GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES

DESIGN AND ANALYSIS OF SINUSOIDAL PWM INVERTER FED FUEL PUMP MOTOR FOR HIGH HORSE-POWER LOCOMOTIVE IN MATLAB

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ABSTRACT

A Fluid Transfer pump (FTP) is used to move fluid liquids such as fuel in the fuel managing system of High Horse-Power Locomotives (HHPL). This paper presents design and analysis of inverter fed fuel pump motor in MATLAB/SIMULINK. A very well-known sinusoidal pulse width modulation (SPWM) technique has been chosen as the control scheme of the inverter. In view of the performance, a three phase induction motor is preferable over a single phase induction motor hence it is proposed to design three phase induction motor driven FTP with three phase inverter for HHPL. The proposed inverter will have low voltage DC input available & inverter directly feds fuel pump motor without any boosting circuit hence the proposed motor will be a specially designed low voltage three phase induction motor.

Keywords—*SPWM, Voltage Source Inverter (VSI), IGBT, 3-ph IM, LC Filter, MATLAB.*

I. INTRODUCTION

India being developing country & a comfortable transportation is important for its growth. Trains contribute major transportation facilities among India in majority like transport of goods, raw materials, posts, couriers and passengers to carry on their journey. A locomotive is a railway vehicle that provides the motive power for a train & fuel is the important ingredient for locomotive to work. A pump is a device used to move fluid liquids such as fuel. A fluid transfer system basically consists of Fluid Transfer Pump (FTP) which is driven by motor fed from available power source. In High Horse-Power Locomotives (HHPL), DC power source is available which can be suitably converted into required level of AC to drive fuel pump motor in FTP. As DC motor requires excessive maintenance because of commutation and also it has very poor reliability; it difficult to use DC motor for fuel pumps. Thus it is required to use AC motor in the fuel managing system of HHPL. In view of the machine efficiency, power factor and starting torque a three phase induction motor (3-ph IM) is preferable over a single phase induction motor [4]. Thus here we have selected three phase induction motor as a fuel pump motor which is directly fed by a three phase DC to AC converter. Inverter is used to convert DC to AC power by switching the DC input voltage (or current) in a pre-determined sequence so as to generate AC voltage (or current) output. Voltage Source Inverter (VSI) & Current Source Inverter (CSI) are the two main types of inverter. Out of which VSI can be used to feed fuel pump motor as VSI gives the independently controlled AC output voltage waveform [6]. There are different switching techniques to control the VSI and for harmonic reduction. They have some advantages and disadvantages. Pulse Width Modulation (PWM) technique is the best one out of them, but the most widely used switching techniques are the Sinusoidal PWM (SPWM) and the Space Vector PWM (SVPWM). The number of industry applications in which induction motors are fed by Sinusoidal Pulse Width Modulation inverter is growing fast. It provides many benefits to their users such as simplicity of circuit, improved control of processes, reduced energy consumption & also it is compatible with today's digital microprocessors as well as analog circuits. Despite such benefits, it can be used to drive low voltage induction motor operation. In this paper Voltage Source Inverter (VSI) is discussed. Later the Sinusoidal Pulse Width Modulation (SPWM) techniques of three phase inverter are described. Then last part is simulation & analysis of proposed system with an appropriate passive filter.

II. THREE PHASE VOLTAGE SOURCE INVERTER

The voltage source inverter (VSI) gives independently controlled AC output voltage waveform and behave as a voltage source for many industrial applications [6]. The output voltage waveform of VSI is unaffected by the load. Due to this property, it is used in many industrial applications such as Un-interruptible power supply (UPS), Industrial (induction motor) drives, Traction, HVDC, etc. Three single phase half bridge inverters are to be connected in parallel to form a three phase VSI as shown in figure 1. It employs three legs each comprising two power semiconductors and two freewheeling diodes. The inverter is fed by a fixed, ripple free DC voltage source.

Power MOSFET and insulated-gate bipolar transistor (IGBT) are largely used power semiconductor devices for inverters. Power MOSFET can operate at higher frequencies, but for low power ratings. IGBT is voltage controlled power transistor. It is not quite as fast as a power MOSFET. IGBT's are generally used for high power ratings as it is suitable for high current operations [5]. Therefore, according to our requirement IGBT is chosen as power semiconductor switch & power diode is used as freewheeling diode to design the inverter.

