Modeling & Simulation of 1-Phase to 3- Phase PWM Rectifier-Inverter Topology for Induction Motor

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Abstract: **This paper includes a new topology of single-phase to three-phase Pulse Width Modulated (PWM) converters for low-power three-phase induction motor drives. The simplest circuit of an AC/DC/AC converter topology, converting a single-phase supply to a three-phase variable-voltage and variable-frequency (VVVF) system is a single-phase full-bridge PWM rectifier and a three-leg three-phase PWM inverter system. The converter supplies balanced output voltages at rated frequency at constant speed and also gives excellent performance such as sinusoidal control of source current, constant DC voltage control and bidirectional power flow. In this paper, Matlab simulink model of Rectifier-Inverter(R-I) system with 3-phase delta connected resistive load & with induction motor (IM) with open loop and closed loop are discussed.**

Keywords: **Single phase-to-three phase, PWM rectifier, PWM inverter, Induction motor**

I. INTRODUCTION

The number of industrial applications in which induction motors are fed by static frequency inverters is growing fast and although much has already been done within this field, there is still a lot to be studied regarding such applications. The advance of variable speed drives systems engineering increasingly leads to the need of specific technical guidance provision by electrical machines and drives manufacturers, so that such applications can be suitably designed in order to present actual advantages in terms of both energy efficiency and costs.

The utilization of static frequency inverters comprehends currently the most efficient method to control the speed of induction motors. Inverters transform a constant frequency constant amplitude voltage into a variable (controllable) frequency-variable (controllable) amplitude voltage. The variation of the power frequency supplied to the motor leads to the variation of the rotating field speed, which modifies the mechanical speed of the machine.

II. INDUCTION MOTOR

The AC induction motor is a rotating electric machine designed to operate from a 3-phase source of alternating voltage. For variable speed drives, the source is normally an inverter that uses power switches to produce approximately sinusoidal voltages and currents of controllable magnitude and frequency. The stator is supplied by a balanced three-phase AC power source. The synchronous speed of the motor n_s is given by

$$n_s = (2 * 60 * \pi * f_s) \div p \quad \text{RPM} \qquad (1)$$

As the induction motor is asynchronous machine, hence the rotor speed will not reach the synchronous speed. The rotating magnetic flux that takes place in the stator is induced in the rotor that will turn at the base speed, which is normally about 0.5 % slower than synchronous speed. If no load is applied to the rotor and 100 % if rotor is stopped completely from turning, then speed slip is given by

$$s = \frac{n_s - n}{n_s} * 100\ (\%) \qquad (2)$$

The stator windings are powered from 3 voltages that differ in phase 120° from each other. By means of an inverter, single DC power supply can be modulated into 3 AC voltages at variable amplitude and variable frequency set by the controller that drives the rectifier and inverter respectively [1].

The block diagram of proposed scheme is shown in Fig. 1 having 1-phase rectifier and DC link capacitor followed by 3-phase inverter and the outputs of the inverter are given to the 3-phase induction motor as supply voltages. The gating signals to the rectifier and inverter are generated by Microcontroller 89c51.

