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Design of Control Circuit, Power Circuit And Tap-Changing Circuit for Cycloconverter Fed Induction Motor Drive

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Abstract: A cycloconverter is a power electronic device used to convert constant voltage constant frequency AC power to adjustable voltage adjustable frequency AC power without a DC link. Among all the methods, the method controlled by cycloconverter, is simple, reliable and economical. The various speed of induction motor is obtained by varying the supply frequency using cycloconverter. A SCR controlled cycloconverter drive works on the principle of variable frequency drive, when the frequency is changed then the speed is also changed. The objective of this paper is to design control circuit, power circuit and tap-changer circuit for cycloconverter fed induction motor drive, using rectifier, Op- amps and SCR.

Keywords: cycloconverter, induction motor, control circuit, power circuit, tap-changer

1. INTRODUCTION

With the increasing motor loads for industrial applications the concept of energy saving has become vital. About 70% of the electrical loads are motor loads. Hence, the requirement of energy savings in electric drives is achieved through power electronic converters.

Variable frequency drives are mostly used for controlling either the torque or the speed of the AC motor. Applications such as pumps, centrifugal fan use the technique of variable frequency to achieve variable speed and variable torque. Variable frequency in AC drives can be achieved by inverter fed or cycloconverter fed drives. The advantage of cycloconverter over inverter fed drive is its single stage conversion.

This research project is designed to control the speed of a single phase induction motor by using cycloconvertor technique by traics. Induction motors in particular are very robust and therefore used in many domestic appliances such as washing machines, vacuum cleaners, water pumps, and used in industries as well. A.C. motors have the great advantages of being relatively inexpensive and very reliable. The induction motor is known as a constant-speed machine, the difficulty of varying its speed by a cost effective device is one of its main disadvantages. The speed of the motor can be varied in two ways, one is by changing the number of poles and the second method is by changing the frequency. The speed control through the first method is uneconomical and the number of poles can't be varied under running conditions and the size of the machine also becomes bulky. These problems can be overcome by the second method. In this method, the frequency can be varied under running conditions also and there is no change in the size of the motor. In this method, the frequency changing device is cycloconverter. A cycloconverter is a power electronic device used to convert constant voltage constant frequency AC power to adjustable voltage adjustable frequency AC power without a DC link. In among all the methods this method is simple, reliable and economical. A pair of slide switches is provided to select the desired speed range (f, f/2, f/3, f/4 and f/5) of operation of the induction motor. These switches are interfaced to the microcontroller. The microcontroller used for this project is from PIC18 family (PIC18F4550). The status of the switches enables the microcontroller to deliver the pulses to trigger the traic in a dual bridge. Thus, the speed of the induction motor can be achieved in five steps i.e. (f, f/2, f/3, f/4 and f/5).

2. CYCLOCONVERTER

Cycloconverters are the direct type converters used in high power applications for driving induction and synchronous motors. Cycloconverters are usually phase-controlled device. Cycloconverter is a device which converts the AC power at one frequency input to a AC power at different frequency output.

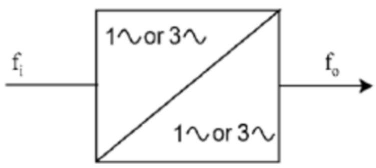

Figure. 1 Cycloconverter

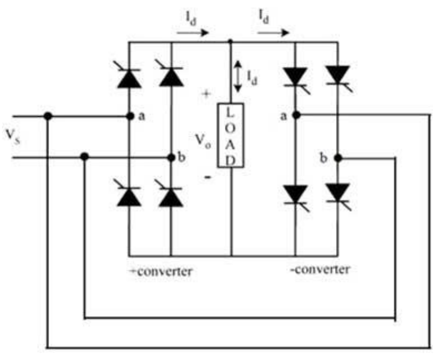

Figure. 2 Single-Phase to Single-Phase Cycloconverter

A cycloconverter is a type of power controller in which an alternating voltage at supply frequency is converted directly to an alternating voltage at load frequency without any intermediate DC stage. The cycloconverter also allows power to flow freely in either direction [3].

