

Speed Control of Induction Motor using Modified Pulse Width Modulation Technique

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Abstract— Alternating Current (AC) motors have speed control capabilities only when operating from alternating current sources, and speed control is achieved by varying the applied voltage and/or the frequency of its inversion. All the known methods of controlling the speed of an AC motor using electronic devices are nothing but variations of either Phase Angle firing control (PFC) or Pulse Width Modulation firing control (PWM). Phase angle firing control is the most common method of speed control. It is cheap and reliable, but torque is low at reduced voltages and the motor may stall on load or not start at all. The Pulse width modulation firing control, on the other hand, produces an average voltage value which is directly proportional to the percentage on and off duty cycle of the applied voltage. It is efficient and can be used on all types of load, but the control mechanism is cumbersome and expensive. The aim of this research is to design a speed controller that brings an induction motor up to speed for a certain number of cycles, and then when the motor is up and running, control the applied voltage by phase angle firing for the remaining number of cycles. The overall effect is still PWM because the controller now averages the speed into a value that is proportional to the percentage duty cycle of the dwell time difference between the applied voltage and the speed induced stator emf. At first the general principles of both the PFC and PWM firing control schemes are discussed and a scheme is proposed, the validity of which is tested via simulation.

Index Terms— Comparator, Phase angle firing Control (PFC), Pulse Width Modulation firing control (PWM), Phase-angle-delayed PWM, Rotor induced stator emf, Thyristor or Silicon Controlled Rectifier (SCR), Zero Crossover Detector.

1.0 INTRODUCTION

AC motors often feature certain advantages over their DC counterparts. They are uncomplicated and rugged in construction, resulting in lower maintenance costs and improved reliability, and their performance characteristics can be adjusted to fit a number of different operating conditions by relatively simple design changes [1]. However, the control flexibility available with these drives is limited and their application is, in the main, limited to applications such as fans, pumps, and similar other applications where speed need be regulated only roughly and where transient response and low-speed performance are not critical [2].

We can have full control over the speed of an AC motor by using a silicon controlled rectifier (SCR) to switch the supply voltage on at any one point in each half-cycle of the voltage waveform, or at more than one point within a window space period allowed for it by pulse-width modulation [3], [4]. The "one-shot" or phase angle firing method requires that the SCR be fired only at one point in each half cycle of the applied voltage. However, the sudden switching part-way into

the applied voltage results in large amount of electrical noise which must be minimized [5]. The "multi-shot" or pulse width modulated firing method requires that an SCR be fired at more than one point in each half cycle of the applied voltage, which means that one must have to contend with the problem of switching off the SCR every time it is switched on and this does not come cheap, especially for high power application [6].

An SCR is self commutating if it is switched on at the zero crossings of the applied voltage waveform, and all the aforementioned problems would not occur. However, full voltage is always applied at start-up, and for an induction motor the starting current can be several times its nominal value. The one difference between PWM and phase angle firing control is the dwell time of the pulse against the time that elapses before the pulse occurs. When an induction motor is up and running, rotor induced stator emf is generated which tends to oppose the applied voltage. If we can develop a speed controller that averages the speed into a value which is proportional to the net voltage applied to the stator winding, we can have a more cost

effective and efficient speed controller that can be used on all types of load.

2.0 Review of Related Work

Using a MOSFET connected in parallel with a Thyristor to ramp up the voltage applied to an induction motor from the leading edge of the supply waveform, rather than from the trailing edge, up to the point where phase angle firing control can take over.

2.1 The Modified PWM Firing Scheme

The basic idea behind this scheme is to use a combined integral voltage control and phase angle-delayed PWM firing pulses, as illustrated in the Block diagram of Fig. 1.