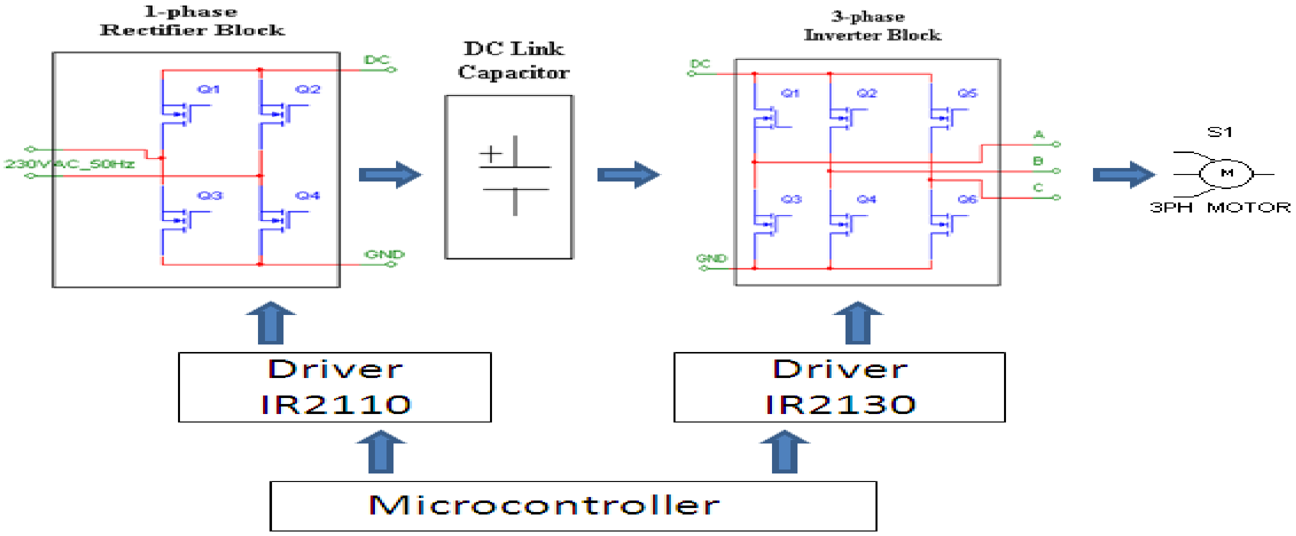

Fig. 1 Block Diagram of Proposed Scheme

III. SOURCE SIDE CONVERTER

A. Single-phase Controlled Rectifier

From the above block diagram, we can see that the controlled rectifier has 1-phase supply of 230 V AC, 50 Hz. The power circuit has 4 N-channel MOSFETs IRF840 which have ratings of 500 V and 8 A. The switching frequency of rectifier is 1 kHz.

The gating signals are generated from 89c51 microcontroller in order to switch on the MOSFET pairs of Q1-Q4 and Q2-Q3. To prevent the switches, power diodes are connected anti-parallel to each MOSFET.

The gating signals are first given to the opto-isolator circuits and then given to the Driver circuits IR 2110. Here, 2 driver ICs are required. The opto-isolator circuit gives isolation between the control circuit and power circuit.

IV. DC LINK CAPACITOR

A. Selection of DC link capacitor

The DC link capacitor is used in DC to AC inverters to decouple the effects of the inductance from the DC voltage source to the power bridge. The bus link capacitor provides a low impedance path for the ripple currents associated with a hard switched inverter. The ripple currents are a result of the output inductance of the load, the bus voltage and the PWM frequency of the inverter. Unfortunately the ripple currents have been the primary factor in sizing the electrolytic bus link capacitor [2].

For a high performance hard switched DC to AC inverter using film capacitors is more useful than electrolytic capacitor. Because the film capacitors are advantageous over electrolytic capacitors in terms of size, weight, lifetime, inverter efficiency and cost [2].

B. Calculation of DC link Capacitor

As shown in block diagram, the source inductance is usually large enough to limit the high frequency ripple current. Therefore the ripple current in the bus link capacitor is essentially the same as the ripple current of the source.

The output voltage V is defined by the following equation:

$$\mathbf{Vout = duty\ cycle * Vbus} \qquad (3)$$

Using Δt for a 50 % duty cycle, $\Delta t = 0.5 * t$ and

$$\mathbf{\Delta V_{0.5t} = V_{bus} / (32 * L * C * f^{2})} \qquad (4)$$

Where $\Delta V_{0.5t}$ is the maximum peak to peak ripple voltage across the bus link capacitor at a 50% PWM duty cycle, V_{bus} is the bus voltage, L is the phase inductance in Henries, C is the bus link capacitance in Farads, and f is the PWM frequency in Hertz.

Now rearranging the equation (4), we can determine the value of DC link capacitor:

$$\mathbf{C = V_{bus} / (32 * L * \Delta V_{0.5t} * f^{2})} \qquad (5)$$

V. LOAD SIDE CONVERTER

A. Three-phase Controlled Inverter

As shown in block diagram, the inverter circuit has 6 N-channel MOSFETs IRF840. The DC supply for inverter is the output of the 1-phase rectifier which is followed by DC link capacitor. The inverter switching frequency is 2 kHz.

The gating signals are generated by 89c51 Microcontroller to switch the MOSFET pairs in 180° conduction mode. The gating signals are first given to the opto-isolator circuits and then given to the Driver circuit IR2130. IR2130 is a driver IC particularly designed for three phase.

The inverter produces three voltage waveforms having fundamental frequency component ranges from 0 to 120 Hz. These output voltages are used to drive the 3-phase induction motor. The motor voltages are in delta connected. Hence, the phase voltages and line-to-line voltages are same.

