Review of Adjustable Frequency AC-AC Drives Using Different Inverter Topologies

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Abstract— **AC drives, inverters and adjustable frequency drives are all terms that are used to refer to the equipment designed to control the speed of an AC motor. AC drives receive AC power and convert it to an adjustable frequency, adjustable voltage output for controlling motor operation. The three common inverter types are the variable voltage inverter (VVI), current source inverter (CSI), and pulse width modulated (PWM) inverter. Another type of AC-AC drive is using cycloconverter. These are commonly used for very large motors. All AC drives convert AC to DC, and then through various switching techniques invert the DC into a variable voltage, variable frequency output. Standard low and medium power induction motor drives are based on the PWM voltage source inverter fed from an uncontrolled rectifier. The dual topology, based on the current-source inverter structure is used in medium- and high-power applications. This paper analyzes present existing motor drives based on different topologies and also compares their performances.**

Keywords— **AC drive, variable voltage inverter, current source inverter, sinusoidal pulse width modulated inverter, hysteresis current controlled inverter.**

I. INTRODUCTION

The varying industrial needs demand more precise control of the outputs of basic electrical prime movers i.e., THE MOTORS. DC motors are easy to control, but they have their own limitations with increase in capacity. Conversely AC motors are very economical but their speed control is comparatively difficult because it requires alteration of supply frequencies. An adjustable frequency drive is a system for controlling the rotational speed of an alternating current (AC) of electric motor by controlling the frequency of the electrical power supplied to the motor.

Variable frequency drives operate under the principle that the synchronous speed of an AC motor is determined by the frequency of the AC supply and the number of poles in the stator winding, according to the relation:

$$RPM = (120*f)/p \qquad (1)$$

Where,

RPM = Revolutions per minute
f = AC power frequency (Hertz)
p = Number of poles (an even number)

Motors speed can be changed by altering the electrical frequency, the number of poles, or both. AC Drives with adjustable speeds have become more popular variable speed control drives used in industrial, commercial and some residential applications. These drives have a wide range of applications ranging from single motor driven pumps, fans and compressors, to highly sophisticated multi-drive machines.

Due to technological advancements some drives which can control AC motors are available which are economical, easy to use and which can provide wide range of speed control both below and above base speeds. These drives fundamentally alter the voltage and frequency being fed to motor according to the requirements using a modulation technique called PWM.

Adjustable Frequency Drives allow precise speed control of a standard induction motor and can result in significant energy savings and improved process control in many applications. These systems are fairly expensive but provide a higher degree of control over the operation and in many cases, reduce the use of energy enough to a least offset if not more than pay for the increased cost. They can control the speed of a standard squirrel cage induction motor. They are suitable not only for new applications, but also for retrofit on existing motors.

In this article, different topologies to vary the supply frequency are discussed. By adjusting the frequency and number of poles, the motor speed can be adjusted but this physical change to the motor would require rewinding and result in a step change to the speed. So for convenience, cost, efficiency and precision, all are achieved at the cost of change in frequency.

II. DIFFERENT TOPOLOGIES

A. Adjustable Frequency Drives Using Variable Voltage Inverter

The **variable voltage inverter (VVI) drive** is the most common power-converter topology for adjustable speed induction motor drives. The VVI ensures a simple and effective motor control since the power circuit can be operated over wide ranges of load frequency and voltages.

