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Designing And Analysis Of Cycloconverter To Run Variable Frequency Drive Motor

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ABSTRACT: Variable frequency generation becomes necessary now a days for ever growing demand of industrial applications. Cycloconverter is such a device which generates variable frequency. The development of the semiconductor devices has made it possible to control the frequency of the cycloconverter according to the requirement and provide a huge amount of controlled power with the help of semiconductor switching devices like THYRISTOR, IGBT. Nowadays, in an up growing industrial sector different types of mechanical devices are use where the motors are playing a great role. However this types of synchronous and induction motors have more loss due to harmonic distortion of the variable frequency drives. The aim of this thesis is to design & analysis of a cycloconverter circuit with suitable power and minimized total harmonic distortion (THD).

Keywords: Cycloconverter with switching devices IGBT, Thyristor, Total Harmonic Distortion, Variable frequency, Firing angle, Single Phase Split phase induction motor, Current, Rotor speed, Electromagnetic torque.

1 INTRODUCTION

A Converter is an electrical device which converts alternating current into direct current (or vice versa) as well as it has the ability to convert a signal from one frequency to another frequency. It also converts analog signal to digital signal. Also converters can control the flow of electrical energy by the supply voltage and current depending on the specific requirements [1]. Here, the main focusing is on cycloconvverter. Cycloconverters are the naturally commutated frequency converters that are synchronized by supply line. They are commonly used in high power applications up to tens of megawatts for frequency reduction [4]. Cycloconverters are usually phase controlled and for the case of phase commutation thyristors can be used. A thyristor closing on natural commutation, turns off on zero current, is almost the only device that can meet the switch voltage and current rating needed at these power levels [2]. Some most commonly used cycloconverters are 3, 6, 12, and 24- pulse cycloconverter.

2 METHOLODOGY

Cycloconverter is an ac to ac converter. It converts supply frequency to a lower frequency in output. This Ac to AC conversion is done using semiconductor switches without any dc intermediate [5]. At first the simulation started with IGBT switching device and Thyristor. After analyzing with these switching devices the final result obtained that Thyristor provide the better performance than the IGBT. The output frequency is 2,3 times lower than the input frequency performed with general circuits and analyzed the THD between them. After the analysis of general part of cycloconverter principle , single phase split phase induction motor connected as a load of cycloconverter. The speed of rotor is obtained with respect to electromagnetic torque. The lower frequency gives the lower speed and vice versa.

3 ANALYSIS

This converter is a combination of different types of switching devices like IGBT, Thyristor. The designed circuit shows corresponding properties on the basis of varied gate pulses. A simulink design has being proposed to run a split phase induction motor at different output frequency after analyzing their characteristics and simulation results.

- IGBT shows inverted output depending on the input sine wave voltage.It starts from negative bank as the pulse is triggered and ends after completing the positive bank and so on. The number of half waves both for negative and positive depending on the reducing output frequency.
- Thyristor starts with positive half depending on the input sine wave voltage. Then it ends after completing the negative half and so on. The number of half cycles is depending on reducing output frequency shown in Figure 2.

The total harmonic distortion is analyzed for output frequency at 2 times and 3 times lower than input frequency. The overall total harmonic distortion is higher in cycloconverter incorporated with IGBT than thyristors as shown in (Table1). It is necessary to obtain the improved performance it will be customary to use thyristors as switching device. Then the delay angle is created by a pulse generator. Initially the pulse angle is zero and after that the firing angle is created at 30 degree and 60 degree. However, their delay angle causes equal and opposite delay for the respective *p-converter* and *n-converter.* The output wave form of 30 degree firing angle is shown in (Figure 4). The main purpose of using firing angle is to operate the switching devices with some delay angle for which the output voltage is cut off after that delay. The operating switch is conducted after the delay of firing angle conducted after the delay of firing angle. The modeling of thyristor based cycloconverter is used to run a split phase induction motor. The thyristor combination shows better performance and proved worthwhile for controlling supply frequency in O/P. Frequency can be varied depending upon the required frequency for load. In Figure 5, the model design of thyristor based cycloconverter to run a single phase motor (split phase induction motor). The simulated outputs show the Total current, main winding current, auxiliary winding current, rotor speed and electromagnetic torque performance with respect to split phase motor at 50Hz, 25Hz, 16.67Hz and

12.5Hz.

