Feed Forward Control of Induction Motor using AC Voltage Regulator

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***Abstract*-This project, deals with variable-speed capacitor-run induction motor driving a domestic fan load using an ac voltage regulator, which is controlled by feed forward control technique. The speed of the induction motor is adjusted by changing firing angles of switching devices and there by obtaining variable speeds. The system is tested for its performance and is also studied under various conditions. Introduction of microcontroller in performing the speed control of the induction motor makes it more flexible, when compared with other traditional methods.**

Keywords: Micro-controller (P89V51RD2), AC Voltage regulator, feed forward control, Squirrel cage Induction Motor

I. INTRODUCTION

Stator voltage control of induction motor drives is a cheaper and more reliable scheme of speed control and is widely used. Capacitor-run single-phase motors combined with stator voltage control are quite commonly used for domestic fans and low-power industrial applications. Generally, a triac is used for varying the stator voltage and to get variable speed. The triac-based controller is superior to a resistance-type controller due to increased energy saving and compactness [1].

The motor used for domestic fans is a capacitor start capacitor-run single-phase induction motor with squirrel cage rotor. The rotor resistance in these motors is higher and is, therefore, quite suitable for wide speed control range using stator voltage control [2]. The commonly employed method of speed control in domestic fan motors is the use of a variable resistance in series with the motor. This scheme is very cheap, and due to this reason, it is popular even nowadays. However, this is an inefficient method of speed control due to the power loss in the series resistance. An alternative scheme is the use of an electronic regulator connected between the main supply and the fan motor, which is superior in power savings[3].

In this project work, incorporating feed forward control technique in the electronic regulator is proposed. The gate pulse required for triac is generated by micro controller. The feed forward control technique is employed by using micro controller.

In feed-forward control, there is a coupling from the disturbance directly to the control variable, that is, a coupling from an input signal to the control variable. The control variable adjustment is not error-based. Instead it is based on knowledge about the process and disturbance.

In this project, the control variable is firing angle and the process is single phase induction motor. The feed forward controller includes line peak value sensing circuit and microcontroller. Based on the variation of the input voltage from nominal value the firing angle to the converter is changed.

The major advantage of micro-controller control system resides in the improvement of performance, flexibility in the implementation and adaptation of control strategies and configurations. The present work makes use of P89V51RD2 Micro-controller, in order to operate induction motor [4]. The various factors which make the microcontroller based system attractive, are

1. Improved reliability and increased flexibility
2. Simplicity of implementation in variable speed drives
3. Low cast, high accuracy
4. Possible to change torque speed characteristics of drive by software modification.

II. BLOCK DIAGRAM

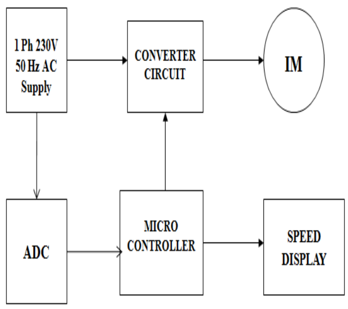

Fig.1. Block diagram

The fig.1 shows the overall block diagram of the speed control of single phase induction motor. The commonly employed method of speed control in domestic fan motors is the use of a variable resistance in series with the motor. But, this is an inefficient method of speed control due to the power loss in the series resistance. An alternative scheme is the use of a triac connected between the main supply and the fan motor.

III. CONVERTER CIRCUIT

The ac voltage regulator (triac) is used as a converter. In triac, there are several methods to control the speed of induction motor [5]. They are,

- Phase Control,
- Integral Cycle Control and
- Integral (Switched) Cycle Control.

The phase angle control method is most suitable for speed control of single phase induction motor.

PHASE CONTROL

Phase Control reduces the speed of the motor via controlling the rms value of the machine's terminal voltage by varying the time delay of the trigger signal at the triac's gate. Fig.2 shows the circuit diagram of phase angle control and fig .3 shows the terminal voltage for an ohmic load and a trigger angle of 90°.