There are three types of cycloconverter: 1.Single Phase to Single phase cycloconverter. 2.Three Phase to Three Phase cycloconverter. 3.Single Phase to Three Phase cycloconverter

3. CYCLOCONVERTER FED INDUCTION MOTOR DRIVE

Cycloconverter is a power electronic circuit that converts fixed voltage fixed frequency input AC voltage to variable voltage variable frequency output AC. The output frequency may be greater than input frequency (step up cycloconverter) or the output frequency may be less than the input frequency (step down cycloconverter).

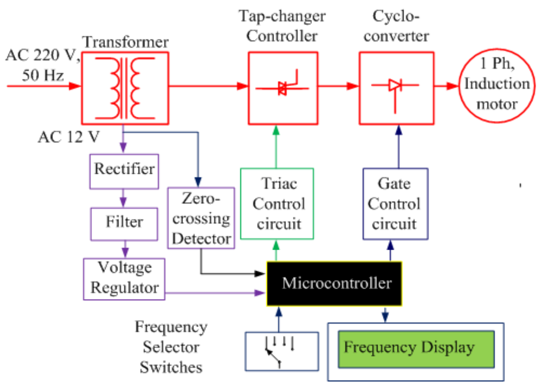

Figure. 3 Block Diagram of Proposed Cycloconverter Controlled Induction Motor Drive

The block diagram for the traic controlled cycloconverter drive for controlling the speed of induction motor is shown in Fig. 3.

This traic controlled cycloconverter drive has following components: transformer, rectifier, filter, voltage regulator, zero-crossing detector, tap changer controller, triac control circuit, cycloconverter, microcontroller, frequency display and single phase induction motor.

Transformer: In this traic controlled cycloconverter drive, the transformer is used for step down the AC voltages and works on the principle of mutual induction. In this case, this would be step down the 220 VAC into 15 VAC.

Bridge Rectifier: This cycloconverter drive consists of electronics components which are operated on DC voltages therefore the AC voltages are converted into DC through bridge rectifier, which consists of four diodes and connected at the output of transformer.

Voltage Regulator: In this traic controlled cycloconverter drive, the voltage regulator is used for regulator the DC voltages which comes from the bridge rectifier. It regulates the 15 VDC into 5 VDC and for this purposes, the LM7805 voltage regulator are used.

Microcontroller PIC 18F4550: In this traic controlled cycloconverter drive the PIC 18F4550 microcontroller are used for the intelligent control of this drive. This microcontroller controls the firing angle of the traic voltages for controlling the speed of motor in five steps. It is powered up with 5 VDC and interfaced with the optocouplers. It is 40 pins microcontroller and programmed in C language with the help of mikro/C software.

Zero-Crossing Detector: The microcontroller has been programmed i.e. C program to give output to optical isolation with zero cross detection circuit. It compares two signals in order to get zero crossing whenever the zero crossing occurs it gives an output.

Mode Selection: In this drive the selection mode is basically the switch, which is used for the selection of frequency and this drive is designed for five frequency steps.

Motor: In this traic, controlled cycloconverter drive, the single-phase AC induction motor is controlled through this drive which is basically the inductive load.

The working principles of the traic controlled cycloconverter drive for controlling the speed of induction motor are as follows.

This traic controlled cycloconverter drive works on the principle of variable frequency drive, when the frequency is changed then the speed is also changed. In this paper, first the single-phase induction motor is driven at fundamental frequency which is 50 Hz, then at f/2 Hz and then f/3 Hz, f/4 Hz and f/5 Hz respectively. At fundamental frequency, the motor runs at its full speed which could be checked by the tachometer, then it would be drive at f/2 then the motor runs at half speed and then motor is drive at f/3, at this frequency the motor speed could be quarter. This drive consists of switch which is for frequency selection mode.

The microcontroller basically increase or decrease delay time of the trigging signal, which is inversely proportional to the speed of the single-phase motor. The delay time is set in microcontroller through programming.