4 Equations

$$V_d = \frac{2\sqrt{2}}{\pi} V \cos\alpha \qquad (1)$$

Where V is the input (rms) voltage. Then the peak of the fundamental output voltage is

$$Vo_1 = \frac{4}{\pi}\frac{2\sqrt{2}}{\pi} V \cos\alpha \qquad (2)$$

The above equation implies that the fundamental output voltage depends on α. For α=0°, $Vo_1 = V_{do} \times 1 = V_{do}$ where,

$$V_{do} = \frac{4}{\pi}\frac{2\sqrt{2}}{\pi} V \qquad (3)$$

If α is increased to π/3 then $Vo_1 = V_{do} \times 0.5$. Thus varying the fundamental output voltage can be controlled.

$$Vo_1(t) = \sqrt{2}\, V_o \sin \omega_o t \qquad (4)$$

Cycloconverter in blocking mode will be found at frequencies

n= 1 $3f_i$, $3f_i \pm 2f_o$, $3f_i \pm 4f_o$, $3f_i \pm 6f_o$, $3f_i \pm 8f_o$, $3f_i \pm 10f_o$ …

n= 2 $6f_i$, $6f_i \pm 1f_o$, $6f_i \pm 3f_o$, $6f_i \pm 5f_o$, $6f_i \pm 7f_o$, $6f_i \pm 9f_o$ …

n= 3 $9f_i$, $9f_i \pm 2f_o$, $9f_i \pm 4f_o$, $9f_i \pm 6f_o$, $9f_i \pm 8f_o$, $9f_i \pm 10f_o$…

n= 4, 5, …

5 Single Phase Cycloconverter With Thyristor

A thyristor is a solid state semiconductor device with four layers of alternating and P-type material. SCR, TRIAC are the switching devices of thyristor family[3]. All of them are solid state switches which act as open circuit until the rated voltage triggered. Thyristor has fast turn and off time and it can be bi-directional and also unidirectional in case of operation.

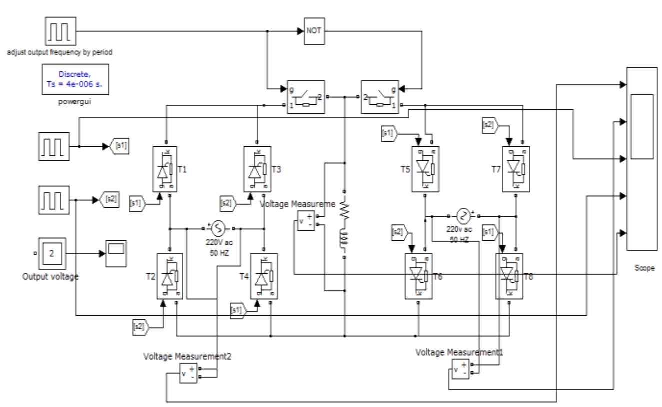

Figure-1 Single phase cycloconverter Thyristor combination

This converter is consisted of two full wave rectifier circuits and a R-L load is used in its output end. Figure 1 T1 and T4 work together for positive, T3 and T2 also work together for positive half cycle. In case of negative half cycle, T5 and T8 work together and T7 and T6 also work together. Pulse is use to control the switches; either the switch will be ON for positive bank or for negative bank. A NOT gate is connected to provide logic 1 and logic 0 to operate positive & negative converter. Frequency can be controlled by changing the period of the pulse as shown in Figure 2.Once the positive cycle starts conducting, the negative part stays inactive and vice versa. Input voltage 220V peak is an ac and the supply frequency 50 Hz. Here, all the Thyristor have zero firing angle.