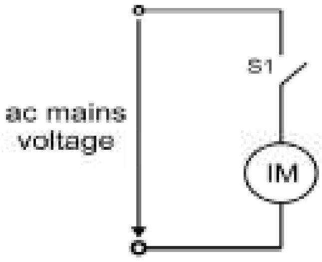

Fig.2. Circuit diagram of phase angle control

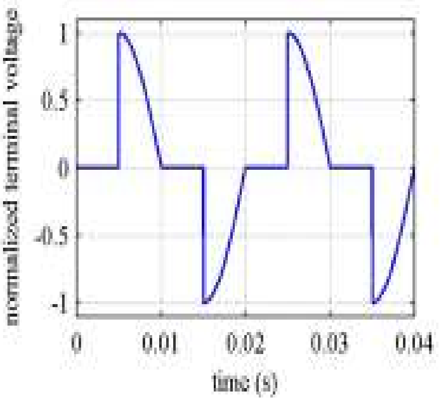

Fig.3.Normalized terminal voltage during Phase Control for a trigger angle of 90°

IV. FIRING PULSE CALCULATION

The trigger signal at the triac's gate is generated by microcontroller. The generation of gate pulse is produced by following steps.

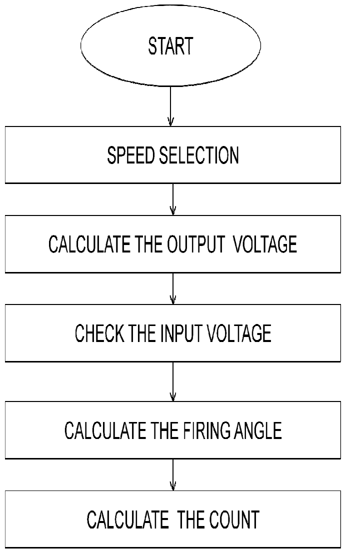

Fig.4. Flowchart of pulse generation

Let the speed of the motor be kept constant, then check the input voltage applied to the triac. For that input voltage and speed selection, calculate the output voltage of the triac. Based on the output voltage, calculate the firing angle of triac. In microcontroller, the triggering pulse is represented in count.

For triggering pulse or gate pulse of the triac is calculated by,

$$V_{orms} = V_{inrms}\sqrt{1-\left(\frac{\alpha}{\pi}\right)+\frac{\sin(2\alpha)}{2\pi}}$$

Where,

V_{orms}= Output rms voltage of the triac
V_{inrms}= Input rms voltage of the triac
α= firing pulse of the triac

From this formula, the output voltage is calculated by feed forward control technique, then the firing pulse is calculated.

After the calculation of firing pulse, converting the firing pulse into micro controller timer counts. It depends upon the following parameters.

1. Frequency
2. Crystal oscillator frequency
3. Number of clock pulse per cycle.

From the above parameters, the value of count in Hexadecimal value is calculated. In count value, first byte represents the timer high count. Last byte represents the timer low count.

For example ,
The firing pulse of 30° is converted into the timer count.
Frequency=50 Hz=20ms
Crystal frequency=11.0592 MHz

Time= 1/(11.0592/12)=1.08µs

for, 30º=1.66ms

count time = $1.66*10^{-3}/1.08*10^{-6}$ =1543

In Hexa decimal=65536-1543=$F9F8_H$

In the above value,

Timer high=$F9_H$

Timer low=$F8_H$

V. STATOR VOLTAGE CONTROL OF INDUCTION MOTOR

A very simple and economical method of controlling speed in a cage-type induction motor is to vary the stator voltage at constant supply frequency. The stator voltage at line frequency can be controlled by the firing angle control of anti-parallel connected thyristor is shown in fig.5. This type has been used extensively as a solid state "soft starter" for constant –speed induction motors. Where the stator voltage is applied gradually to limit the stator current.

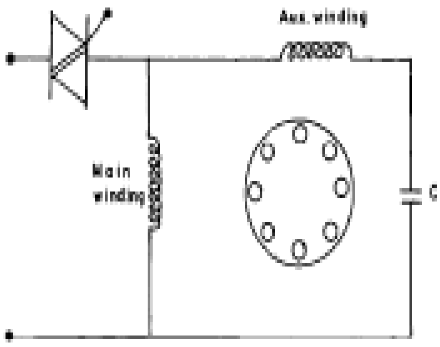

Fig.5. Stator voltage control of induction motor

VI. SIMULATION OF FIRING PULSE GENERATION CIRCUIT USING PROTEUS SOFTWARE

The figure7 shows the circuit implementation for the generation of the firing pulses using Proteus ISIS 7 professional software and the figure8 shows the simulated results of the circuit.