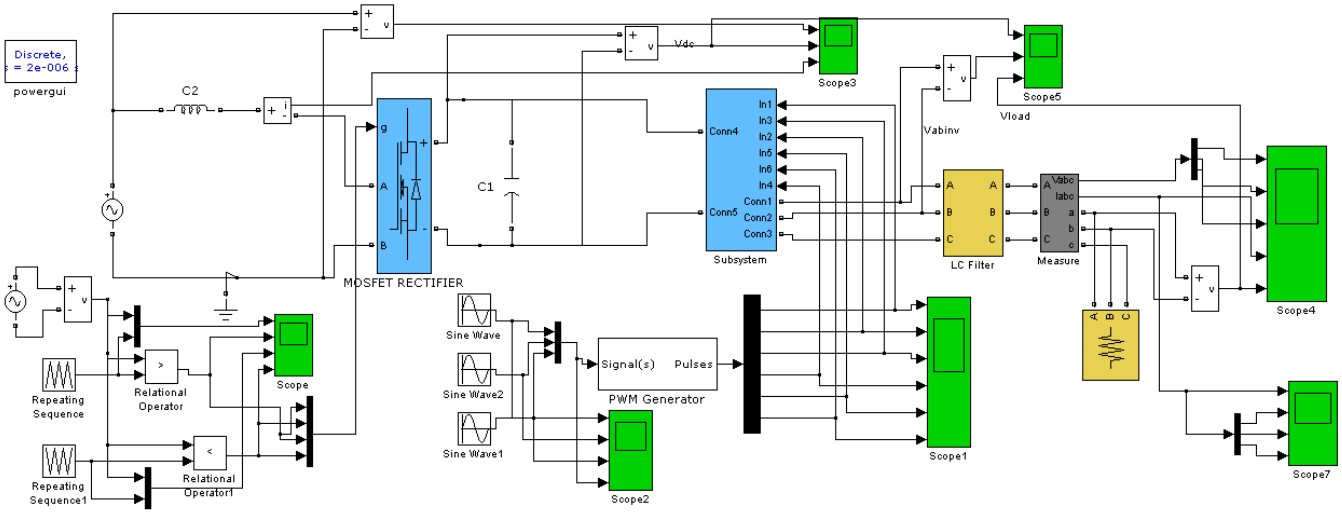

Fig. 2 Simulink model of Proposed Scheme with Resistive Load

B. Simulink Model of A Proposed Scheme with Different Loads

A. With resistive load and open loop

In Fig. 2, the simulink model of proposed scheme with resistive load is shown. This is open loop simulink model of proposed scheme. Here, 1-phase PWM controlled rectifier is used and the gating signals for 4 MOSFET switches are generated by sine-triangle modulation technique which is shown in the Fig. 2.

The DC link capacitor is followed by 3-phase PWM inverter and the 3-phase output voltages are connected to the stator of the 3-phase induction motor. The 6 gating signals for 3-phase inverter are generated by sine-triangle modulation technique.

The positive signals and negative signals generated are shown in Fig. 3 & 4. The DC link output voltage waveforms with supply voltage and supply current waveforms are shown in Fig. 5. The output phase voltages and output current waveforms are shown in Fig. 6 & 7 respectively.