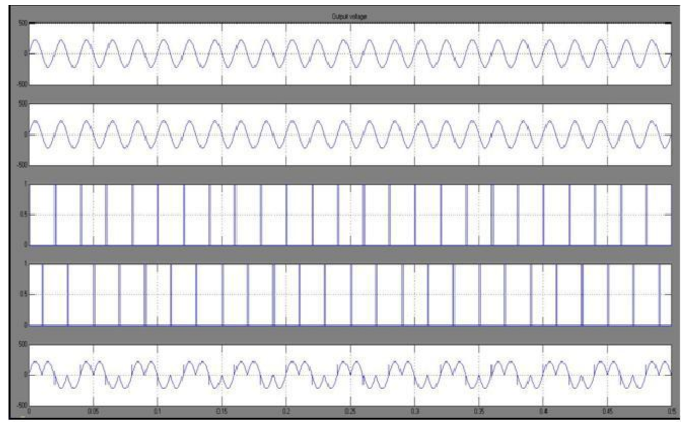

Figure-2 Voltage Waveform shows the input frequency is 2 times the output frequency for thyrsitor

One full cycle is converted to two positive half cycle. And in case of 2nd cycle, it shows negative rectification and converts to two negative half cycles and so on as shown in Figure 2.

Table 1. Total Harmonic Distortion

No:	Switching device	Output cycle	THD
1	IGBT	2 times lower than input	65.85%
2	IGBT	3 times lower than input	71.98%
3	Thyristor	2 times lower than input	62.58%
4	Thyristor	3 times lower than input	68.33%

5.1 Cycloconverter With Different Firing Angle

In cycloconverter two single phase controlled converters operates as a bridge rectifier. However, their delay angle causes equal and opposite delay for the respective *p-converter* and *n-converter*. If converter positive is operating alone, the average output voltage is positive and if converter negative is operating, the output voltage is negative. Figure 3 shows the cycloconverter with varied firing angle causing delays.

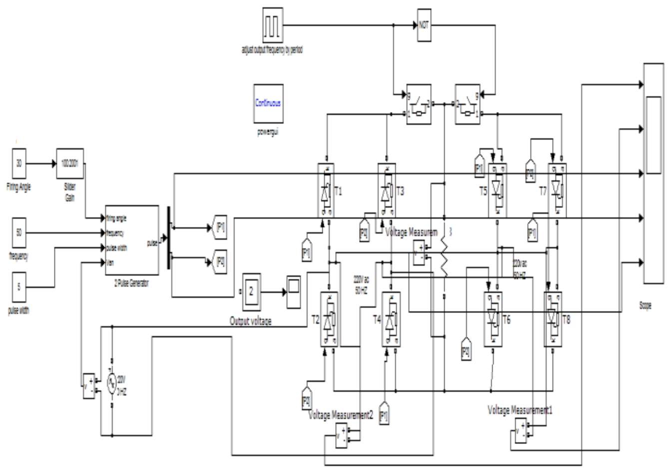

Figure-3 Cycloconverter with firing angle system

This is the circuit combination to produce different delay angle which is helped the switching device to run at some delay.