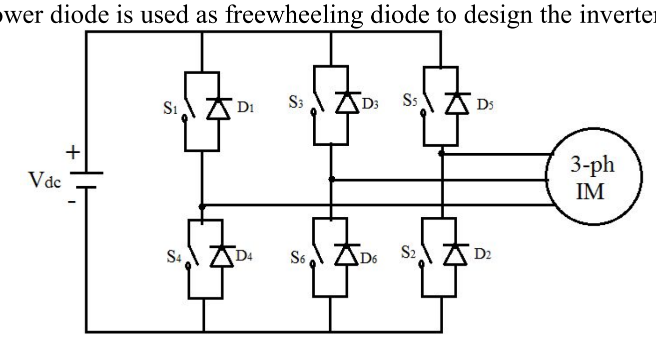

Figure 1: Three-phase voltage source inverter

III. SPWM TECHNIQUE

In this technique a high frequency triangular carrier wave is compared with the low frequency sinusoidal reference wave which determines the switching instants of control switches. The switching signal is generated by comparing the sinusoidal waves with the triangular wave as shown in figure 2. The comparator gives a pulse when sine voltage is greater than the triangular voltage and this pulse is used to trigger the respective inverter switches.

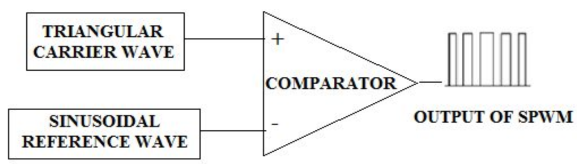

Figure 2: Sinusoidal Pulse width modulation

This technique is characterized by constant amplitude pulses with different duty cycles for each period. The width of these pulses are modulated to obtain inverter output voltage control and to reduce its harmonic content [8]. The SPWM technique directly controls the inverter output voltage and frequency according to the reference sine function. Fundamental frequency of output voltage is controlled by the frequency of reference sinusoidal waveform.

Suppose the amplitude of sinusoidal reference wave is Am, and the amplitude of triangular carrier wave is Ac, then the ratio m=Am/Ac, is known as the modulation index. It is to be noted that the amplitude of applied output voltage can be controlled by controlling the modulation index [2]. When m is greater than one, lower order harmonics will be appeared in the inverter output, therefore m should be less than one.

The ratio of frequency of the triangular carrier waveform to the frequency of sinusoidal reference waveform is known as frequency modulation ratio which controls harmonics in the output voltage. For three-phase SPWM inverter frequency modulation ratio should be a multiple of three & an odd integer for controlling of output voltage harmonics.

SPWM for three phase inverter requires three sine waves which are 120º shifted with each other and a common high frequency triangular carrier wave to generate the modulating signals for the three phases.

IV. SIMULATION STUDY

Generation of SPWM Switching Signal

SIMULINK block diagram of SPWM control is shown in figure 3. For the generation of control or switching signal for three phase SPWM inverter, first step is to generate three phase sine waves. Sine wave generator is used to generate sinusoidal waves of selected amplitude & frequency so as to give required output voltage of inverter. These sine waves then compared with a common carrier triangular wave; generated by triangle generator. It generates triangular wave of selected frequency with fix amplitude of one. Thus, amplitude of sine waves is actually modulation index of inverter. A high carrier frequency will results in low harmonics in output of inverter & gives sinusoidal current (plus a superimposed small ripple at a high frequency) in the motor [2]. Figure 4 shows three phase reference sine waves & triangular carrier wave. Figure 5 shows generated gate signals which are then used to trigger the respective inverter switches.

