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VS PWM inverter feed induction machine using Volts per Hertz Control Scheme

Abstract. *In this article a voltage source inverter (V.S.I) is developed for use in pulse width modulation (P.W.M) speed control systems for three phase a.c motors. This system uses the technique of sine-wave modulation and employs a purpose-designed L.S.I circuit for PMW generation. A constant torque control scheme is employed in order to keep the air-gap flux and consequently the motor output torque constant. Steady state and transient behavior performance of our system is investigated. Experimental results are also being presented.*

Streszczenie. *Opracowano przekształtnikowe źródło napięcia VSI zastosowane do sterowania trójfazowym silnikiem z wykorzystaniem modulacji PWM. Zbadano pracę w stanie ustalonym oraz w stanach przejściowych. (**Przekształtnikowe źródło napięcia do zasilania silnika indukcyjnego bazujące na strategii Volts per Hertz**)*

Keywords: variable frequency and variable voltage (V.V.V.F), voltage source inverter (V.S.I), constant Volts/hertz scheme, PWM inverter
Słowa kluczowe: źródło napia)ęciowe, przekształtnik, silnik indukcyjny

Introduction

Variable speed ac drives are used in ever-increasing numbers because of their well-known benefits for energy efficiency and for flexible control of processes and machinery using low-cost readily available maintenance-free ac motors. Advances in solid state power conversion devices have opened up new field of application for ac machines to variable speed drive applications where formally only dc motors where practical. A.c motors such as squirrel cage induction motor for example have a robust rotor construction; result in a cheaper motor and a higher power/weight ratio. Unfortunately, it is inflexible in speed when operated on a standard constant frequency a.c supply and runs slightly are available [1].

Modern methods of static frequency conversion have liberated the a.c motors from its historical role as a fixed speed machine. But the inherent advantages of adjustable frequency operation can not be fully realized unless a suitable control technique is employed. The basic control action involved in adjustable speed control of induction motors is to apply a variable frequency variable magnitude a.c voltage to the motor to achieve the aims of variable speed operation [2].

With the recent advances in power electronics (bipolar transistor, inverter grade thyristor, GTO thyristor, IGBT etc.) and miniaturization/mass production of control electronics (development of VLSI technology and microprocessor based digital control systems), variable frequency and variable voltage (V.V.V.F) a.c motors drives have come into increased use in various industrial applications.

A voltage source inverter is commonly used to supply a variable frequency variable voltage to a three phase induction motor in a variable speed application.

PWM drives are more efficient and typically provide higher levels of performance

A suitable pulse width modulation technique is employed to obtain the required output voltage in the line side of the inverter

In general, two basic types of inverters exist: Voltage-source inverter (VSI), employing a dc link capacitor and providing a switched voltage waveform, and current-source inverter (CSI), employing a dc link inductance and providing a switched current waveform at the motor terminals. CS-inverters are robust in operation and reliable due to the insensitivity to short circuits and noisy environment. VS-inverters are more common compared to CS-inverter since the use of Pulse Width Modulation (PWM) allows efficient and smooth operation, free from torque pulsations and cogging. Furthermore, the frequency range of VSI is higher and they are usually more inexpensive when compared to CSI drives of the same rating. The most common AC drives today are based on sinusoidal pulse-width modulation SPWM. Both voltage source inverters and current source inverters are used in adjustable speed AC drives. However, voltage source inverters with constant Volts/Hertz (V/f) are more popular, especially for applications without position control requirements, or where the need for high accuracy of speed control is not crucial [3].

Constant torque operation

Many variable speed drives require a constant torque output and this can be achieved if the air-gap flux in the motor is maintained constant. In practice, all electric motors usually operate near saturation in order to fully utilize the core materiel. From the classical law of Faraday, the E.M.F induced in winding is proportional to the rate of change of the magnetic flux. Therefore, as the operation frequency is reduced or increased the rate of change of flux is also reduced or increased accordingly. So when the operation frequency is reduced, the EMF, and therefore the applied voltage (if the stator impedance is negligible); must be reduced proportionately or the saturation flux density is exceeded, resulting in excessive iron loss and magnetizing current. When the operating frequency is increased, the applied voltage should be increased proportionately in order to maintain the magnetic flux density.

The key to regulate speed is to hold the rated Φ_m as a constant. As the excitation system in d.c motor is individual, it is easy to hold it by compensating armature for the proper current. And the flux in a.c motor is determined by the combination magnetic field of rotor and stator.

$$E_g = 4.44\, f_1 N_1 K_{N1} \Phi_m \tag{1}$$

where: E_g: Induction electromotive force RMS that air-gap flux generated per phase in rotor, f_1: Rotor frequency, N_1: Number of conductors per phase, K_{N1}: Fundamental winding factor, Φ_m: Air-gap flux per pole.

