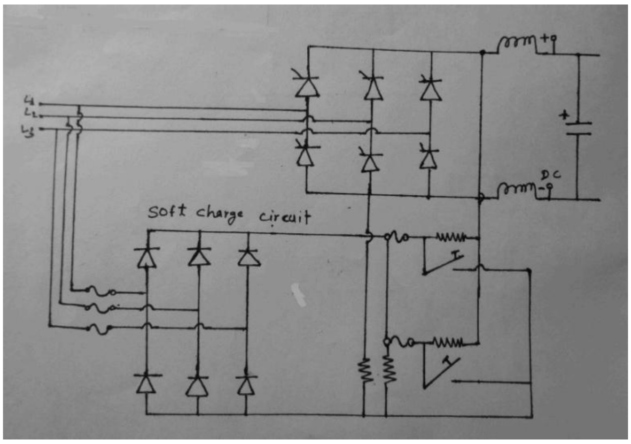

Fig. 5 Charging circuit

On larger drives, 22 – 450kW (30 – 600Hp), a part of the rectifier section is known as the soft charge circuit, which is used to power up the drive. With this circuit, when power is applied, the inrush of current is restricted going to the large capacitors in the DC Link, so that they may charge up slowly (within a couple of seconds). If this circuit was absent, line fuses would be blown every time the VFD was started. The soft charge circuit on some of the VFDs has a resistor or two in line with the current to slowly allow charging of the capacitors. This current resistor even has its own safety, a thermal switch, which shorts out if the current rush is too high in the soft charge circuit. The shorted thermal switch blows fuses on the soft charge circuit preventing the drive from starting.

Once main power is applied to the drive, the SCRs in the main rectifier section remain off. The much smaller rectifier section in the soft charge circuit starts, applying DC power through the current resistors charging up the capacitors in the DC Link. When these capacitors are charged to the DC voltage minimum value, the control section starts the firing of the SCRs in the main rectifier. Because of the amp draw through the current resistors in the soft charge circuit, time is needed to cool them off, so the 22 – 450kW (30 - 600 Hp) drives are limited to 2 start per minute.

F. Brake Circuit

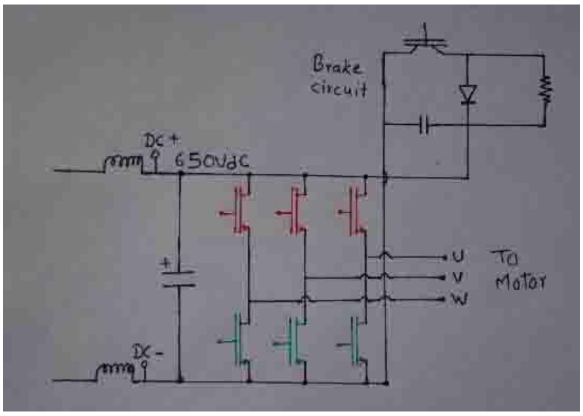

Fig. 6 Circuit for breaking

This Brake Option, also known as Dynamic Braking, is used with devices that need to stop or change directions quickly, such as conveyors, hoists and centrifuges. On drives that have the brake option, an additional IGBT transistor is used to remove extra power coming back into the drive when the motor, which has a large inertia, is stopping or changing direction. The only HVAC related application that might use dynamic braking is for some fans for boiler combustion. This option is not required for the vast majority of HVAC applications.

V. Functions of VFD

The function of VFD is not limited to control the speed with varying the power but it performs some other function too. Some of them are discussed below

- The VFD is able to start and stop the motor even if the power supply is not off.
- This allows the operator to match the speed of the motor to a particular speed according to the demand.
- Another function of the VFD is to maintain the torque of the motor regardless of the speed and load.
- It is important to Limits on current, torque, speed, heat and voltage and others protect the VFD & motor. This can be placed in the program of the VFD so an operator cannot go beyond a maximum limit.
- The VFD automatically extends the ramp times, during ramp up and ramp down, to avoid tripping of the drive.
- The switching of the motor from forward to reverse can be done inside the VFD.
- In many applications, particularly involving fans and pumps, the major function of the VFD is to save energy.

VI. Control Arrangements for a VFD

There are many control arrangements are present to control all these arrangement. Some of them are as follow

- Local or Hand Control
- Remote or Auto Control
- Multi-motor
- Master/Slave
- Closed Loop
- Cascade Control – Fixed Stages
- Cascade Control – Variable Stages
- Build Automation System (BAS) - Enable
- BAS – Enable and Reference
- BAS – Serial Communications

VII. Problem of Harmonic

Harmonic current distortion causes heat and this has an adverse effect on the supply transformer and cables. Based on the impedance of the supply line and transformer, current distortion can cause harmonic voltage distortion, which can interfere with other equipment attached to the same supply transformer. Harmonic Current Distortion increases the RMS current and can result in overheating of the supply transformer and cables. Harmonic Voltage Distortion can interfere with other equipment attached to the same line. Here some of the methods are given to reduce the harmonics.

A. Redistribute Sensitive Loads

B. Rewire as Virtual 12 Pulse

C. Add Remedial Hardware

a) Line Reactors

b) Filters

c) Isolation Transformers

VIII. Conclusion

VFD is very useful for the plants where high power rating motors are used and used at a variable speed. It will save the power but torque will remain same. Its initial cost is somewhat higher than the other drives but by using this its cost can be easily taken back in the form of power saving. Some benefits are concluded the areas follow

- Energy savings on most pump and fan applications.
- Better process control and regulation.
- Speeding up or slowing down a machine or process.
- Easy setup & programming
- Retrofits
- Better design
- Protection from overload currents
- Safe Acceleration

Acknowledgment

This paper is the result of not only my hard work. It can't be possible without guidance of Sharavan Tripathi sir and Hazari Prasad rai sir. I want to thank my friends who had carried a case study with me on the VFD. I want to thank my best friend Sonia Choudhary who always inspire me. This paper is just because of her. I want to thank my mom and dad because of them I am able to write this paper. I also want to thank god for giving me this life and for being always with me and for giving me my luck.

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