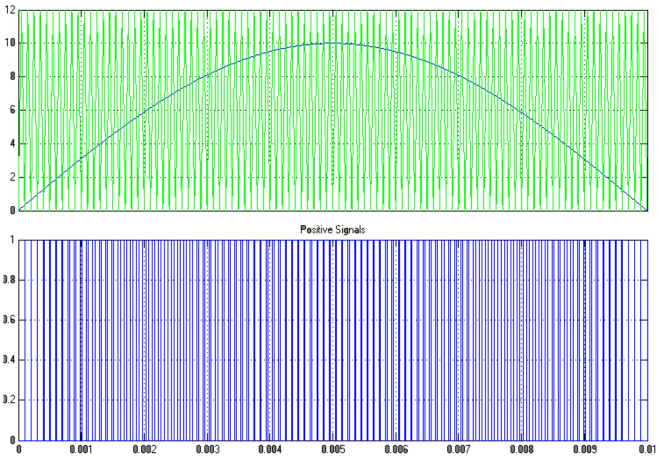

Fig. 3 Positive Signals

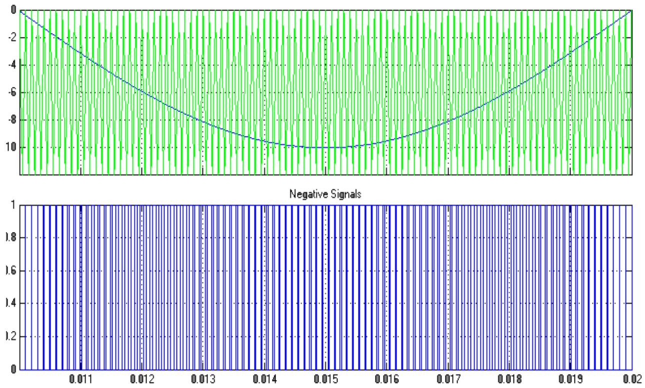

Fig. 4 Negative Signals

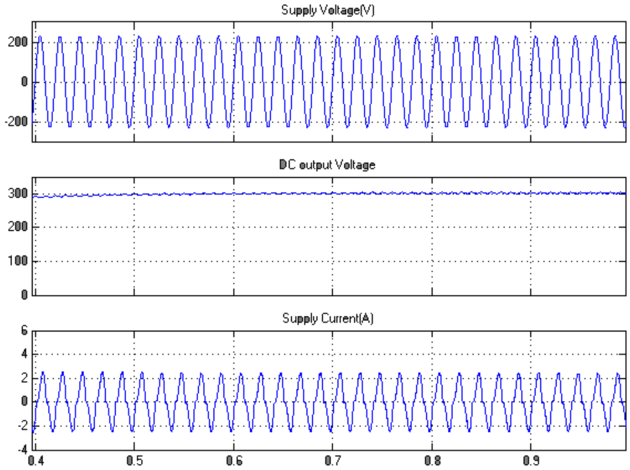

Fig. 5 DC link Capacitor Voltage

Here we can see that initially the DC link capacitor voltage is zero and gradually increases and get constant value nearly about 300 V. The supply current is nearly of 2.5-2.7 A and it is lagging from the supply voltage. The resistive load is delta connected.

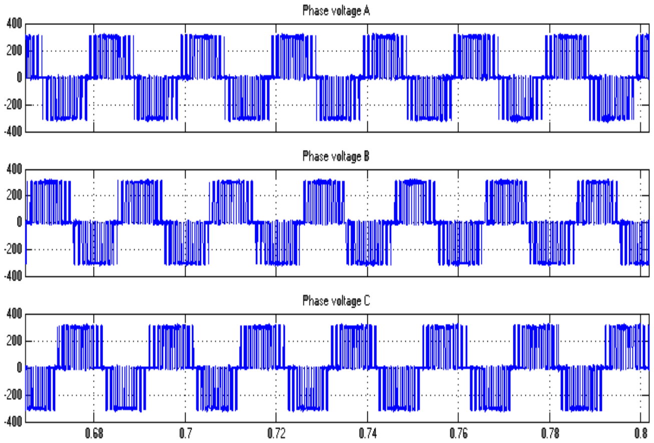

Fig. 6 Output Phase Voltages

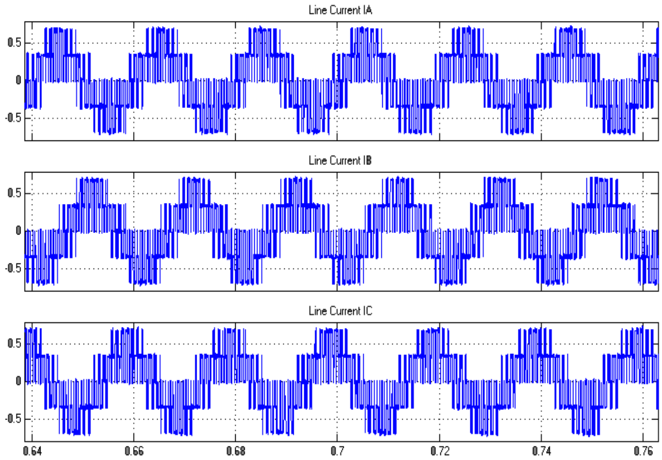

Fig. 7 Line-to-line Currents

B. With motor load and open loop

The Matlab simulink model of proposed scheme having motor load in open loop is same as shown in Fig. 2, only there is motor load instead of resistive load. There are so many difficulties faced during simulation in selection of source inductance and DC link capacitor.

The DC link capacitor output voltage waveform is shown in Fig. 8 with single phase supply voltage and supply current waveforms. The stator voltage and stator current waveforms are shown in Fig. 9. The waveforms of rotor speed wm (RPM), output frequency f (Hz) and torque Te (N-m) are shown in Fig. 10. We can see that the output frequency is nearly about 650 Hz, which is the switching frequency of three-phase inverter. Hence by changing the switching frequency, the torque can be regulated within defined range. Fig. 11 shows the three stator current waveforms of the induction motor.