From formula (1) we know now that Φ_m can be controlled by the adjustment of E_g and f_1. While the conditions that over and under the base-frequency of motor must be considered separately.

Given by formula (1), Φ_m can be a constant as long as E_g/f_1 is a constant. However, it is difficult to control the induced electromotive force directly. In general, when a high EMF (Electromotive Force) is loaded, the winding voltage drop of stator can be ignored and $U_1 \approx E_g$ can be taken, so U_1/f_1 is a constant. However, when the motor works under the base frequency, U_1 and E_g are both lower, and the winding voltage drop of stator can not be ignored, so the only way to compensate the voltage drop in winding is to increase U_1.

During the speed regulation over the base frequency, rotor frequency can increase continuously, while U_1 can only be increased to the rated voltage U_{1n} at most.

It can be therefore concluded that in order to keep the air-gap flux constant, the applied voltage/frequency ratio must be held constant. This mode of operation is known as constant V/f operation and has been widely used for induction motor drives as a general purpose inverter, particularly in cases where the lower limit of the operating frequency rang has to be chosen relatively high, near rated motor frequency. In this case the voltage drop across the stator impedance can be neglected, thus the motor terminal voltage is considered equivalent to the EMF.

For continuously variable speed control, the output frequency of inverter must be varied. The applied voltage to the motor must also be varied in linear proportion to the supply frequency to maintain constant motor flux. At low frequency, where the motor inductive reactance is low, boosted voltage is used to compensate for the stator IR voltage drop. Thus control of both voltage and frequency is necessary for proper variable speed operation.

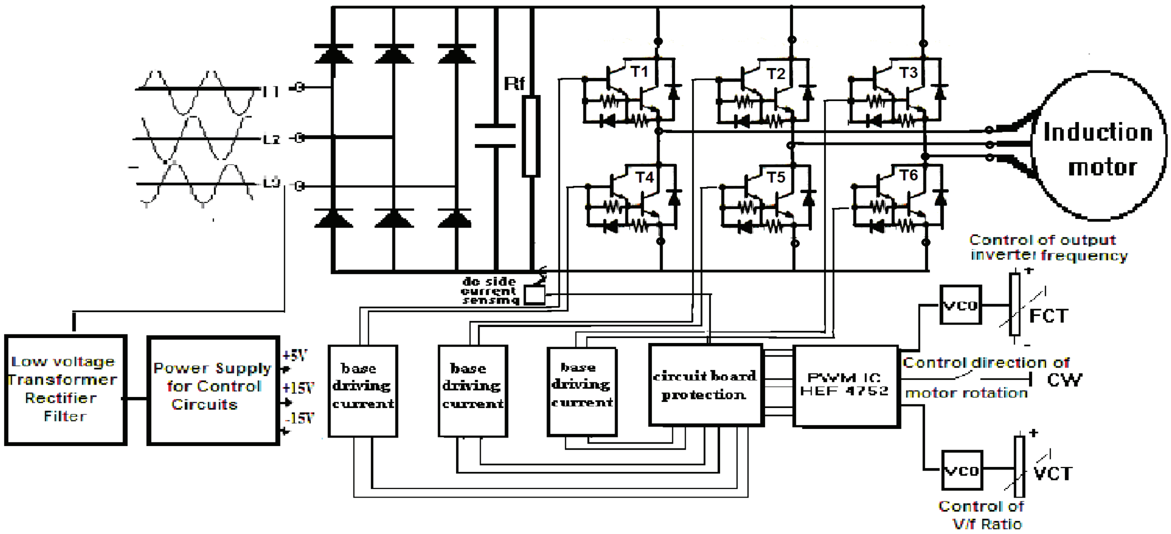

Fig.1 Block Diagram of the control system

System description

Figure 1 shows a simplified block diagram illustrating the essential of our control system. This system consists of a dc power source, a dc link filter, a voltage source inverter, an induction motor, and same circuit of control system. The d.c power source converts the constant-frequency ac power to dc power by a three-phase, full wave diode bridge rectifier; the dc voltage is smoothed by a smoothing capacitor d.c link filter and then applied to a three-phase bridge inverter witch converts dc power to variable voltage variable frequency ac power supply to the motor. Transistors are being used as switching devices along. In our case an EVK31-050 Fuji power modules Darlington bipolar transistor are chosen.

The two control parameters required are frequency and voltage, the frequency command also generates the voltage command through a volts/hertz ratio.