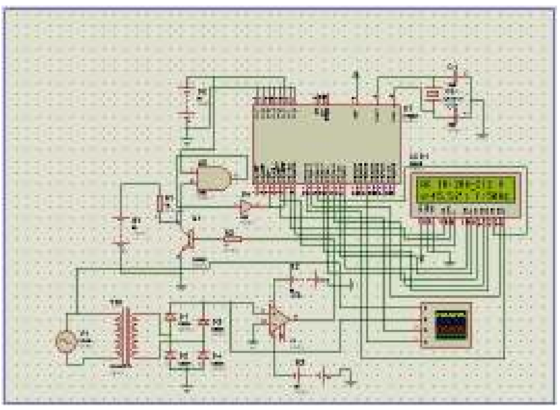

Figure7: circuit implementation using proteus software

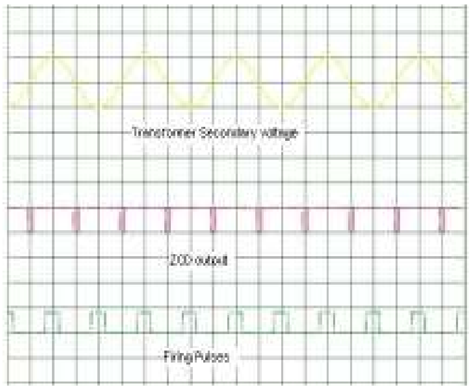

Figure8: simulation waveforms for firing pulse generation circuit

VII. VOLTAGE CALCULATION FOR DIFFERENT SPEEDS

The different voltage values are applied to the single phase induction motor and getting the corresponding speed and torque values are calculated. The selected speed ranges and their respective voltage and torque values are tabulated.

SPEED IN RPM	TORQUE	VOLTAGE
1470	1.138	140
1400	1.028	80
1200	0.7267	52
1000	0.5345	46
700	0.3642	38
300	0.0534	32
0	0	0

Table 1. Voltage calculation for different speed

The firing angles and count values are calculated for the different speed ranges with supply voltage of 230 V.

SPEED IN RPM	VOLTAGE	FIRING ANGLES	COUNT
1470	140	113	E946
1400	80	157.85	E048
1200	52	170.63	DDB6
1000	46	172.65	DD4E
700	38	175	DCD6
300	32	176.45	DC8B
0	0	180	DBD4

Table 2. Count calculation for different speed

VIII. HARDWARE IMPLEMENTATION AND OPERATION OF THE SYSTEM COMPONENTS

A. Step down transformer

Here a 230 volt to 12volt Step-down transformer is used, to avoid damage of electronic circuits .

B. Analog peak detector circuitry

The measurement of the peak value is essential to take the feedforward control. A simple peak detector using operational amplifier is shown in the figure [6].The circuit fallows the voltage peaks of input signal and stores the highest value on a capacitor. If a higher peak signal value comes along, this new value is stored. The highest peak value is stored until the capacitor is discharged.

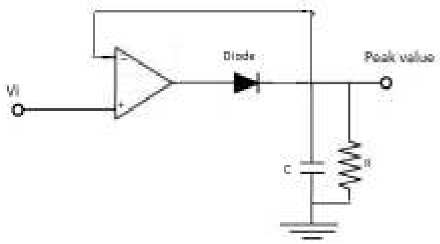

Figure2: Peak Detector

C. 4 bit flash type ADC circuitry

After detecting the peak value the deviation of this peak value from nominal value is converted into digital using four bit flash type analog to digital converter (ADC) ,rather than absolute RMS value of the supply voltage .This adjustment is carried out by op amp (IC741) based adder/subtract circuit .Four bit window detector circuit and priority encoder from the flash type ADC. The schematic of flash ADC is shown in figure 3

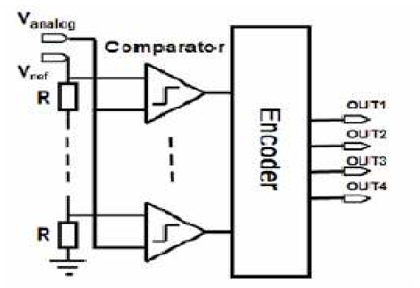

Figure3 : Schematic of flash type ADC

4 bit window detector requires 15 number (2^4 -1) of comparators. Four LM339 Quad comparator ICs are used for this purpose. To encode 16 comparator outputs, a 16 line to 4 line priority encoder (Two -IC74148) is used. Typical conversion time is 100ns or less.