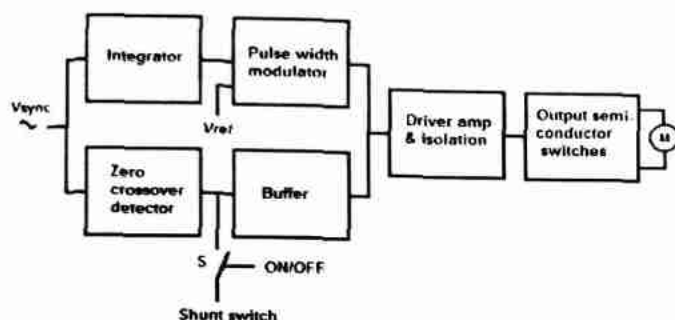


Figure 1: The Basic Idea Block Diagram

In the related firing scheme shown in Fig.2.2, a power transistor is utilized in parallel with an SCR to ramp up the applied voltage before the SCR is allowed to fire. The ramping voltage is buffered, say by a voltage follower. The SCR shorts out the parallel transistor as soon as it conduct and remains conducting for the remaining part of the voltage cycle. The larger the area under the voltage curve, the more is the power delivered, and hence the speed of the induction motor.

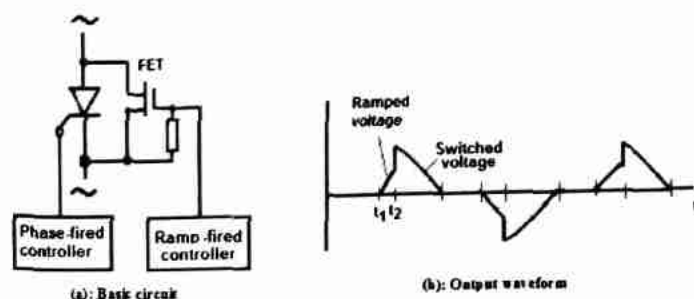


Figure 2: The Related Firing Scheme Block Diagram

(i) Synchronizing Voltage (V_{sync})

At the front end of the diagram is the pulsating DC voltage, V_{sync} , derived from a 220/6-0-6 V 50 Hz centered tapped transformer. The DC control voltage is also derived from the transformer.

(ii) The Integrator

The pulsating dc voltage is metered by variable resistor $VR1$ into comparator (Comp.1), which outputs

a voltage of constant amplitude everywhere except at the crossover points. The integrator then realizes the integrator function by producing a ramping voltage, as shown in Fig. 2.

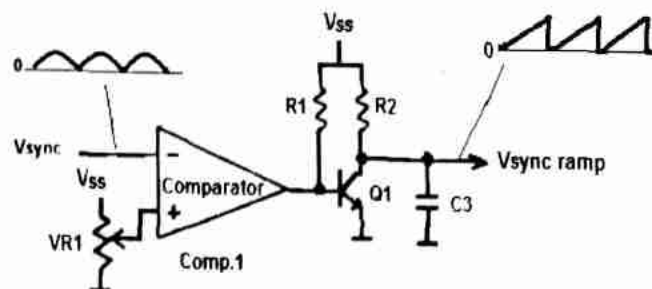


Figure 3: Synchronized ramp generator

(iii) The PWM Generator

The ramping voltage is fed to the second comparator (Comp.2), as shown in Fig. 4, where pulse width modulation takes place. The firing delay, and hence the speed of the motor is changed in the range $0^\circ \leq \alpha \leq 180^\circ$ as the potentiometer $VR2$ is adjusted [7], [8]. The function of the differentiator, composed of $C4$, $R4$ and $D5$, is to produce narrow firing pulses of width determined by the time constant $R4C4$.

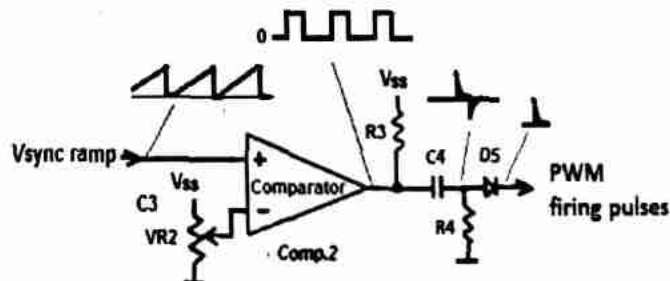


Figure 4: The PWM generator

(iv) The Zero Crossover Detector

The function of the zero crossover detector, shown in Fig. 5, is to produce pulses at the crossover points of the applied voltage. These pulses turn a thyristor on only at the crossover points of the applied voltage and the thyristor latches on to itself and can only turn off also at a zero crossover. A delay timer with transistor switch, $Q2$, is arranged to shunt the detector output at the end of the set time, whereupon the measurement cycle stops and the PWM pulses take over the firing. The entire process continues until it is either stopped or reset.

