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SIMULATION & FABRICATION OF 1-PHASE CYCLOCONVERTER FOR SPEED CONTROL OF INDUCTION MOTOR

Ashish J. Gohel (*PG Student*)

Department of Electrical Engineering, SSEC, Bhavnagar

Abstract — ***The purpose of this paper is to vary speed of induction motor using cycloconverter. Cycloconverter is the device which can change frequency in single step. Induction motor speed can be varied using change of frequency. With the help of proper control circuit design, gate pulses to be obtained & given to cycloconverter. Frequency can be divided by 2 or divided by 3 and according to that the speed of induction motor is also divided by 2 or divided by 3.***

I. INTRODUCTION

In a cycloconverter, the alternating voltage at supply frequency is converted directly to a low frequency output voltage, without any intermediate DC stage. A cycloconverter operates as a direct ac to ac frequency changer with an inherent voltage control feature. The basic principle of this converter is to construct an alternating voltage waveform of lower frequency from successive segments of voltage waves of higher frequency ac supply by a switching arrangement was conceived and patented in the 1920s. [1][2].

The operating principle of this converter was developed in the early 1930s when the grid-controlled mercury rectifiers became popular. The technique was first applied in Germany, where the three-phase, 50 Hz AC supply was converted to the single-phase AC at 16.67 Hz, for the Railway Traction application [1].

Further, in the USA a 400 HP motor speed control scheme, in which a synchronous motor was supplied from a cycloconverter, comprising of eighteen thyristors was in operation for several years. However, the practical and commercial utilization of these schemes waited until the SCRs became available in the 1960s [2]. With development of large power SCRs and microprocessor based control, the cycloconverter today is a matured practical converter for application in large power low speed variable voltage variable frequency (VVVF) ac drives in cement and steel rolling mills as well as in variable speed constant frequency (VSCF) systems in aircraft and naval ships [4].

Since the 1960s, as developed by Siemens and Brown Boveri, one of the early installations has employed a motor rating of 6.4MW having a rotor diameter of 5m and 16.5m in length while the stator construction is similar to that of hydroelectric generator with 44 poles requiring 5.5Hz for a maximum speed of 15 rpm. A 12-pulse 9.46MVA 120/33.1Hz cycloconverter liner synchronous motor combination for the Maglev Vehicle ML 500 a high-speed train (517 km/hr) has been in the process of development in Japan since the early 1980s.

II. CYCLOCONVERTER

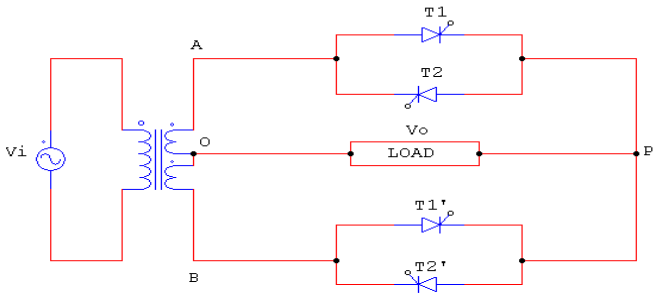


Figure 1. Single Phase Mid-tap Transformer Type Cycloconverter

The single-phase to single-phase cycloconverter with mid-tap transformer type. As shown in fig.1. in this type of arrangement midpoint tap transformer is use to obtain variable voltage and variable frequency. Waveforms shown are obtained by varying the number of cycle covered by positive and the negative converters and firing angle.

The frequency can be varied by varying the conduction period for each mosfet. The gate pulse for SCR can be provided by either by using firing circuit. Here for positive half cycle of input or supply.T1, T2' are forward biased, T1 is given pulse. For negative half cycle of input or supply T1', T2 are forward biased. T1' is given pulse. For another positive half cycle T2' is given pulse. For another negative half cycle T2 is given pulse. By using cycloconverter we can vary voltage and frequency. As AC motor characteristics require the applied voltage to be proportionally adjusted whenever the frequency is changed in order to deliver the rated torque this method is also called volts/hertz.. For optimum performance, some further voltage adjustment may be necessary especially at low speeds, but constant volts per hertz are the general rule. This ratio can be changed in order to change the torque delivered by the motor.