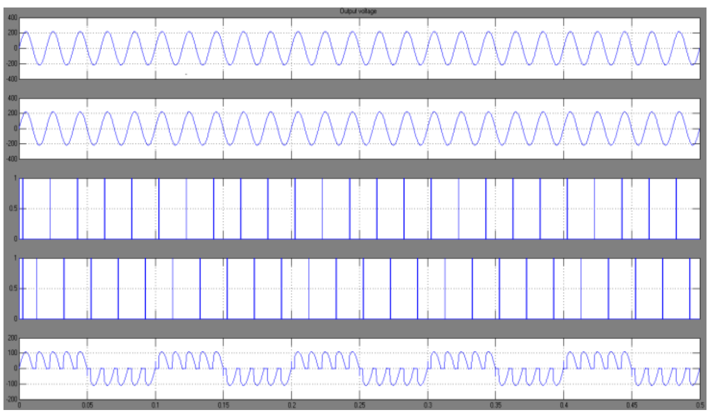

Figure-4 Cycloconverter output for 30º firing angle

For 30º firing angle, the operation of switches starts after the delay angle. As a result the output voltage goes to cutoff during delayed angle. The output voltage of cycloconverter is bascially made up of segments of input voltages and the average value of a segment depends on the delay angles of that segment. IF the delay angles of segments were varied in such a way that the average values of segments correspond as closely possible to the variations of desired sinusoidal output voltage, the harmonics one the output voltage can be minimized by the help of this delay angle(firing angle).

6 Cycloconverter With Split Phase Induction Motor

Split phase induction motor consists of running winding, starting winding and centrifugal switch. The reactance difference in the windings creates separate phases, which produce the rotating magnetic field that starts the rotor. The single phase motor is running when the speed and torque have been raised. This motor consists of squirrel cage rotor and single winding stator. The stator of a split phase motor has two windings (main and auxiliary) are displaced in space by 90 degrees. The auxiliary winding is made of thin wire so that it has a high R/X ratio as compared to the main winding which has thick enamel copper wire. These windings are phase shifted to produce a rotating magnetic field for starting to allow the motor to have better starting torque. Initially rotor is at rest and the supply is given through the stator winding. It rises the mmf along the winding which is stationary in space and varying the magnitude. It also varies from positive maximum to zero to negative maximum. Then the mmf of stator induces currents in the short-circuited rotor of the motor which gives rise to mmf. The induced current of the rotor is such that developing mmf opposes the stator mmf. Since the angle between two mmf is zero, rotor remains stationary. The thyristor based cycloconverter output is connected to Split phase induction motor. The supply voltage is 220 V ac at 50 HZ frequency. Single phase cycloconverter is used as motor‟s input as shown in Figure 5.

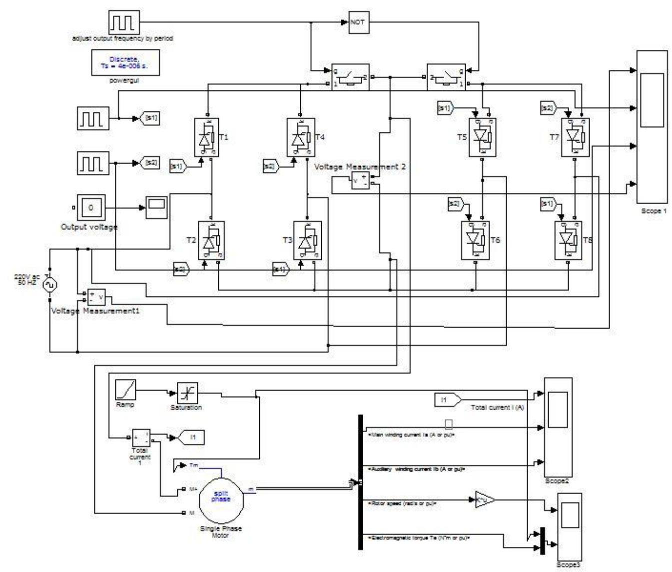

Figure-5 Cycloconveter with Split phase Induction motor

Here, output frequency is one third of input frequency. The output frequency is being controlled by changing the period of “adjust output frequency by period” signal. Outputs of Total current I (A), Main winding current Ia (A or pu) and auxiliary winding current Ib (A or pu) are taken across the machine output at Scope 2. Outputs of Rotor speed (rad/s or pu) and Electromagnetic torque Te (N*m or pu) are taken across machine output at scope 3. Motor has three inputs Tm, M+ and M-. M+ and M- are connected with positive end and negative in of cycloconverter. Tm is shaft mechanical torque input to control the centrifugal switch shown in (Figure 5). The main winding is designed for operation from 75% synchronous speed. The main winding design is such that the current lags behind the line voltage because of the copper coils in the steel stator build up a strong magnetic field which provides the buildup current in the winding. The auxiliary winding is not wound identically to the main, but contains fewer turns of much smaller diameter than main winding.