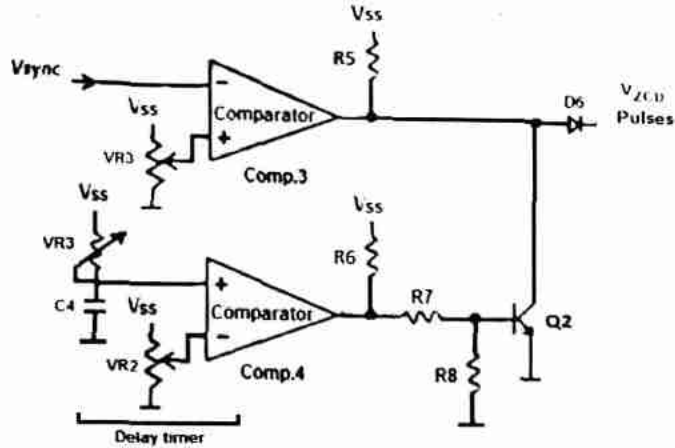


Figure 5: Zero cross detector with Shunt switch and Buffer

(v) The Output Circuit

The output circuit is designed to meet the two objectives of strengthening the trigger pulses and providing proper isolation. The firing pulses are coupled to the driver stage through an opto-isolator, which in turn is coupled to the thyristors through a pulse transformer, as shown in Fig.6. Each thyristor of the inverse parallel pair will conduct depending on which anode is positive with respect to the potential on its cathode when the trigger pulse arrives. A reverse-biased thyristor cannot conduct whatever the polarity of the trigger pulse applied to its gate terminal.

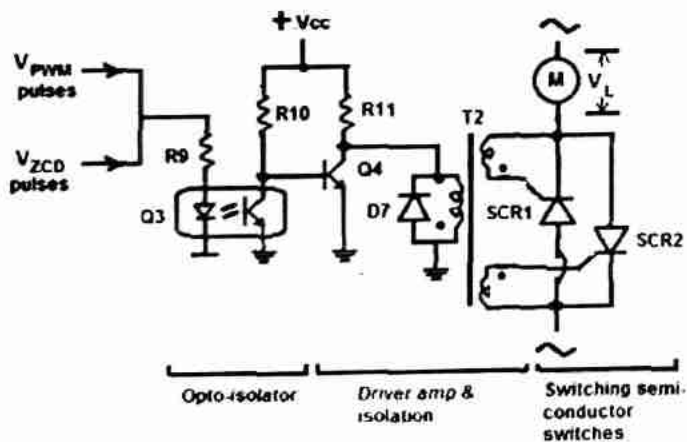


Figure 6: Driver amplifier & isolation circuit for single phase motor.

3.0 Circuit Design and Analysis

The design of the control circuit is accomplished using the highly interactive Multism computer simulation software (version 14.0.1). The main focus here is circuit design and analysis at the component level. Computer simulation reveals the true nature of the circuit before it is implemented on a circuit board. The most important aspect of this simulation is to calculate the values of the RC timing elements, and armed with a general understanding of how the circuit works, all

the other components may be determined by simulation using variable resistors and potentiometers. An RC timing circuit determines how long it takes to charge (or discharge) a capacitor and the following equations apply:

$$C = Q/V \quad (1)$$

where C is in Farads, Q is in Coulombs and V is in volts.

Also,

$$C = I \cdot \Delta t / \Delta V, \quad (2)$$

where I is the current (in terms of the charge displaced per unit time Q/t) in amps and ΔV is the permissible voltage drop in volts during the time period Δt seconds that the current flows out [9].