The input voltage, Vs is an ac voltage at a frequency, fi, as shown in Fig.2 (A). All the thyristors are fired at α=0° firing angle, i.e. thyristors act like diodes. Note that the firing angles are named as αP for the positive converter and αN for the negative converter. The frequency of Vo can be changed by varying the number of cycles the positive and the negative converters work. It can only change as integer multiples of input frequency in Single Phase to Single Phase Cycloconverter. For example, to obtain the input frequency four times the output frequency as shown in fig.2 (B) fired positive group and negative group converter alternately.

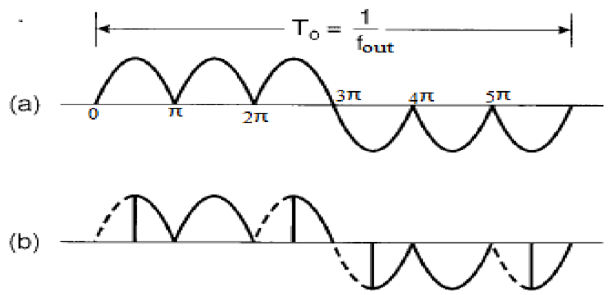


Figure 2. (a) Input Voltage Waveform of Single Phase to Single Phase Cycloconverter

Figure 2. (b) Output Voltage Waveform for Zero Firing Angle of Single Phase to Single Phase Cycloconverter (Input Frequency is Four Times Output Frequency)

III. CONTROL CIRCUIT

The function of the control circuit is to deliver correctly timed, properly shaped and firing pulse to the gates of the thyristors in the power converter so as to generate a voltage of the desired wave shape at the output terminals of a cycloconverter. The control circuit can be arranged in four functional blocks:

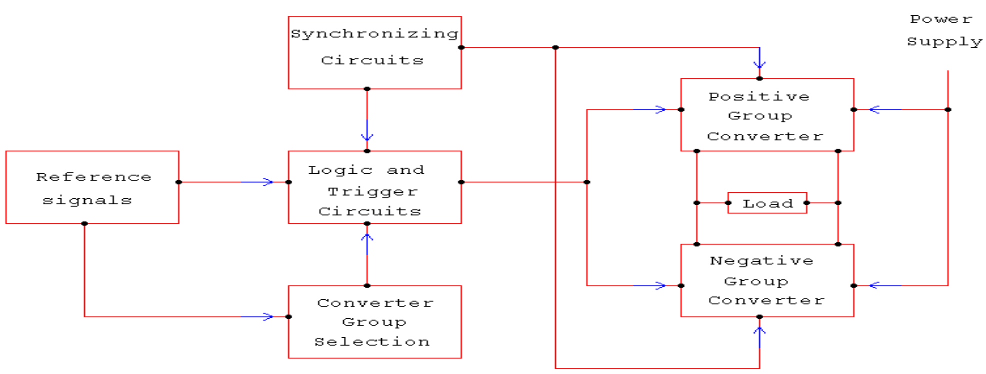


Figure 3. Block diagram of control circuit

1. Synchronizing circuit
2. Reference voltage sources.
3. Logic and triggering circuit
4. Converter group selection circuit.

1. Synchronizing Circuit:

The low voltage signals must be synchronized to the voltage supplied to the main power circuit. Step-down transformers may be used for this purpose with filter circuit to avoid waveform distortion if any. While deriving the modulating voltages at the supply frequency, the phase shifting network may also be required. To determine the instants at which the firing pulses are to be produced to the thyristors in the two converter groups, the modulating voltages are compared with the reference voltages.

2. Reference Voltage Signals:

The reference signal is designed to control the output voltage in the sense that the output voltages tend to follow the reference signal. It means that if the amplitude and frequency of the reference signal is varied, then the amplitude and frequency of the output voltage varies automatically. In the case of three-phase to three-phase cycloconverter, the reference signal does additional function of shifting by phase shift of 120 degree. In the design approach, a fixed high frequency oscillator and resistor capacitor phase shifting networks are used to generate a three-phase sine wave. In the case of three-phase, three mixers are used to combine the fixed and variable frequency. The output of the mixer stage is square wave with half wave symmetry. It generates a fundamental and a series of odd harmonics.

It is clear that varying resistor and fundamental frequency respectively controls the amplitude and frequency of the reference waves, while the phase sequence of the three-phase output is controlled by setting fundamental frequency greater or less than fixed frequency. Varying resistor from 0 to 1 controls the amplitude.