The above mentioned drive uses an SCR rectifier to convert the incoming AC voltage into DC. The SCRs provide a means of controlling the value of the rectified DC voltage from 0 to maximum. The L1 choke and C1 capacitor(s) make up the DC link section and smooth the converted DC voltage. The

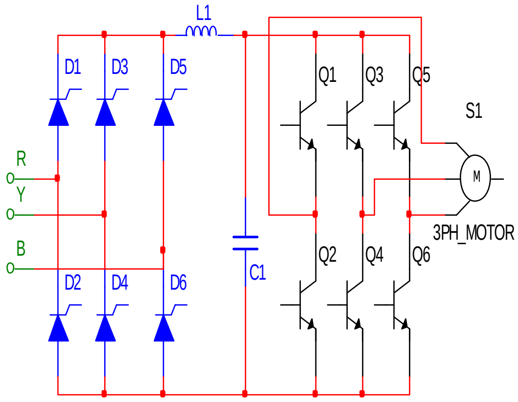

Fig. 1 Variable Voltage Inverter

inverter section consists of six switching devices. Various devices can be used such as thyristors, transistors, MOSFETS, and IGBTs. [1]

This type is often referred to as **six-step inverter** because it takes six 60° steps to complete one 360° cycle. Although the motor prefers a smooth sine wave, a six-step output can be satisfactorily used. Here, the torque pulsation occurs each time a switching device, such as a bipolar transistor, is switched. Figure.2 shows the output line voltage and line current waveforms for the star-connected load. The pulsations can be seen in current waveform according to the speed variations in the motor. The speed variations are sometimes referred to as cogging. The non-sinusoidal current waveform causes extra heating in the motor requiring a motor derating. [1]

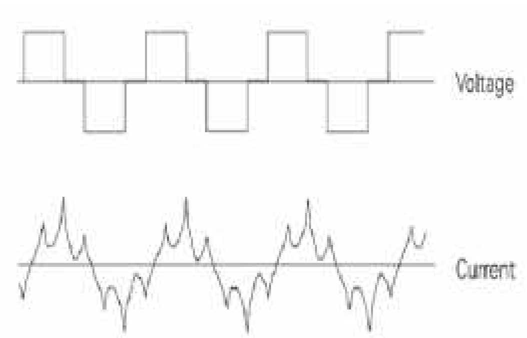

Fig. 2 Output Voltage and Current Waveforms [1]

B. ADJUSTABLE FREQUENCY DRIVES USING CURRENT SOURCE INVERTER

In **current source inverter (CSI)** drives, the inverter switches are fed from a constant current source. While a true constant current source can never be a reality, it is reasonably approximated by a controlled rectifier (SCRs) with a current control loop with a large DC link inductor to smooth the current. The inverter section also uses SCRs for switching the output to the motor. The current source inverter controls the current in the motor. The motor must be carefully matched to the drive [1].

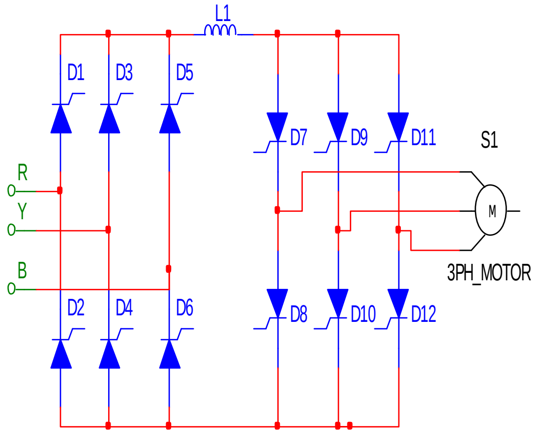

Fig. 3 Current Source Inverter

Most of all, the power circuit of the CSI is simpler and more robust than the VVI due to no freewheeling diodes with unidirectional current flow. The CSI permits four quadrant operations transferring the electric power in both directions using the controlled rectifier with closed-loop current control. The CSI can provide a higher reliability related with a dc-link inductor than a capacitor for the VVI and inherent over current protection by current regulation of the controlled rectifier. The CSI is more efficient because of the quasi-square-wave mode operation, which turns ON and OFF only once per cycle of the output current. [7]

Figure.4 shows the output line voltage and line current waveforms for the star-connected load. As seen in Figure.4 current spikes, caused by switching, can be seen in the output. At low speeds current pulses can cause the motor to cog. [1]