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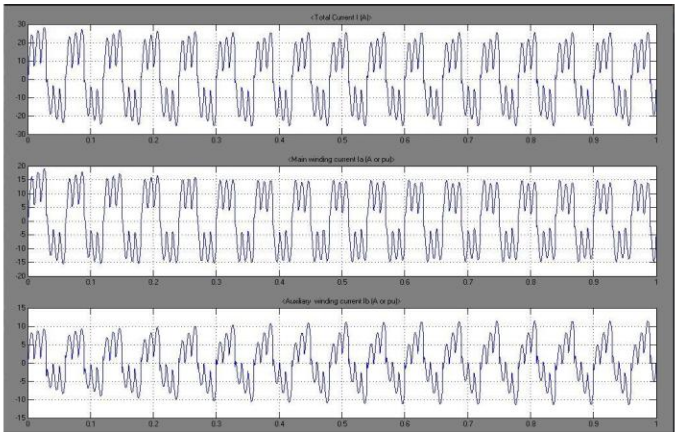

Figure-6 Wave shapes of output currents across the motor (output frequency is one third of input frequency)

First one is total current I, second one is main winding current Ia and third one is auxiliary winding current Ib through the motor as shown in Figure 6. In first wave shape, total current of the motor is being shown. The total current is the vector sum of the main winding and auxiliary winding current. Outputs continues 3 half cycle wave for positive conversion and also 3 negative half cycle for 180 degree negative conversion since the output frequency is one third of input due to cycloconverter as discussed briefly in chapter 3. In case of 1st half cycle, peak current is 22 A. In case of second half bridge, peak is approximately 25 A and 3rd one is maximum with 29 A. In case of negative portion, peak current 1st half cycle is -20 A, peak current is -21 A for 2nd half cycle and 3rd half cycle is -22 A. And the whole process is continued till the motor stops. The current are fluctuating due to the main winding and auxiliary winding current. 2nd and 3rd wave shapes shows the main winding current and auxiliary winding current of the motor. The auxiliary winding or start winding is the first to become magnetized when the voltage is supplied. The current in the main winding begins later. Since the reactance of auxiliary winding is higher than main winding, so current of main winding current as a result, main winding current is higher than auxiliary. The main winding peaks are respectively 15 A, 16 A and 19 A approximately for three positive half cycle and -15 A, -15.1 A and -15.2 A approximately for three negative half cycle. In case of auxiliary winding, peaks are respectively 7 A, 8 A and 9 A approximately for three positive half cycle and -7 A, -8 A and -9 A approximately for three negative half cycles.

6.1 Waveshapes Of Rotor Speed & Electromagnetic Torque at Different Frequency

The speed of motor with different speed and electromagnetic torque are showed below with proper waveshapes

