Operational Amplifier based control circuit for single phase multiple PWM inverter for Induction Motor Drive Application

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Abstract— **This article explores the variable speed of a single phase induction motor by varying supply frequency with the help of Multiple Pulse Width Modulation based Inverter. In PWM voltage source inverter the variation of both voltages to frequency should be done simultaneously to keep their ratio constant. In this investigation a simple novel control circuit is adopted using OPAMP. The PWM AC motor drives are widely used to control the speed of conveyor systems, blower, pump, and other industrial applications. The Multiple PWM inverter system using IGBTs improves power factor and provides required variable speed. The multiple PWM topologies along with the proposed control circuit are analyzed through 'Multisim' simulation.**

Index Terms: **Single Phase IM drive, MPWM Inverter, OPAMP based control**

I. INTRODUCTION

Traditionally voltage source inverter (VSI) and current source inverter (CSI) inverters are used for power control of Adjustable Speed Drives (ASDs) [1-2]. These inverters consist of a diode rectifier, dc link and an inverter bridge. Adjustable speed AC machine system is equipped with an adjustable frequency drive that is a power electronic device for speed control of an electric machine. It controls the speed of the electric machine by converting the fixed voltage and frequency of the grid to adjustable values as required. The speed of an induction motor is controlled by varying the frequency of the power applied to its stator windings. In order to obtain substantially full-load torque capability at all operating speeds it is also necessary to be able to achieve maximum air-gap flux in the motor. In a voltage-source inverter drive, flux is often held near maximum at all times by maintaining a constant motor voltage-to-motor speed ratio [3-5].

Recently there is a growing interest in single-phase PWM inverter circuit that changes DC input voltage to a single-phase variable-frequency and variable-voltage output. This controlled DC is converted into controlled pulses using a voltage to frequency converter. These controlled pulses are fed to the inverter bridge for producing the variable voltage variable frequency output. The output is fed to the single-phase induction motor for controlling its speed [6].

The object of the op-amp based multiple PWM inverter is to demonstrate a closed loop, variable speed, induction motor drive system which has maximum torque capability up to base speed without the use of tachometers or other devices for measuring slip frequency [7-8]. voltage signal feedback from the motor windings to derive the alternating current command wave forms, which together with the current feedback, controls the PWM voltage source inverter, and hence, the excitation frequency and motor speed. Op-amp based multiple PWM inverters for induction motor drives provide a low cost and highly efficient single stage structure with reliable operation. This novel control circuit using linear ICs is simple, reliable and scores over other conventional power control strategies for ASDs.

II. PROPOSED OPERATIONAL AMPLIFIER CONTROL TOPOLOGY FOR INDUCTION MOTOR

A) Operational amplifier control

In pulse width modulation technique several pulses are produced in each half cycle but the width of the pulses is not the same as in case of multiple pulse width modulation, however the width of each pulse is varied in accordance with the amplitude of the feedback voltage wave. The block diagram Proposed Operational-amplifier control based PWM inverter shown in fig 1. This A square wave of 50 Hz is generated by an OP-AMP. Here a POT of value 2 MΩ is used to vary the frequency of the square wave above 50 Hz.

There after another square wave of fixed frequency about 5 kHz is generated. Integrating this high frequency square wave, the triangular wave f_c (also called carrier signal) is generated. Integrator is a circuit whose output is proportional to the area of its input waveform. The RC circuit itself acts as a simple integrator. The output of PWM wave f_r is called as reference signal. And the triangular waves are compared using two OP-AMPs. The comparator is circuits provide an output indicating the relationship between two voltages and when feedback wave of has a higher magnitude than the triangular wave the comparator output is high; otherwise it is low shown in fig 2.