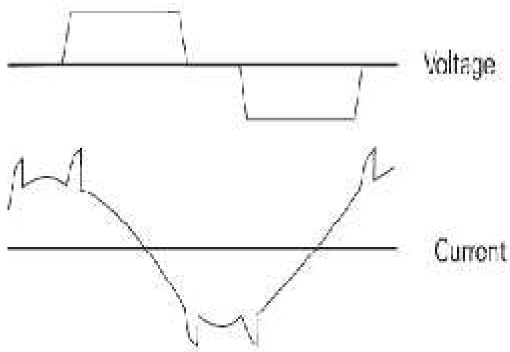

Fig. 4 Output Voltage and Current Waveforms [1]

C. Adjustable Frequency Drives Using Pulse Width Modulated Inverter

The performance of the converter system largely depends on the quality of the applied current control strategy.

Therefore, current control of PWM converter drive is one of the most important subjects of modern power electronics. In comparison to conventional open-loop voltage PWM converters, the *current-controlled PWM (CC-PWM) converters* have many advantages [2].

Pulse Width Modulated Inverter is voltage source inverter. Pulse width modulated (PWM) drives provide a sinusoidal current output to control frequency and voltage supplied to an AC motor. PWM drives are more efficient and typically provide higher levels of performance.

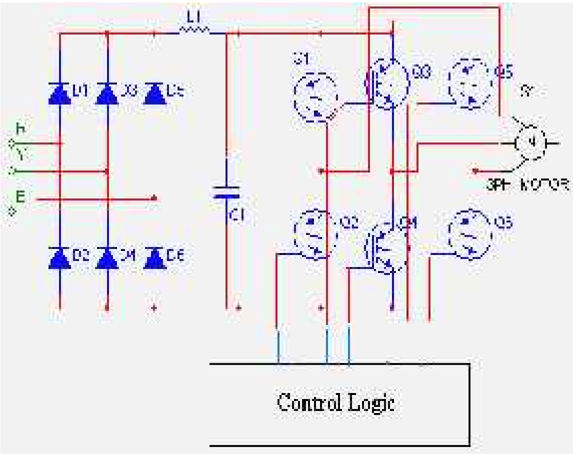

Fig. 5 Pulse Width Modulated Inverter

The converter section consists of a fixed diode bridge rectifier which converts the three-phase power supply to a DC voltage. The L1 choke and C1 capacitor smooth the converted DC voltage. Output voltage and frequency to the motor are controlled by the control logic and inverter section. The inverter section consists of six switching devices. The control logic uses a digital control to switch the IGBTs on and off providing a variable voltage and frequency to the motor [1].

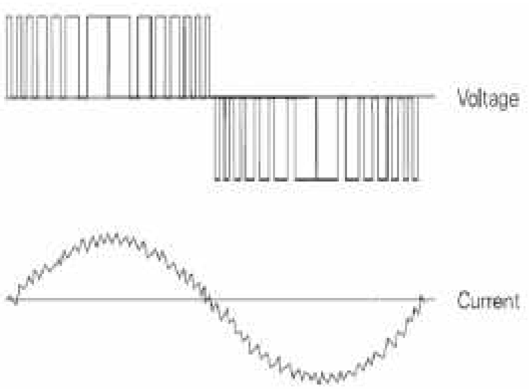

Fig. 6 Output Voltage and Current Waveforms [1]

The voltage and frequency is controlled electronically by circuitry within the AC drive. The output voltage and output current waveforms are shown in Figure.6 [1]. In this type, if the controlled rectifier is used, then power factor is more improved as compared to other topologies.

D. Adjustable Frequency Drives Using Hysteresis Current Controlled Inverter

The basic hysteresis current control is based on an on-line PWM control that fixes the output voltage of the inverter instantaneously. **Hysteresis PWM** refers to the technique where the output is allowed to oscillate within a predefined error band, called "**Hysteresis Band**". The schematic for this case is same as the case of PWM inverter, only the current control strategy is different. The switching instants, in this case are generated from the vertices of the triangular wave shown in Figure.7. In terms of quick current controllability and easy implementation hysteresis band current control method has the highest rate among other current control methods such as sinusoidal PWM [13].