D. Zero cross detection circuitry

For the measurement of frequency of line voltage and to detect the firing instant to converter, the zero crossing detection of the supply voltage is essential.

Figure4 shows the zero crossing detection circuitry (ZCD). For the implementation of ZCD a diode bridge and a comparator is used. The output of ZCD circuit is given as input to microcontroller.

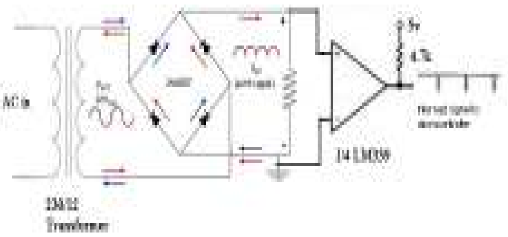

Figure4: Zero cross detection circuitry

E. The control circuitry

Microcontroller is the heart of control circuitry. The control circuitry include microcontroller , opto isolator snd gate driver circuit .The basic power circuit for P89V51RD2 microcontroller is shown in the figure 5[7] .

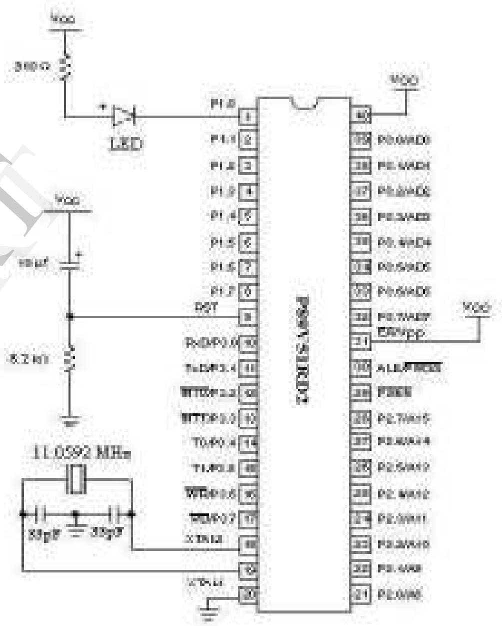

Figure 5: Basic power circuit of P89V51RD2 microcontroller

Based on the ADC value and the frequency of the supply (line) voltage, the timer is loaded with appropriate delay count value. The delay count values for different firing angles are shown in the table 1. The count values are calculated for a supply frequency of 50 Hz .

As the firing pulses from microcontroller are very short duration with 5 volts peak, these are not enough to trigger the switches and also to avoid damage to microcontroller because of high voltage of power circuit an opto isolator and a gate driver circuit are used for this purpose. Opto isolator is used to convert 5volt range pulse to 15 volt range pulse where as gate driver circuit is used to drive the witches and to avoid damage to the controller.

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IX. ALGORITHM FOR THE GENERATION OF FIRING PULSES

Figure6 shows the step by step procedure for generating the firing pulses[1]. First the frequency of the supply voltage is measured. Based on ADC value and frequency of supply voltage the delay count of timer will be selected using look up tables. At the instant of zero crossing of the supply voltage an interrupt signal is generated to the microcontroller by the ZCD circuit, at that instant the timer will be started. When the timer overflows firing pulse will be generated to the converter.