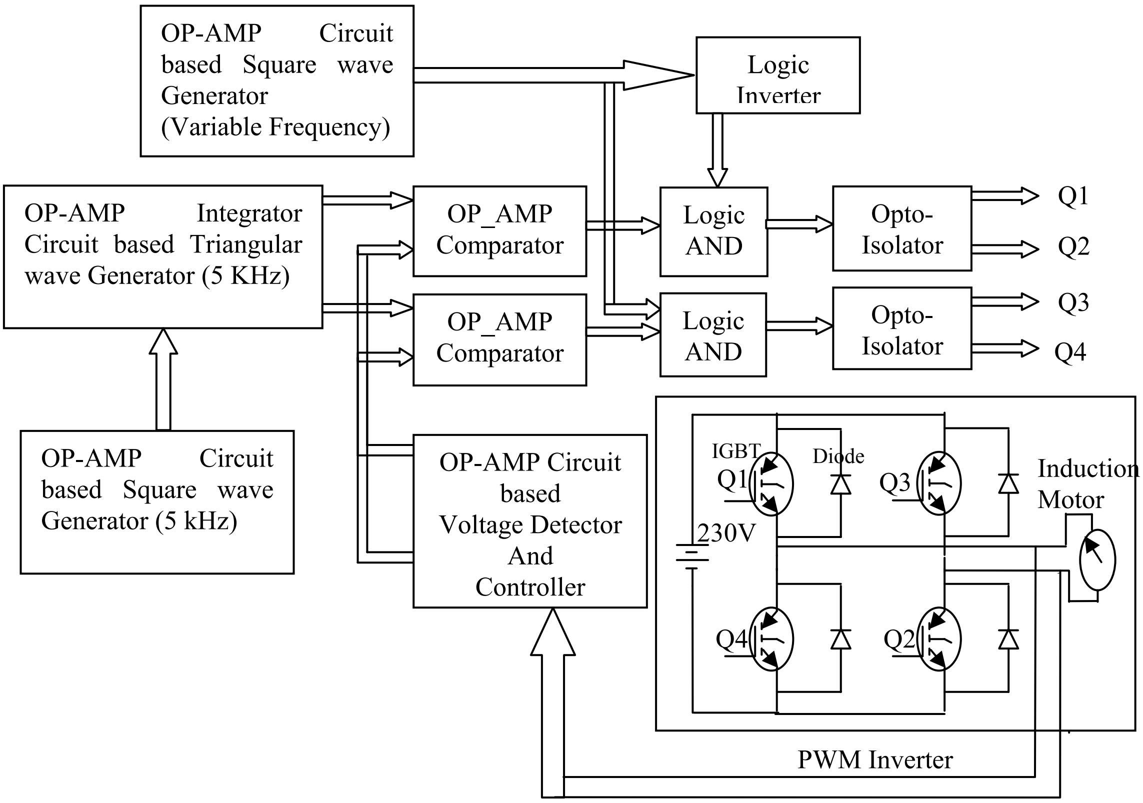

Fig 1 Proposed Operational-amplifier control based PWM inverter

The reference signal frequency f_r determines the output frequency f_O of the inverter, and its peak amplitude A_{rms} controls the modulation index M, and thereby the *rms* output voltage V_O. If the ratio of these two signals (reference and carrier) is equal to m, then the number of pulses in each half – cycle is $M-1$ Now recall that voltage gain (A_v) of an amplifier is defined as the ratio of output voltage to the input voltage.

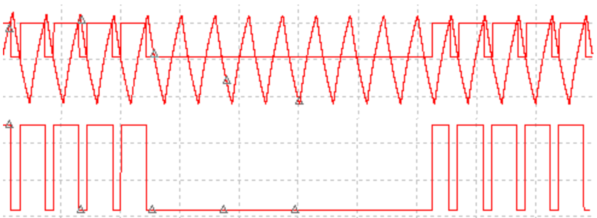

Fig 2 Gate signal voltage

At last the output of the first comparator is ANDed with the square wave of variable frequency by using chip 7408 and the output of the second comparator is ANDed with the inverted square wave of variable frequency inverter 7404 to generate the triggering pulse for triggering the POWER IGBTs. The pulses are isolated trough four Opto-couplers, so that each POWER IGBTs of the inverter bridge is being triggered separately.

By using power IGBT IRG4RC10K and diode S5227N build the inverter bridge circuit. In Inverter Bridge four IGBTs are used. Suppose we indicate the IGBTs by Q_1, Q_2, Q_3, and Q_4. Now source pins of Q_1 and Q_3 are connected with the positive side of 230V D.C. supply.