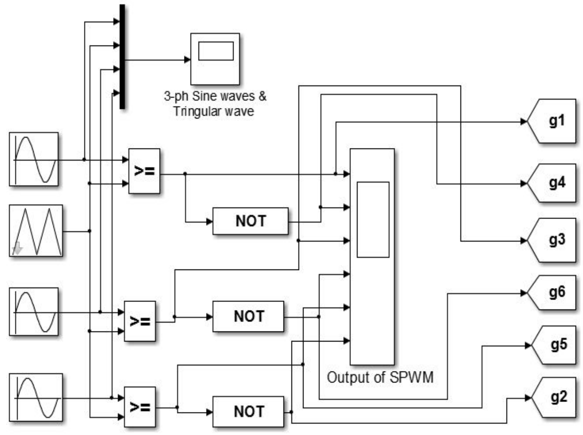

Figure 3: SIMULINK block diagram of SPWM control

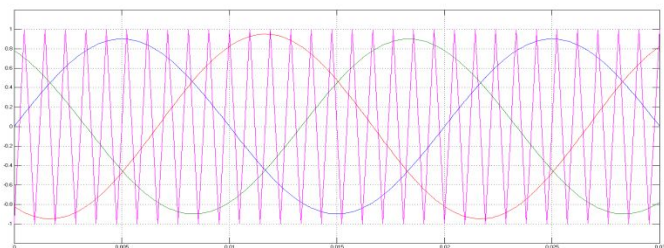

Figure 4: Three phase reference sine waves & triangular carrier wave

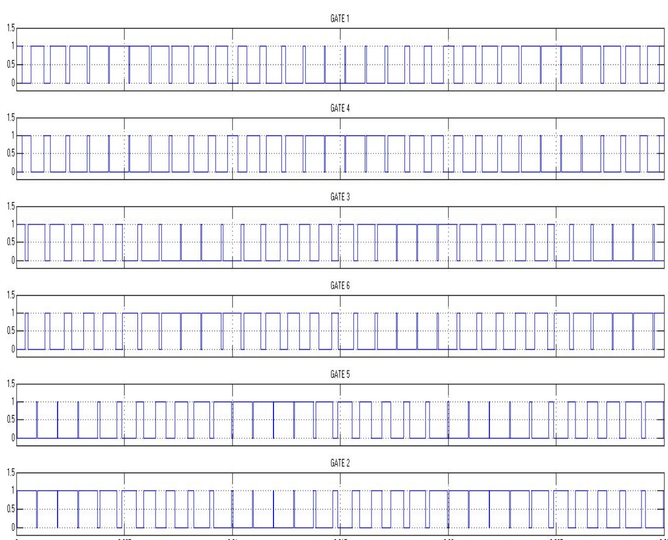

Figure 5: Gate signals

Three Phase VSI fed 3-ph IM

A three phase VSI fed to three phase induction motor is developed in SIMULINK as shown in figure 6. A three-phase squirrel cage motor rated 0.33 HP, 48 V, 50 Hz & 2850 RPM is fed by a three phase inverter connected to a DC voltage source of 84 V. The inverter is modeled using IGBT switches and the motor by the "Asynchronous Machine" block. The load torque applied to the machine’s shaft is calculated from output power of motor. Motor parameters such as rotor resistance, mutual inductance, stator & rotor inductance etc are calculated with the help of no load test & locked rotor test results [3].

Inverter with SPWM control gives modulated output voltage & sinusoidal current with small ripples as shown in figure 7. Thus a small ripple is also present in stator & rotor current of induction motor as shown in figure 8. Figure 9 shows waveform of rotor speed & electromagnetic torque respectively. There are fluctuations in the starting of rotor currents, electromagnetic torque but this is absent in speed because of machine’s inertia. Motor’s inertia prevents noise from appearing in the motor's speed waveform [2].