A resistor in series with a capacitor determines how long it takes to charge or discharge a capacitor, and for a step input, it takes approximately four time constants, or $4RC$, to fully charge or discharge a capacitor, that is,

$$t_p \geq 4RC, \quad (3)$$

where t_p is the duration of the step input and RC is the circuit time constant. The time constant is in seconds when R is in ohms and C is in farads. A series RC circuit is sensitive to frequency. At low frequencies, for which the resistance is very much less than the capacitive reactance, ($R \ll X_c$), almost all the input voltage will appear across the capacitor, and at frequencies for which the resistance is much greater than the capacitive reactance, ($R \gg X_c$), almost all the input voltage will appear across the resistor. Thus for a good voltage integration at low frequencies, the resistance must be very much less than ten times the capacitive reactance [10].

That is, $R \ll 10X_c$, where $X_c = 1/2\pi fC$, or

$$0.314RC \ll t_p \quad (4)$$

where $t_p = 0.5/f$. Conversely, for a good voltage differentiation at high frequencies,

$$0.314RC \gg t_p \quad (5)$$

3.1 The Power Supply and Synchronizing Circuit.

The synchronizing voltage (V_{sync}) is derived from a half wave single phase bridge rectifier shown Fig. 7. The rectifier produces approximately 6Volts pulsating DC every 10 millisecond of the 20 millisecond period of the 220VAC 50Hz ac waveform. The pulsating DC is further rectified by the diode D4 and filter capacitor C2 to provide 5volts working voltage, V_{ss} , for the logic circuit. The higher operational voltage, V_{cc} of 9volts for the driver stage, is produced by a full wave rectifier block.

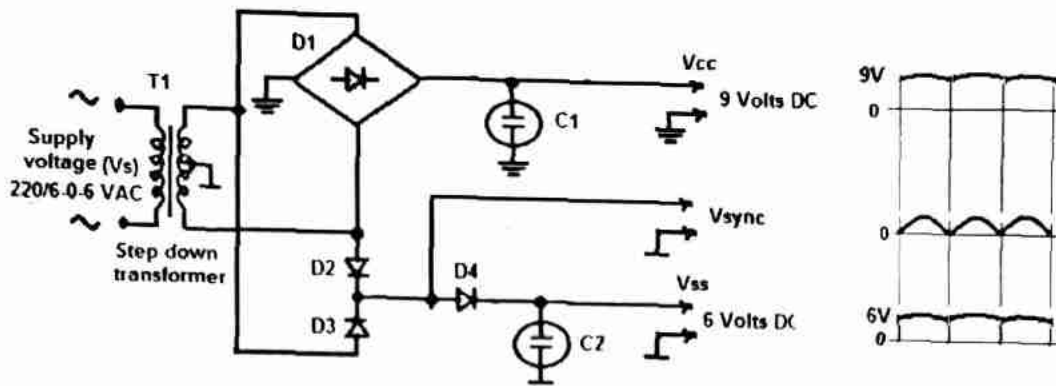


Figure 7: Power supply & synchronization with typical waveforms

The maximum current drawn by the circuit is by a 100Ω collector load in the output transistor circuit, that is $9/100 = 90\text{mA}$. Assume an overall current demand of 100mA . Then the size of the smoothing capacitor, $C1$, must supply current to regulate the voltage between sine peaks or 10 milliseconds period of a 50Hz supply. For a 10mA power supply at 6V and a maximum voltage drop of approximately 1 volt, $C1$ from (2) is:

$$C1 = \frac{0.01 \times 0.01}{1} = 0.0001\text{F} = 100\mu\text{F}.$$

Similarly, for a 90mA power supply at approximately 10 volts and a maximum voltage drop of 2 volt, $C2$ is

$$C2 = \frac{0.09 \times 0.01}{2} = 0.00045\text{F} = 450\mu\text{F}.$$

A small ceramic capacitor may be added to filter out any noise generated by the circuit.

3.2 The Trigger Circuit

The trigger circuit consists of the phase angle-delayed PWM generator in parallel with the Zero crossover detector circuit as shown in Fig.8.