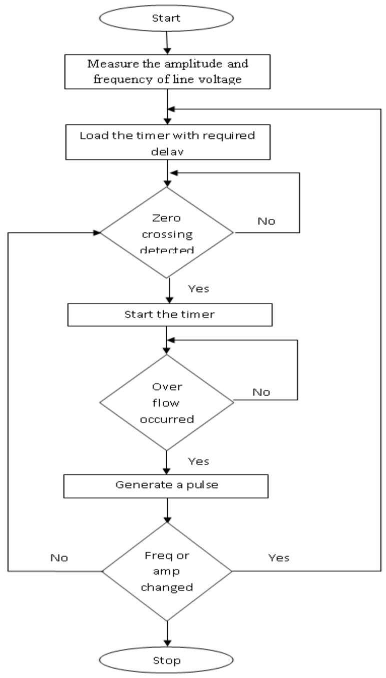

Figure6: Flow chart for the generation of firing pulses

X. RESULTS

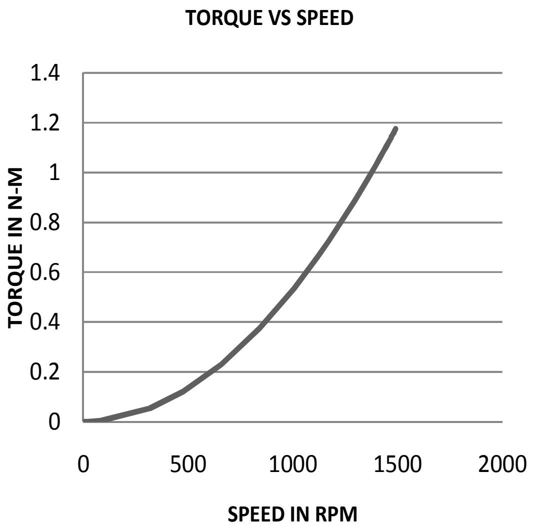

Fig.6. Torque vs Speed characteristics

The figure.6 shows the torque-speed characteristics of single phase induction motor. The above graph shows the fan–type drive (T_L= $k\omega_r^2$). From this curve, the speed corresponding to voltage levels is obtained. These are the points of intersection defining stable operating points for variable speed operation.

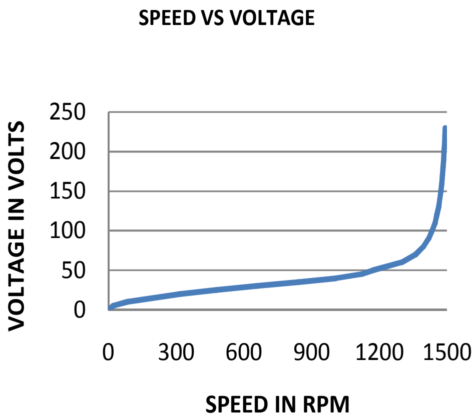

Fig.7. Speed vs voltage of induction motor.

The fig.7 shows the variable voltage applied to induction motor and gets the corresponding values of speed readings. This is a stator voltage control of single phase induction motor. In this fig.7, variation of voltage is taken from varying the firing angle of converter according to that get the output rms voltage

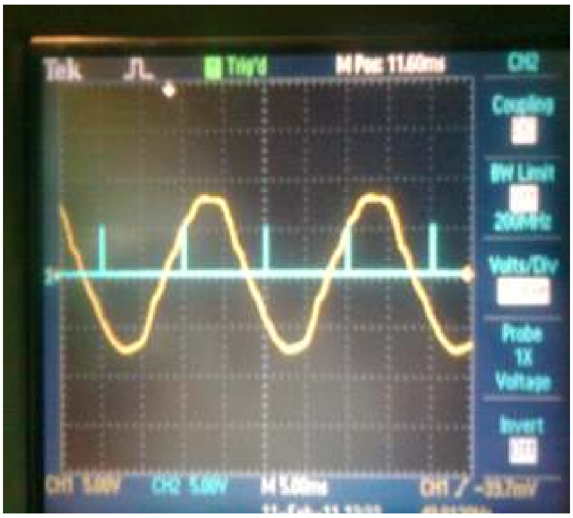

Fig.8 Firing pulse for the Triac at 43.8^0

The fig.8 shows the firing pulse for the Triac is generated by microcontroller(P89V51RD2). It shows the delay angle or firing angle of the AC voltage regulator(Triac).

XI. CONCLUSION

The speed control of single phase induction motor is achieved by varying the firing angle of ac voltage regulator (triac). The output voltage of the converter is calculated by feed forward control technique. The firing pulse is depending upon the converter output voltage. The firing angle of the converter is taken from the microcontroller.

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