PWM is employed in a wide variety of applications, ranging from measurement and communications to power control and conversion. In ac motor drives, PWM inverters make it possible to control both frequency and magnitude of the voltage and current applied to a motor. As a result, PWM inverter-powered motor drives are more variable and offer in a wide range better efficiency and higher performance when compared to fixed frequency motor drives.

The energy, which is delivered by the PWM inverter to the ac motor, is controlled by PWM signals applied to the gates of the power switches at different times for varying durations to produce the desired output waveform.

PWM waveforms generation

PWM is used to control the voltage and reduce the harmonic contents in the inverter output. In particular, sinusoidal PWM has been show to give minimum harmonic contents in the inverter output voltage. However, the relative complexity of control makes this modulation strategy difficult to implement.

Many types of sinusoidal Pulse width modulation system have been developed in the past; these were designed with analogue components as they are easy to design and can be implemented with relatively inexpensive components.

Nevertheless, there are several drawbacks with analogue systems including aging, temperature drift and reliability. Regular adjustment is required in those cases. Furthermore, any upgrade is difficult, as the design is hardwired. Digital systems, on the other hand, offer improvement over analogue circuits. The mentioned drawbacks as drift and external influences are eliminated since most functions are performed digitally.

In this article a voltage source inverter (V.S.I) is developed for use in pulse width modulation speed control systems for three phase a.c motor. This system uses the technique of sine-wave modulated pulse width modulation and employs a purpose-designed L.S.I circuit type HEF 4752V manufactured by Phillips which has been developed specially for signal generation in such systems, and overcomes all the previous disadvantages [4] [5].

The LSI integrated circuit HEF 4752V is used to control asynchronous motors inverters, basing on PWM principle. The circuit summarizes three signals out of phase by 120°, to which the average varies sinusoidal in time [6].

The modulation of the output waveform is achieved by opening and closing the upper and lower switching element in each phase of the inverter. Closing the upper element gives a high output voltage, and closing the lower element gives low output voltage.

The basic function of the PWM I.C is to provide open and close the switching elements in the appropriate sequence to produce a symmetrical three-phase output.

The HEF 4752V uses a totally digital approach and it is provide three complementary pairs of output drive waveforms which, when applied to a three-phase bridge inverter, produce a symmetrical three-phase output. The output waveforms are pulse width modulated using double edged modulation such that the average voltage difference between any two of the output phases varies sinusoidally. The integrated circuit has four clock inputs FCT, VCT, RCT, and OCT which are used to control the output waveforms [7].

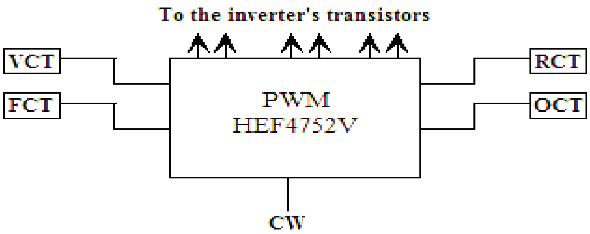

Fig.2 HEF 4752V inputs

The four clock inputs have the following functions:

- FCT (Frequency clock trigger): this determines the stator frequency (fout), thereby controlling the motor speed.

The clock frequency of FCT is related to output frequency of inverter as [2]:

(2) $f_{FCT} = 3360 \times fout$

The output frequency of the inverter can be controlled from 0 to 100 Hz by varying frequency of FCT.

- VCT (Voltage clock trigger): this determines the stator frequency/voltage ratio.

The level of the average inverter output voltage at given output frequency is controlled by the VCT clock input. The change in the output voltage is achieved by varying the modulation depth of the carrier. Increasing f_{VCT} reduces the modulation depth and hence the output voltage, while decreasing f_{VCT} has the opposite effect. The relation between f_{VCT} and f_{OUT} is given by:

(3) $fVCT\ (nom) = 6720 \times fout(max)$

With VCT fixed at fVCT (nom), the output voltage will be linear function of the output frequency up to fout(max).

- RCT (Reference clock trigger): this set the inverter maximum switching frequency. The reference clock input RCT is a fixed clock used to set the maximum inverter switching frequency fs(max) .

The clock frequency f_{RCT} is related to fs(max) as,

(4) $f_{RCT} = 280 \times fs(max)$

The absolute minimum value of the inverter switching frequency fs(min) is set by the IC at $0.6 \times$ fs(max)

- OCT (Output clock trigger): this sets the minimum pulse-width allowable. Ooperating in conjunction with the data input K, the output delay clock OCT is used to set the interlock delay period which is required at the change over between the complementary output at each phase. With K high the inter-lock delay period is given by 16 fOCT (ms), where fOCT is in kHz [9].