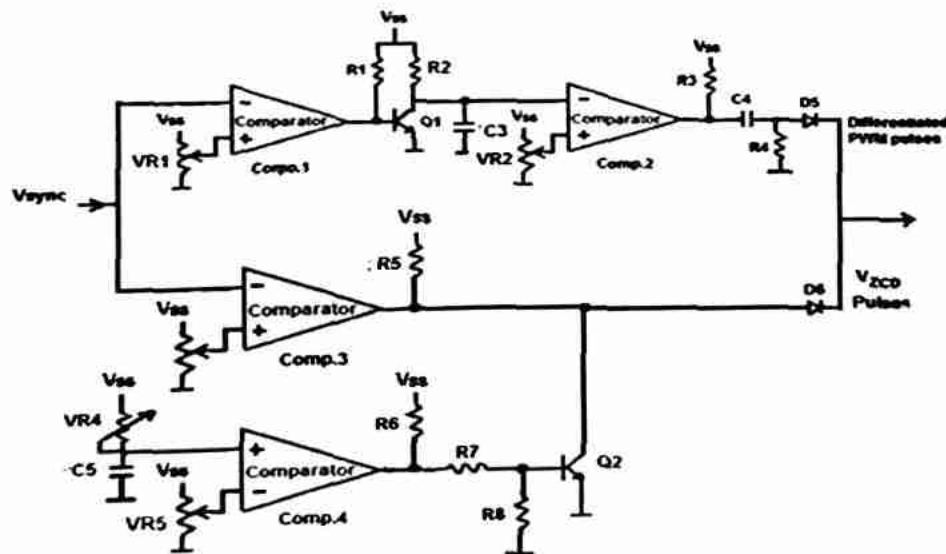


Figure 8: The trigger circuit simulation diagram

(i) The PWM Generator Circuit

Assuming a permissible current drain of 1mA , $VR1 \approx V_{ss}/1\text{mA} = 5\text{V}/1\text{mA} = 5\text{k}\Omega$. Since the transistor is used purely as a switch, we may assume any available NPN transistor and determine the value of $R1$ at which the transistor just conducts by simulation. From (4), $0.314R2C3 \ll t_p$ where $t_p = 0.5/f$. At the supply frequency of 50Hz , the period of a half cycle is 10ms , that is $t_p = 10 \times 10^{-3}$ seconds, and $0.314R2C3 \ll 10 \times 10^{-3}$, or $R2C3 \ll 32 \times 10^3 \times 10^{-6}$. Let $C3 = 1\mu\text{F}$, then, $R2 \ll 32\text{k}\Omega$. Let $R2 = 5\text{k}\Omega = R3$,

and $VR2 = VR1$. Assume, $C4 = 1\mu\text{F}$ and determine $R4$ by simulation.

(ii) The Zero Crossover Detector Circuit

The zero crossover detector is essentially an integral cycle firing and control circuit with a time delay effect after power-up provided by $VR4$ and $C5$. The values of $VR4$ and $C5$ are determined by using (3), or $t_p \geq 4RC$, for a time duration of approximately five cycles. Assume $VR3=VR5=VR2$ and $R5=R6=R1=R3$. Simulate $R7$ and $R8$ to guarantee transistor cut off.

transistor is open), and what happens when the time is up (in which case the shunt transistor is closed). Fig. 12a shows that the pulses are high when the delay timer is running, and Fig. 12b

shows that the pulses are practically zero when the time is up. When the time is up, the measurement cycle stops and the phase-angle

delayed PWM pulses alone do the firing. The entire process will, however, continue until it is either stopped or reset.