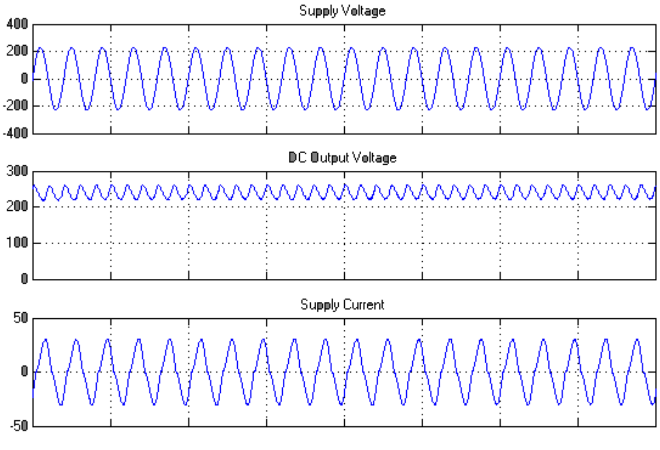

Fig. 8 DC link capacitor voltage

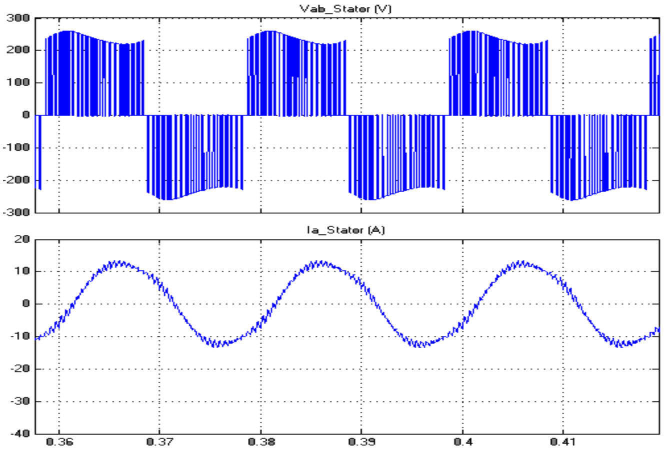

Fig. 9 stator voltage and stator current waveforms

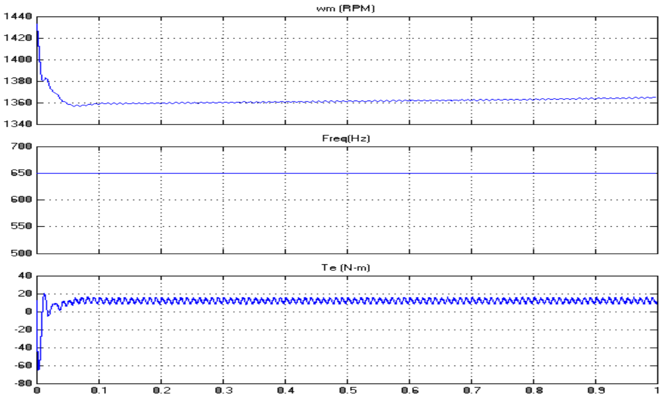

Fig. 10 Rotor speed wm (RPM), Output frequency f (Hz), Torque Te (N-m)

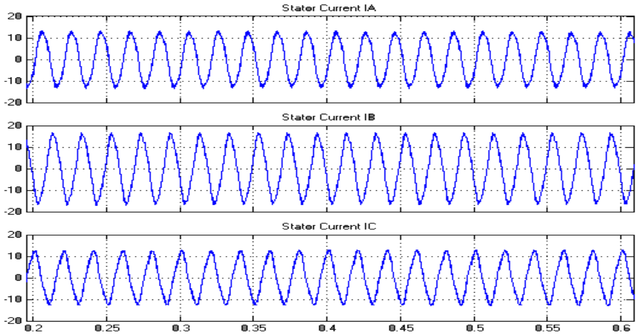

Fig. 11 Stator current waveforms

VI. CONCLUSION

In the above paper, the operation of PWM R/I system has been discussed in brief. Also this paper demonstrates scalar control 1-φ to 3-φ conversion in an induction motor drive system. Simulation tests verify the performance of induction motor drive system and power line condition for sinusoidal currents. Also gives speed & torque regulation with speed control.

The proposed control technique assures:

- High dynamics of speed control.
- Good stabilization of load torque for wide range speed control.
- Regenerative braking.
- Low THD.

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