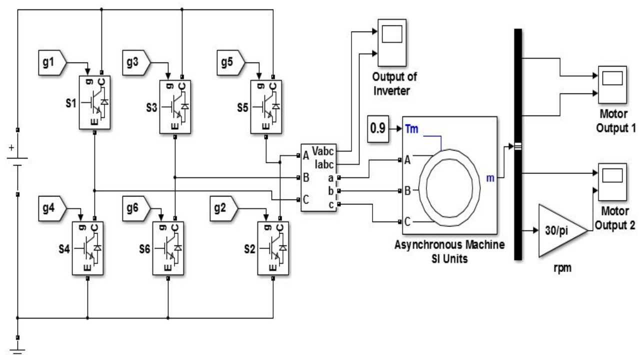

Figure 6: SIMULINK block diagram of VSI fed 3-ph IM

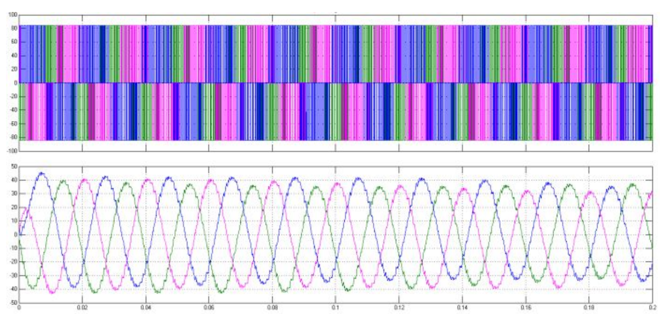

Figure 7: Line to line output voltage (volt) & current (ampere) of inverter versus time (seconds) graph respectively

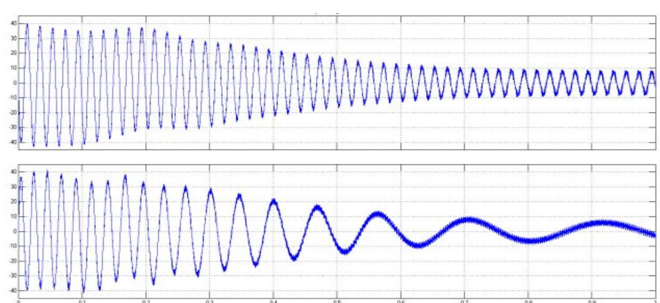

Figure 8: Stator & rotor current (ampere) of motor versus time (seconds) graph respectively

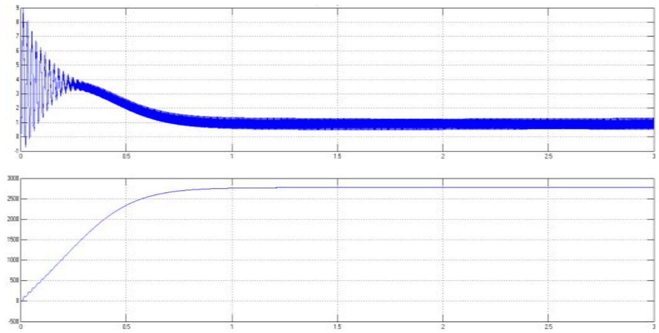

Figure 9: Rotor speed (RPM) and electromagnetic torque (N.m) versus time (seconds) graphs respectively

Filter Design

The output voltage waveform of an ideal inverter should be sinusoidal. But practically, the voltage waveform of inverter is non sinusoidal & contains harmonics. Though the harmonic content of output of inverter can be minimized or reduced significantly by switching techniques, still it contain large number of harmonics content as shown in figure 7. Attenuation of these harmonics can be achieved by several methods such as by an LC filter, pulse width modulation, selected harmonic reduction and by multilevel inverters [7]. Moreover in PWM technique, if the carrier frequency is increased, the harmonics components are reduced but switching losses will get increased.

RC & LC filters are the most widely used passive filters for inverter. They are divided into 1st order, 2nd Order & 3rd order filters according to the combination of the passive components. LC is a 2nd order filter and LCL is the 3rd order filter [7].

Here we have used a 2nd order low pass LC filter in which the capacitor maintains the load voltage constant whereas the inductor makes the current smoother [1]. The inductance offers high impedance to harmonic voltage; higher the harmonic number, higher will be the impedance & lower will be the magnitude of harmonic at the output. The capacitance offers shunt path to harmonic current. The calculation for 2nd order LC filter is done by using the following equation:

$$f_{cut-off} = \frac{1}{2\pi\sqrt{LC}} \qquad (1)$$

In this case the capacitor has been assumed to be 2200µF. According to the output voltage specification it is given that there should not be any harmonics from 150Hz to 1.5 KHz. So the cut-off frequency should be 150Hz. So the value of L is calculated as-

$$L= 1/\left[(2200 * 10^{-6}) * (2\pi * 150)^2\right] = 0.5mH$$

After connecting the filter to the output side of inverter, the total harmonic distortion (THD) is reduced to less than 5%.