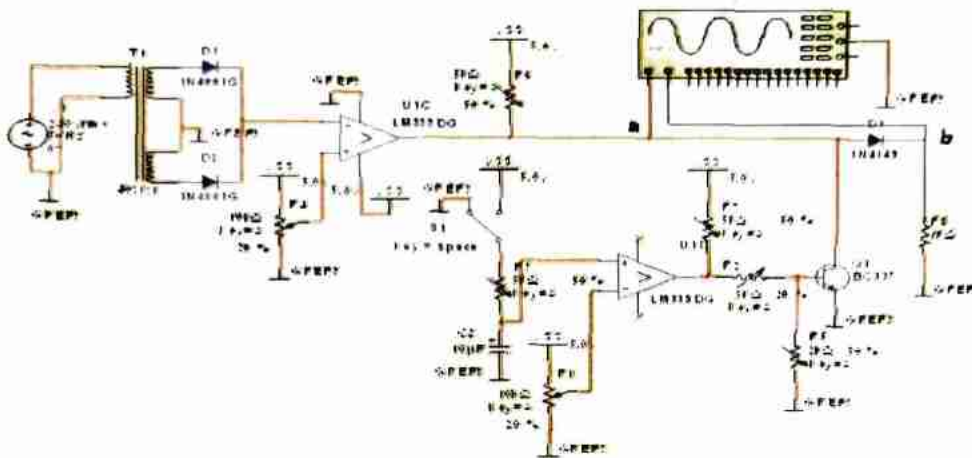
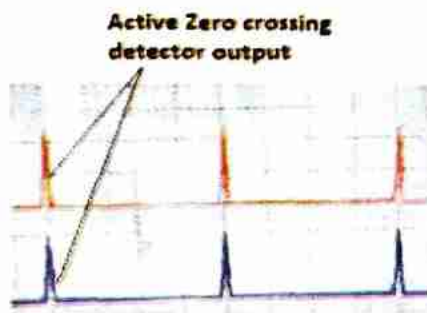
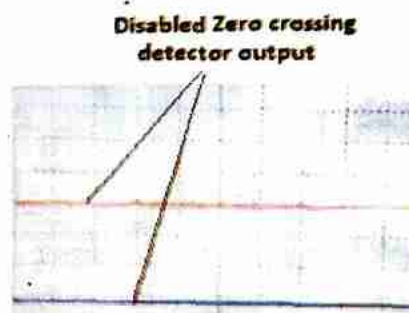


Figure 11: Simulation diagram of the Burst firing and control circuit



(12a)



(12b)

Figure 12a: Waveform of simulation ZCD with Switch S1 open; Figure 12b: Waveform of simulation of ZCD with Switch S1 closed

The output model used for simulation uses a function generator to drive the output circuit as shown in Fig.13. The resulting waveform is shown

in Figures.14. The glowing (actually blinking) lamp indicated the circuit works as designed.

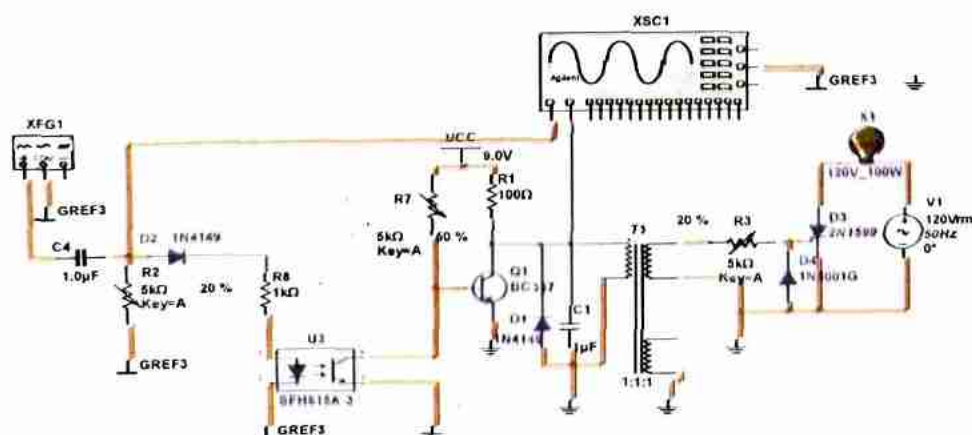


Figure 13: Output circuit Simulation diagram

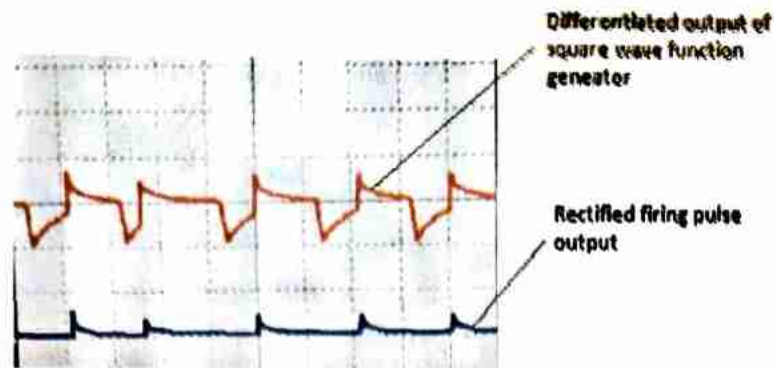


Figure 14: Waveform of Output circuit simulation diagram of Fig. 13

The real time simulation analysis of the output circuit at the test points a & b shown in Fig.15 shows the firing pulses advance or retard as the