The digital signal CW controls the direction of motor rotation. When the input CW is high, the phase sequence is a, b, c and when low it becomes a, c, b.

The IC HEF4752V has 12 inverter drive output, out of which 6 outputs have been used and these outputs are connected to the base of power transistors for implementing to the inverter bridge.

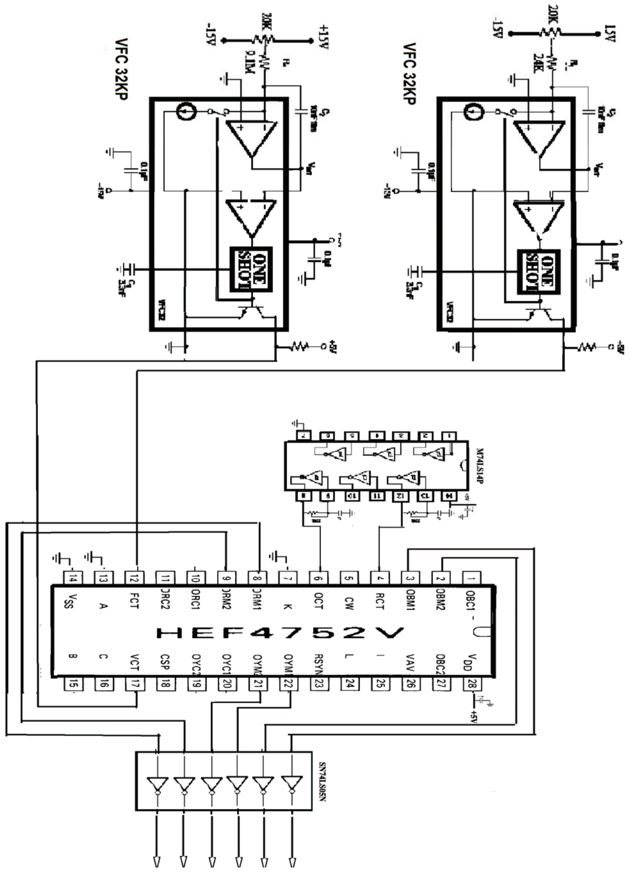

Fig.3 Detail of PWM control circuit

The control system is presented in more detail in figure 3. The output frequency varies from 0 to 100 Hz with bi-directional speed control; the maximum switching frequency is fixed at 1.5 KHz. At low output frequencies the carrier ratio has a value of 168, giving torque smoothness at low speeds As the fundamental frequency is increased, the carrier ratio is reduced in integer steps at discrete points in the frequency range approaching 70 Hz, the carrier ratio is reduced to 15, and there after pulses are dropped in a manner that maintains quarter wave symmetry until six step operations is achieved.

Volts/hertz control is automatically achieved in the present PWM circuit by making the output voltage directly proportional to the output frequency. The level of the average inverter output voltage at given output frequency, is controlled by the VCT clock input, changes in output voltage being achieved by varying the modulation depth [10].

The clock inputs FCT and VCT are supplied from voltage to frequency converter VFC32-KP witch provides an output frequency accurately proportional to its input voltage, while the clock inputs RCT and OCT are controlled by fixed oscillators. Hex Schmitt trigger IC 74C14 are used for Signal conditioning.

Figure 4 shows the variation in motor voltage, torque and horse-power (HP) as function of frequency for the imposed operating characteristic. The motor operate in constant torque region using the constant volts/hertz. Above 50 Hz the voltage is usually maintained constant so the torque margin is reduced at higher frequencies and therefore the motor operate at constant horse-power mode [11].

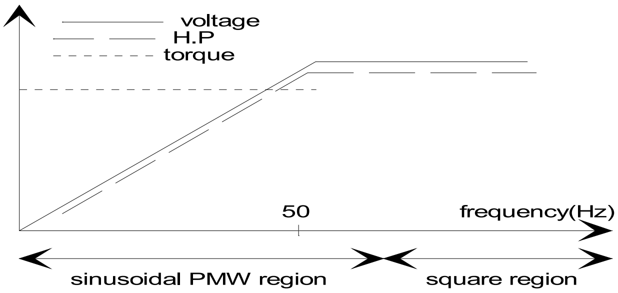

Fig.4 Motor torque capability

Experimental results

Experimental control system is built and tested for four pole squirrel cage induction motor drives (2KW, 220V, 50Hz, 8A, 1460tr/min). In this part a few experimental waveforms will be presented. First, figure 5 presents the experimental waveforms for clock inputs (OCT, VCT, OCT, FCT) of the PWM IC.