4. DESIGN OF CONTROL CIRCUIT, POWER CIRCUIT AND TAP-CHANGING CIRCUIT FOR CYCLOCONVERTER

Overall circuit design of cycloconverter is divided into three sections as follows;

1. Control circuit
2. Power circuit and
3. Tap-changing circuit

4.1 Control Circuit Design

Fig. 4 shows the control circuit diagram of cycloconverter, It consists of power supply circuit, zerocrossing circuit and positive and negative half signal circuit.

For designed and calculation of power supply circuit,

Maximum design current of both voltage regulator =1A

Required minimum input voltage > 12V + 3V

Limited maximum input voltage = 25V

Minimum input AC voltage = (12V + 3V)/ √2 = 10.6V

Maximum input AC voltage = 25/ √2 = 17.7V

Therefore, 220:12 V step down transformer is selected.

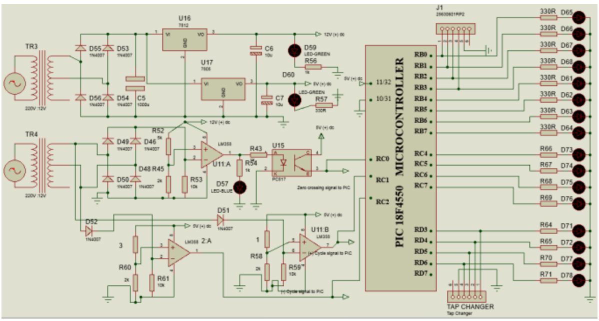

Figure. 4 Control Circuit Diagram for Cycloconverter

According to the maximum voltage 25V and maximum current 1A, 1N4007 (1A, 1000V) diodes are selected for bridge rectifier.

The maximum ripple voltage present for a full-bridge rectifier circuit is not only determined by the value of the smoothing capacitor but by the frequency and load current, and is calculated as:

n = number of pulse per cycle

n = 2

Ripple factor RF is

$$RF = \frac{\sqrt{2}}{(n^2 - 1)}$$

$$RF = \frac{\sqrt{2}}{(2^2 - 1)} = 0.816$$

Form Factor FF is

$$FF = \sqrt{n} = \sqrt{2} = 1.414$$

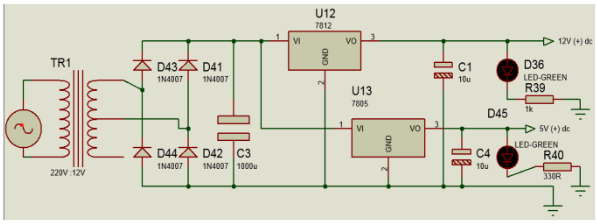

Figure. 5 Power Supply Circuit Diagram of Control Circuit

Fig. 5 shows the circuit diagram of DC supply. The output voltage of high power DC supply circuit can be calculated as the follow;

V_{dc} (max) = $\sqrt{2}$ V_{ac} (in) = $\sqrt{2}$ x 17.6 = 25 V

where, V_{ac} (in) = AC line voltage

V_{dc} (avg) = $\frac{2 \times V_{dc\,(max)}}{\pi}$ = 0.637 x 17.6 = 11.2V

$$n = \frac{f_{ripple}}{f_{source}} = \frac{f_r}{f_s}$$

$$f_r = nf_{source} = 2 \times 50 = 100hz$$

$$P_{DC} = \frac{P_L}{\eta} = \frac{12}{0.95} = 12.63W$$

$$R_L = \frac{V_{DC}^{\ 2}}{P_{DC}} = \frac{25^2}{12.63} = 49.99 \approx 50\Omega$$

$$C = \frac{1}{RF \times R_L \times f_r} = \frac{1}{0.816 \times 50 \times 100} = 245\mu F$$

So,

$C = 1000\mu F$ is selected and greater than $C = 245\mu F$

To eliminate the noise at the output of LM7805 and LM7812, 0.1 - 100 μF capacitor can be installed across the output terminals.