reference voltage is changed. From the result of the simulation the full components' values become known as shown.

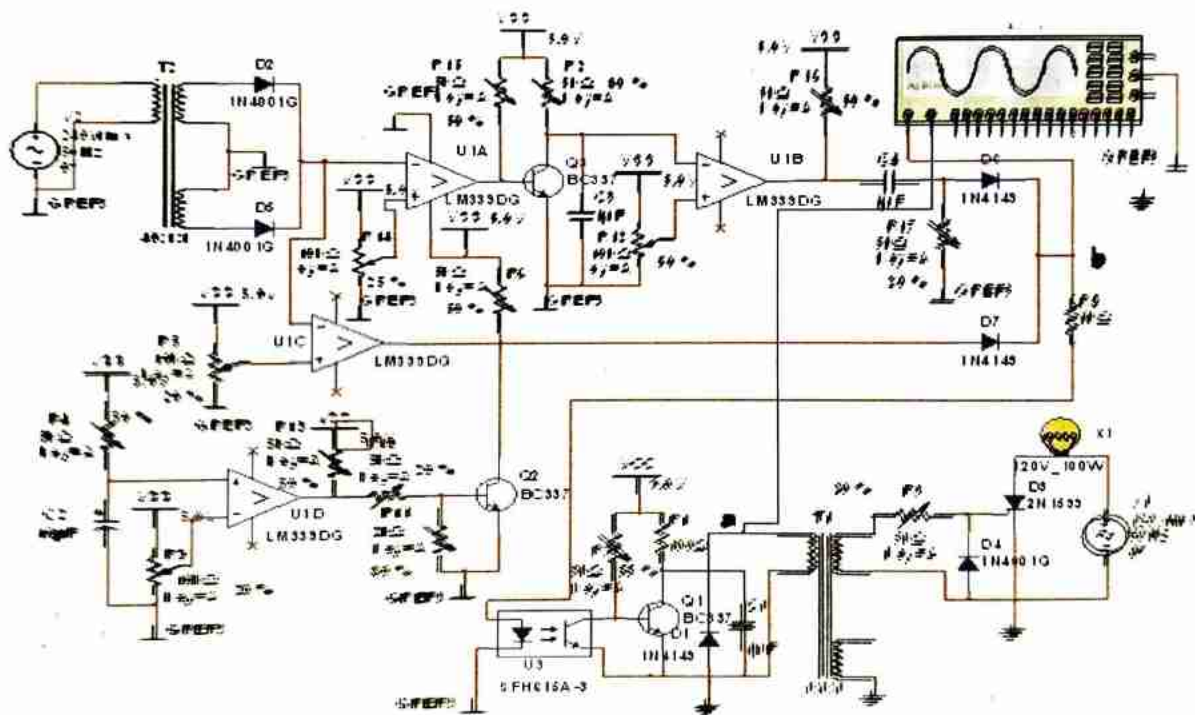


Figure 15: Complete simulated circuit diagram

5.0 Conclusion

The speed control circuit of an induction motor using the modified PWM technique was and the results show that this method is realistic. The speed control circuit was implemented and tested successfully. The Multism simulation platform was used to design and analyze the , a single Triac or two SCRs connected in inverse parallel may be used for full-wave AC control. A single SCR may also be used for full-

implemented and tested successfully. The Multism simulation platform was used to designed and analyze the circuit circuit and the results show that this method is feasible. Although the foregoing circuit was designed and simulated using a single SCR in series with a single phase supply wave AC control by connecting the SCR in series with a bridge rectifier.

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