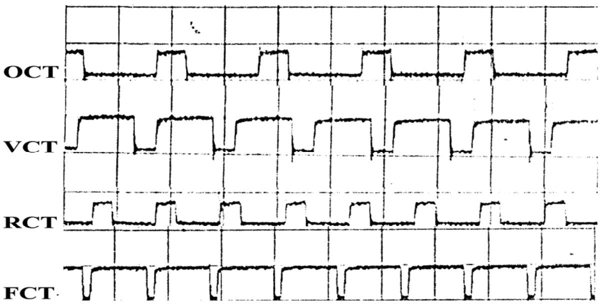

Fig.5 Experimental waveforms for clock inputs (OCT, VCT, OCT, FCT) of the PWM IC

The experimental waveforms of the three complementary pairs of inverter drive signals are presented

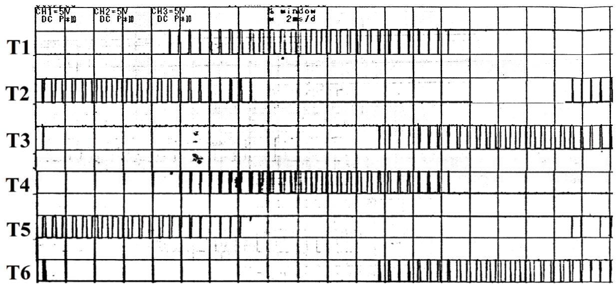

Fig.6 Experimental waveforms of the three complementary pairs of inverter drive signals

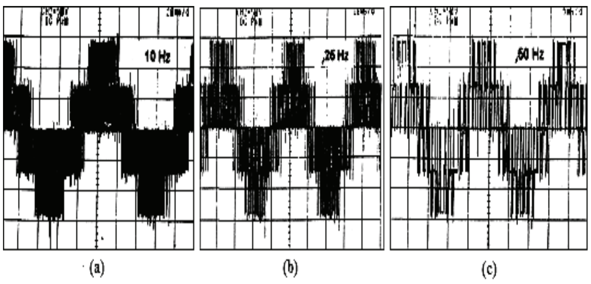

Fig.7 Experimental results of the motor at different frequencies: Voltage waveforms: (a) 10Hz, (b) 25Hz, (c) 50Hz

Figure 7 (a), (b), (c) shows experimental waveforms of PWM line to line voltage for various fundamental frequencies. The currents in one of the stator phases are given in figure 8 (d), (e), (f). From these figures it can be seen that the output current waveforms is nearly sinusoidal. The more sinusoidal current output produced by the PWM inverter reduces the torque pulsations, low speed motor cogging, and motor losses noticeable. The rotor speed evolution of a loaded motor at 10 Hz is presented in Fig. 9.

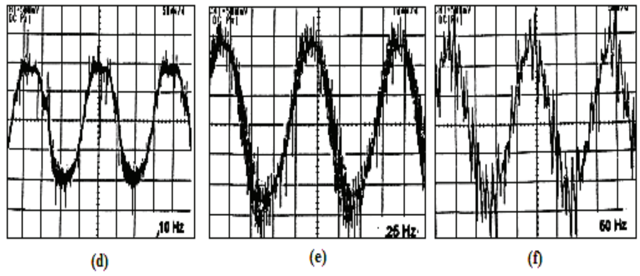

Fig.8 Experimental results of the motor at different frequencies: Current waveforms: (d) 10Hz, (e) 25Hz, (f) 50Hz

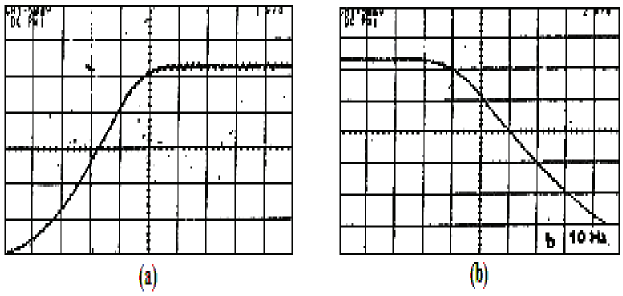

Fig.9 Rotor speed at 10 Hz. (a) Starting, (b) Braking

Conclusion

Variable-speed induction motor drives are being widely used in various industrial applications. PWM inverters are the most preferred for these applications since control of voltage, frequency, and harmonics are all achieved within the inverter itself. In this article a voltage PWM inverter using Volts per hertz control was realized. The experimental waveforms for a 2 KW induction motor drives are given and the circuit operation of this inverter in the PWM technique is clearly showed. It has been shown that the system presented offers the advantage of relatively good performances and simple control circuitry. References

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