The outputs of the controlling circuit are connected to the gate pins of all IGBTs, its automatic switches operated by gate pulse. We use control circuit pulses to ON or OFF the IGBTs of the bridge to get sinusoidal A.C. supply. The drain pins of Q4 and Q2 are connected with the negative side of 230V D.C. supply. Now when Q1 is ON due to gate pulse the D.C. current flows through it, then Q2 is ON and make a closed loop through load attached in the middle of the bridge. So, the upper half of the sinusoidal pulse appears across the load. Next, Q3 is ON and D.C. current flows through it. When Q4 become ON, the current flows through the load and the lower part of the sinusoidal supply appears across the load. Now we get the desired A.C. supply for motor. Here every IGBT is become ON when the amplitude of the gate pulse is $3.8V \cong 4V$.

B) Induction motor

This Induction motors are of two types - Squirrel-cage motor and Wound-rotor motor [1-3]. For squirrel-cage type motor based supply frequency control methods are discussed.

Synchronous speed is defined as

$$N_s = 120\frac{f}{P} \qquad (1)$$

Motor speed is defined as

$$N_r = (1-s)N_s \qquad (2)$$

Now, we can vary synchronous speed, which can vary by varying the supply frequency and can vary the motor speed.

Voltage induced in stator is proportional to the product of supply frequency f_s and air-gap flux φ_m

$$E = 4.44 k_w \varphi_m f_s T_{ps} \quad (3)$$

If stator drop is neglected, then E is equal to V. Then the supply voltage will become proportional f_s to φ_m and

$$V = 4.44 k_w \varphi_m f_s T_{ps} \quad (4)$$

Any reduction in the supply frequency f_s keeping the supply voltage constant causes the increase of air-gap flux φ_m. Induction motors designed to operate at the knee point of the magnetization characteristic to make a full use of magnetic material. Therefore, the increase in flux will saturate the motor. This will increase the magnetizing current and distort the line current and voltage, increase in core loss and stator I^2R loss and produce a high-pitch acoustic noise [5]. Also, a decrease in flux is also avoided to retain the torque capability of motor. Therefore, variable frequency control below rated frequency is generally carried out at rated air gap flux by varying supply voltage with frequency so as to maintain $\frac{V}{f}$ ratio constant at the rated value (Fig 3).

Power = 1/12 hp
Current =0.85A;
Voltage =230V
Speed =6500 r.p.m;
Power factor =0.8

Fig 3 Induction motor

To run a motor we need power supply. In speed variation of single phase induction motor by varying frequency variation method we have to vary external resistance of the control part of the control circuit to vary frequency of the supply of motor.

The power part consists of Supply Voltage and Inverter Bridge. In supply 230 V A.C. is required for the motor. To obtain this voltage, the value of required D.C. voltage we can obtain by the following equation [1]

$$V_{ac} = 0.612 m_a V_{dc} \quad (5)$$

where,

V_{ac} = Supply voltage for the induction motor.

m_a = Modulation index = $= \frac{V_{\sin}}{V_{tri}}$ (6)

V_{dc} = Supply D.C. voltage for inverter

$$\therefore V_{dc} = \frac{V_{ac}}{0.612 m_a} \quad (7)$$

$$= \frac{230}{0.612 \times 0.7} = 537V$$

The variable frequency control provides by operational amplifier controller based PWM inverter, its give perfect running and transient performance due to the following features;

(i) Speed control and breaking operation are possible from zero speed to base speed.

(ii) During transient the operation can be carried out at the maximum torque with reduce current giving good dynamic response

(iii) Copper losses are low and the efficiency and power factor are high.

(iv) Drop in speed from no load to full load is small.

III. SIMULATION RESULT AND ANALYSIS

The operational amplifier based multiple PWM control technique executed and evaluated through multisim. The multisim is National Instruments Electronics Workbench Group equips design engineers and researchers with powerful and innovative circuit design technology.

A square wave of 50 Hz is generated by an OP-AMP shown in fig 4. Here a POT of value 2 MΩ is used to vary the frequency of the square wave above 50 Hz.