This designed filter is connected to SIMULINK model as shown in figure 10. Inverter output is made very much close to the sinusoidal after filtering as shown in figure 11. As soon as the filter is connected to inverter, the output will go into transient state, for initial few cycles after that steady state will be achieved. The ripples in stator & rotor currents of induction are filtered to give smooth stator & rotor currents as shown in figure 12. Figure 13 shows waveform of rotor speed & electromagnetic torque respectively after filtering.

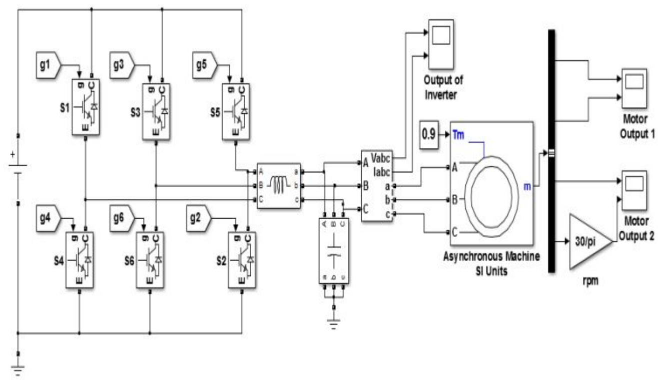

Figure10: SIMULINK block diagram of VSI fed 3-ph IM after filtering

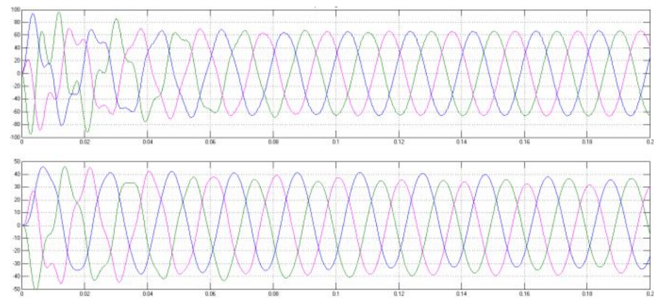

Figure 11: Line to line output voltage (volt) & current (ampere) of inverter versus time (seconds) graph respectively after filtering

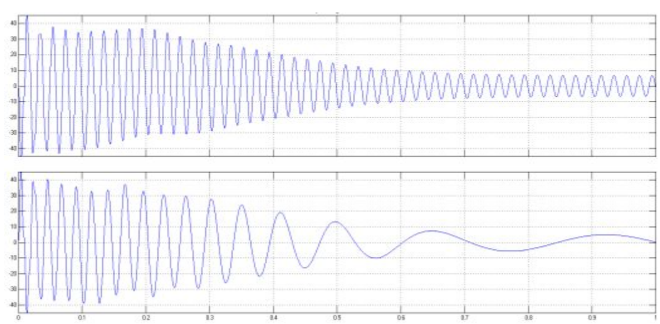

Figure 12: Stator & rotor current (ampere) of motor versus time (seconds) graph respectively after filtering

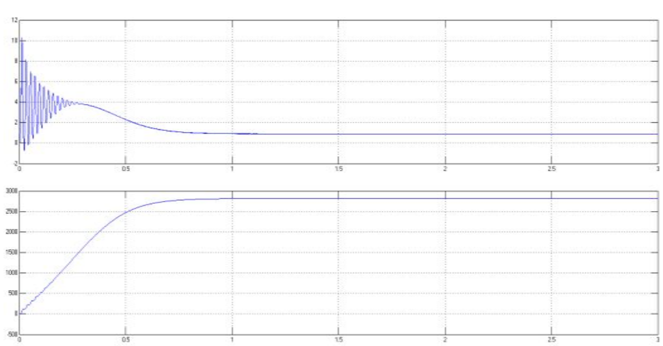

Figure 13: Rotor speed (RPM) and electromagnetic torque (N.m) versus time (seconds) graph respectively after filtering

V. CONCLUSION

The design & analysis of Sinusoidal PWM three-phase VSI with three phase induction motor as a load is done in SIMULINK. The simulation results proved that SPWM technique is very essential for harmonic reduction & to give required output voltage & frequency. After certain selected SPWM frequency, low pass filter is used to filter out harmonics. The second order LC filter is designed so as to give sinusoidal output of inverter (with small transient distortion). After filtering, the noise introduced due to SPWM in three phase induction motor is also got reduced.

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