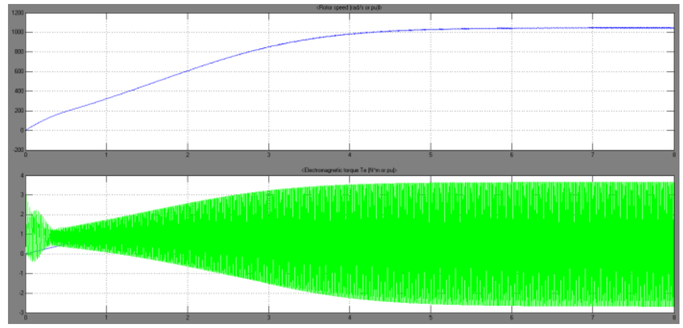

Figure-7 Wave shapes of rotor speed and torque at 50Hz

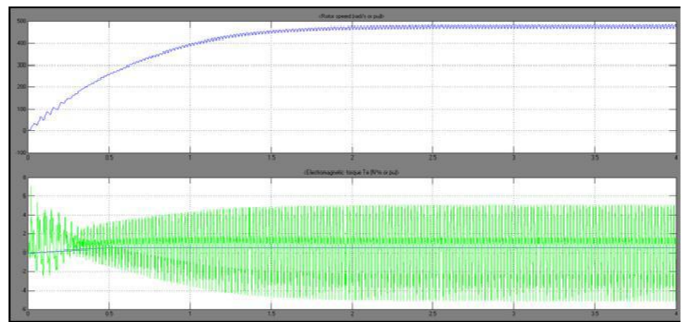

Figure-8 Wave shapes of rotor speed and torque at 25Hz

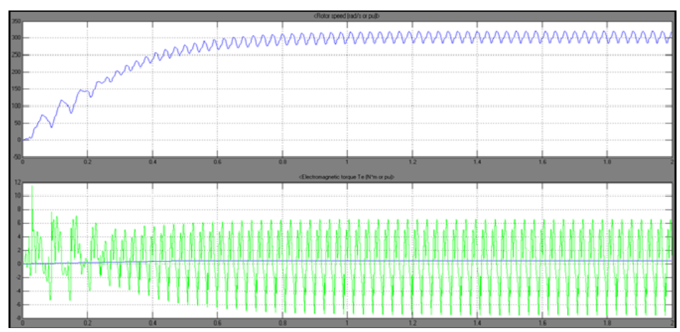

Figure-9 Wave shapes of rotor speed and torque at 16.67Hz

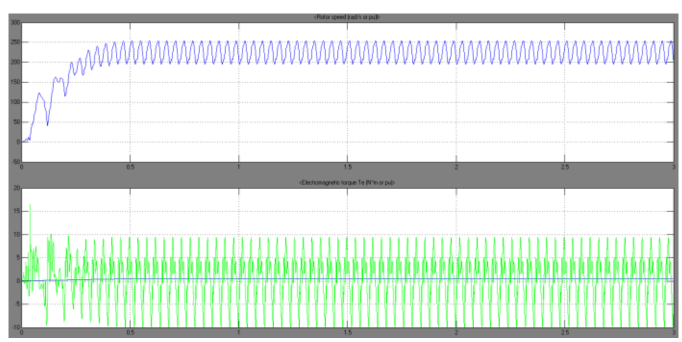

Figure-10 Wave shapes of rotor speed and torque at 12.5Hz

From the above figures, it can be concluded that splits phase induction motor works better on different frequency.

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Torque is varying with time and rotor speed, and maximum voltage can be achieved more quickly and get stable in a specific range and so on. The change in speed of motor depends on the frequency. This circuit can be used as the variable frequency motor drive at variable speed with smooth operation.

7 CONCLUSION

Single phase cycloconverter used for Single phase split phase induction motor to generate supply torque characteristics that matches with demand torque characteristics of particular machine by the use of designing cycloconverter different desired frequency are obtained to equalize the torque demand of machine. This different frequency of cycloconverter is also useful to replace flywheel from the operating machine which reduces the cause of torsion vibration and fatigue damage of machine. With better switching technology such as higher speed thyristors or new high power integrated gate bipolar transistors cycloconverter could be used with these cyclo - converter high frequency generators. This would effectively eliminate output-to-input ratio issues including the unfilterable sub harmonics and inter harmonics contained in both outputs and inputs. This cycloconverter is operating for single phase supply. It is possible to implement for three phase supply for three phase load with less distortion than the single phase with greater speed implement in real world and also workable for three phase source.

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