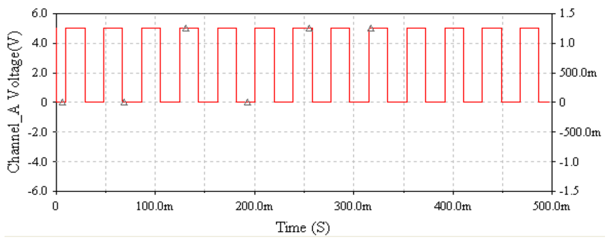

Fig 4) 50 Hz sinewave wave

Another square wave of fixed frequency about 5 kHz is generated. And integrating this high frequency square wave for triangular wave generated shown in fig 5.

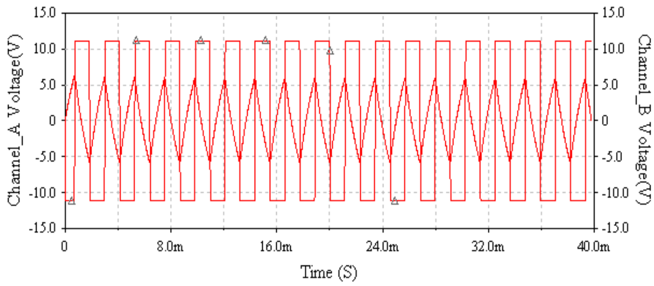

Fig 5) 5 kHz square wave and integrated Triangular wave

The output of PWM detected voltage controlled by operational amplifier circuit and also its act as a reference signal waveform, shown in figure fig6.

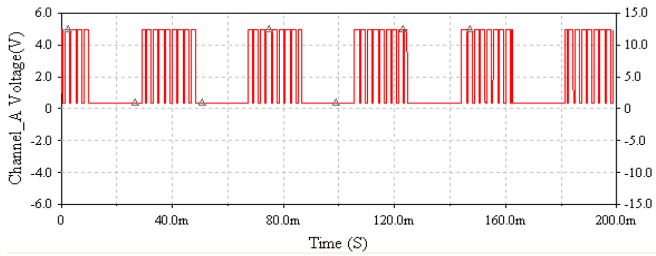

Fig 6) output of the detector amplifier wave

The output of PWM detected reference voltage and the triangular wave are compared using two OP-AMPs comparator circuit, shown in waveform Fig 7. It generate gate signal for drive the PWM inverter.

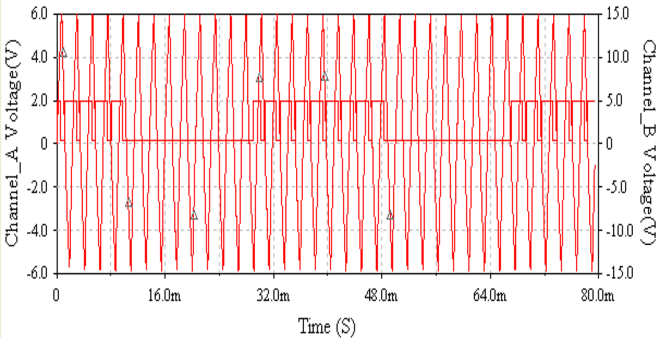

Fig 7) Tringularwave and detector voltage (reference signal) wave

The output of the first comparator is ANDed with the square wave of variable frequency by using chip 7408 and the output of the second comparator is ANDed with the inverted square wave of variable frequency inverter 7404 to generate the triggering pulse for triggering the POWER IGBTs shown in figure Fig 8.

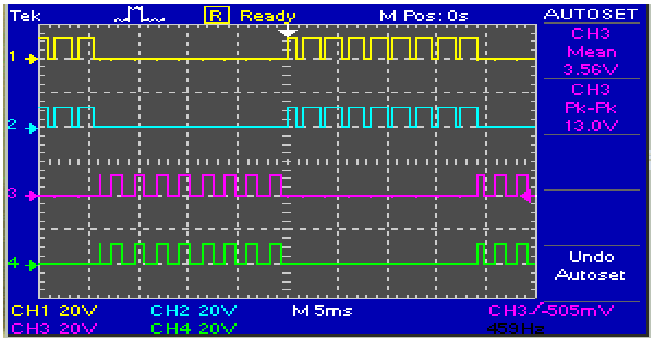

Fig 8) Triggering pulse for drive the Power IGBTs

The output of the inverter fed to the induction motor shown in Fig 9. Its variable frequency and controlled the variable speed of induction motor.