The operating voltage of LED = 2 - 3.5V

The standard voltage of LED = 3V

The operating current of LED= 10 mA

The resistance of LED= 3V/ 10 mA = 300 ohm

So, required series resistor for 12V supply

R = 9 × 300/3 = 900 ohm ≈ 1000 ohm

So, required series resistor for 5V supply,

R= 330 ohm

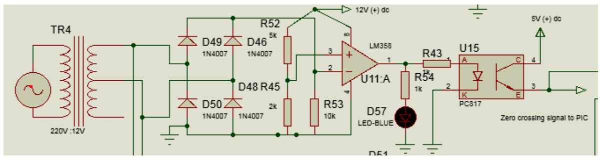

Figure. 6 Zero Crossing Circuit of Control Circuit

For design and calculation of zero crossing circuit,

The non-inverting input voltage = (12/7k) 2k = 3.43V

10k ohm resister is selected for grounding of inverting input.

For design and calculation of positive and negative half signal circuit,

The non-inverting input voltage= (12/7k) 2k= 3.43V

10k ohm resister is selected for grounding of inverting input.

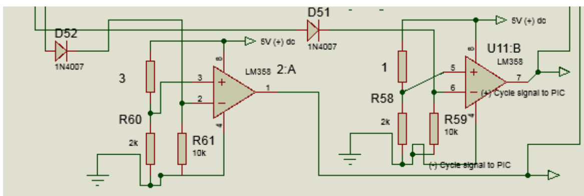

Figure. 7 Positive and Negative Half Signal Circuit of Control Circuit

4.2 Design Calculation of Power Circuit and Tap-Changer Circuit

For 1 HP load,

The maximum voltage across SCR = 220 x √2= 311V

The rated current of SCR for 1HP = 1HP / (√2V cos Φ)

= (746)/ (220 × √2 × 0.8) = 3A

At the starting the motor starting current increases 5 times of rated current.

So, the maximum current of SCR = 5 × 3= 15A

TYN 616 SCR is selected for both power circuit and tap-changer circuit because its voltage is 600V and current is 16A. Both are more than the required rating.

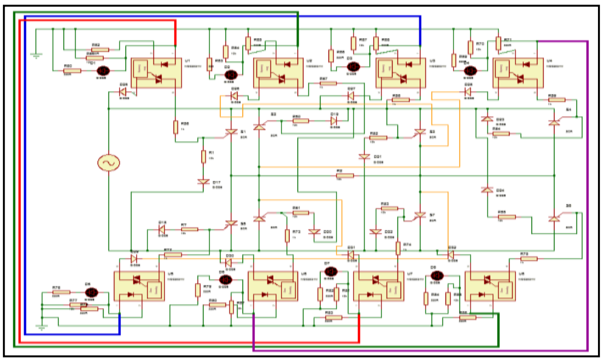

Figure. 8 Power Circuit Diagram of Cycloconverter

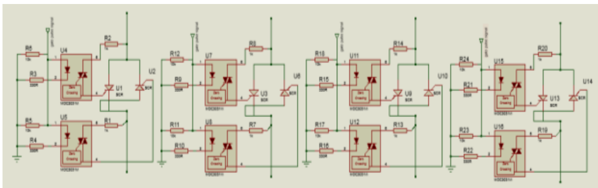

Figure. 9 Tap-changer Circuit Diagram of Cycloconverter

According to the data sheet of TYN 616 SCR, minimum gate current is 2 mA and maximum gate current is 25mA.

1N4007 (1A, 1000V) is selected for all diodes in the power circuit.

According to the guide of zero crossing optocoupler (MOC 3041) datasheet, 1kΩ, 1W resisters is selected for all gate signal of SCR.

1kΩ, 1W resisters is selected for all gate signal of SCR.

5. CONCLUSION

Many of the domestic and industrial applications require variable frequency. The cycloconverter plays a pivotal role in achieving this task. In this paper, the control circuits, power circuit and tap-changing circuit for cycloconverter have been designed using rectifier, Op- amps and SCR. By applying this design calculation results, a speed control of single phase induction motor by using single phase cycloconverter, can be implemented.

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