In most of the PWM applications the interval between two consecutive switching actions varies constantly within a power frequency cycle. It means that the switching frequency is not constant but varies in time with operation point and conditions. In principle increasing inverter operating frequency helps to get a better compensating waveform.

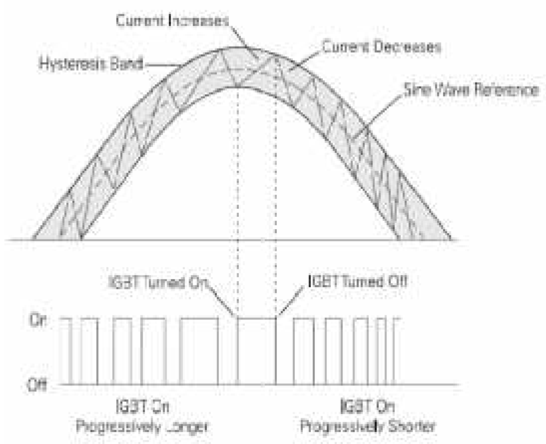

Fig. 7 Output Voltage and Current Waveforms [1]

The hysteresis-band current control method is popularly used because of its simplicity of implementation, among the various PWM techniques. Besides fast-response current loop and inherent-peak current limiting capability, the technique does not need any information about system parameters [3].

The bandwidth of the hysteresis current controller determines the allowable current shaping error. By changing the bandwidth the user can control the average switching frequency of the inverter and evaluate the performance for different values of hysteresis bandwidth. Hysteresis PWM can be implemented with both analog circuits and DSPs. However, for the sake of flexibility and reliability, digital implementation is becoming more and more popular.

TABLE I
COMPARISON OF DIFFERENT TOPOLOGIES

Parameter	VVI Drive	CSI Drive	PWM inverter Drive	Hysteresis current controlled Drive
Efficiency	High	Low	High(Constant)	High
Configuration	Simple	Simple	Complex	Simple
Speed Range	Wide	Wide	Wide	Wide
Regenerative Capability	No	Optional	No	No
Multi-motor Capability	Yes	No	Yes	Yes
Power Factor	Good	Poor	Good	Good
Cogging Problems	Yes	Yes	No	No

III. APPLICATIONS

Adjustable Frequency drives have been widely utilized to improve the efficiency in residential and commercial sectors. The applications for adjustable frequency drives include: (a) Light and Medium Industry such as auto part assembly, food production, semiconductor manufacturing, and light machining, (b) Process Industry such as pulp and paper mills, chemical plants, oil refineries, and steel mills, (c) Heavy Industries such as mining, oil and gas production, and power plants, (d) Water and Wastewater such as municipal water and wastewater plants, and irrigation, (e) Commercial HVAC such as heating and cooling of commercial buildings, (f) Agricultural Industries such as farms for irrigation and product processing, (g) Industrial and high speed applications, (h) Pumps, blowers and fan applications, (i) Wind turbines, PV and solar applications [4]-[6].

IV. CONCLUSION

From the above discussion, it is concluded that the fast growth of the power electronics has changed the traditional power application of induction motors from fixed rotating speed to variable speed drive. The VVI fed AC drives are specially used for high speed applications. The thyristor based current source inverter (CSI) fed AC drives are often employed in high power applications. These types of drives are used for 120˚ mode of operation. Therefore it results for fixed power application only. The PWM inverter fed AC drives are more popular for adjustable speed applications. Hysteresis current-controlled inverter drives are capable of delivering nearly sinusoidal current waveform with unity and even leading power factor and also give fast response to bidirectional power demands [14].

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