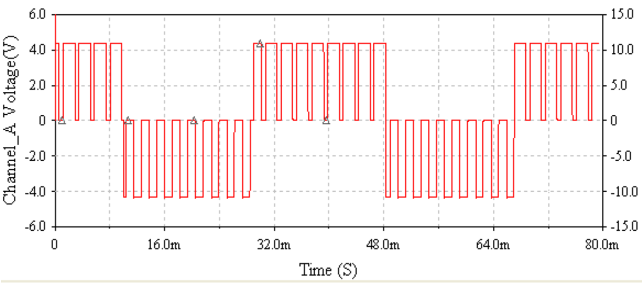

Fig 9) output of the inverter fed to the induction motor

The spectrum analyzer is used to measure amplitude versus frequency in the load voltage and current shown in fig10 and 11 respectively. It performs a similar function in the frequency domain. It operates by sweeping through a range of frequencies. The spectrum measurement is must be checked for harmonics of the carrier signal that might interfere with PWM inverter. If the same signal (with harmonics) is displayed on a spectrum analyzer the amplititude of its fundamental frequency displays, as well as its frequency components harmonics.

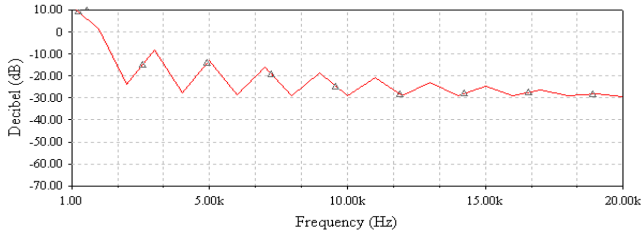

Fig 10 spectrum analysis of load voltage with PWM

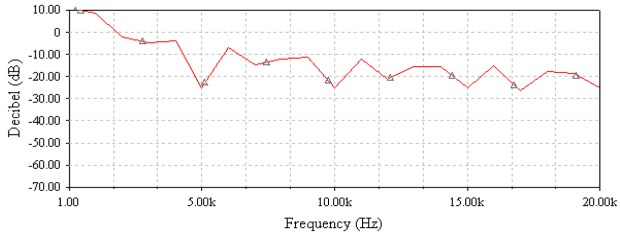

Fig 11 spectrum analysis of load current with PWM

Fourier analysis of PWM inverter output voltage analyzed with fundamental frequency of 50 Hz. The simulation model shown in fig 12, its express the 2nd, 4th and 6th order of harmonic less than 3rd, 5th and 7th order of harmonic is acceptable and can be considered as a healthy motor-drive system.

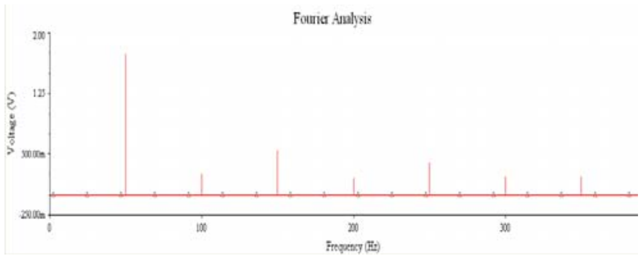

Fig 12 FFTs of motor current and supply current of model

IV. Conclusions

The novel operational amplifier based control circuit for Single Phase Multiple PWM inverter fed Induction Motor drives is investigated and simulated by using multisim. An op-amp based PWM facilitates design so that pulses are at the full supply voltage and will produce more torque in a motor by being able to overcome the internal motor resistances easily. A resistive speed control will present a reduced voltage to the load, which can cause stalling in motor applications. In a PWM circuit, commonly used small potentiometers may be used to control a wide variety of loads.

Harmonic losses in the stator and rotor can affect motor temperature rise. Harmonic fed back to the power system is reduced by the use of filters that are connected to the incoming power supply. The Multiple PWM inverter closed loop system using IGBTs facilitates improving the power factor and provides required variable speed of the motor. Op-amp controller is a simple approach and low cost solution. The circuit is efficient and reliable and certainly scores over other conventional control strategies.

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