3. Logic & Control Circuit:

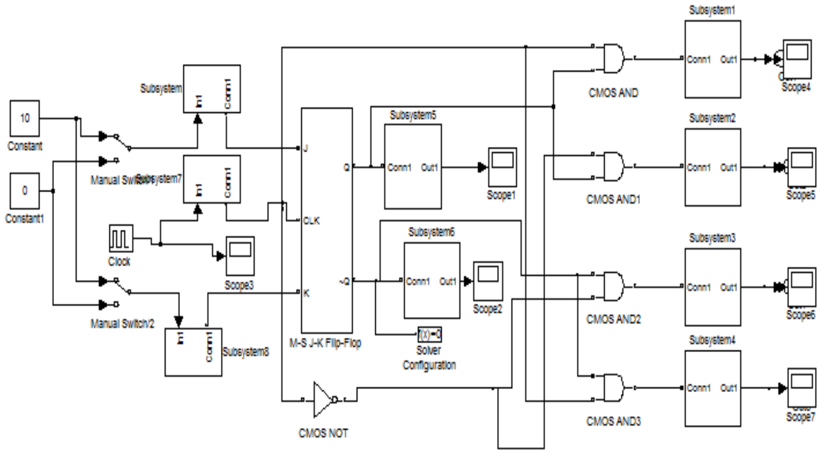
The reference voltage is compared with the modulating voltages and corresponding respectively to supply voltages. Comparators produce short pulses. This pulse gives to J-K flip-flop. The J-K flip-flop in which both J-K inputs are allowed in the HIGH state i.e. when both J=K=1,Q flips to the Q inverse and vice versa. This flip-flop constructed with 4-NAND gates. Any frequency divides in multiple 1/2n of the supply frequency. In other words, any frequency fi/2, fi/4 and fi/8 can be derived from the frequency using the standard J-K flip-flop.

If both the J and K inputs are held at logic 1 and the CLK signal continues to change, the Q and Q' outputs will simply change state with each falling edge of the CLK signal. (The master latch circuit will change state with each rising edge of CLK.) We can use this characteristic to advantage in a number of ways. A flip-flop built specifically to operate this way is typically designated as a T (for Toggle) flip-flop. The lone T input is in fact the CLK input for other types of flip-flops. The JK flip-flop must be edge triggered in this manner. Any level-triggered JK latch circuit will oscillate rapidly if all three inputs are held at logic 1. This is not very useful. For the same reason, the T flip-flop must also be edge triggered. For both types, this is the only way to ensure that the flip-flop will change state only once on any given clock pulse. Because the behavior of the JK flip-flop is completely predictable under all conditions, this is the preferred type of flip-flop for most logic circuit designs. The RS flip-flop is only used in applications where it can be guaranteed that both R and S cannot be logic 1 at the same time.

The pulse output is ANDed with the input coming from the circuit. The output of the ANDed gate is given to the driver circuit, which amplifies and isolates the pulses and drives the respective thyristors. In most applications, sinusoidal reference signals and cosinusoidal modulating signals are commonly employed. The waveforms are drawn for one half cycle of the output voltage for the positive converter with the unity power factor load. The same procedure can be followed for developing the output voltage for the other half cycle of the positive converter. For negative converter, different modulating signals have to be taken into account.

For 25Hz output frequency we have to use one J-K flip-flop or T flip-flop. First supply voltage compare with comparator and gating square pulse train of 50% duty cycle at V2. This pulse use as clock for J K flip-flop, which will give 25Hz pulse train [8]. Now for required pulse we have to do ANDed the both signal as we gate from comparator and from flip-flop. Similarly for negative group pulse we have to use NOT gate with both output pulse. Now use all the different type of combinations of pulses and ANDed them we got the output pulse for positive and negative converter as shown in output waveform.

For divide by 4-frequency output of bridge type of cycloconverter we have to use one other J-K flip-flop. The clock of this flip-flop is given from previous flip-flop. So output of this flip-flop will give divide by 4-frequency pulse train. Now for suppress one cycle we have to do ANDed the both signal as we gate from comparator and from flip-flop. Similarly for negative group pulse we have to use NOT gate with both output pulse. Now use all the different type of combinations of pulses and ANDed them we got the output pulse for positive and negative converter as shown in output waveform.



Similarly for divide by 8-frequency output of bridge type of cycloconverter we have to use one other J-K flip-flop. The clock of this flip-flop is given from previous flip-flop. So output of this flip-flop will give divide by 8-frequency pulse train. Now for suppress one cycle we have to do ANDed the both signal as we got from comparator and from flip-flop. Similarly for negative group pulse we have to use NOT gate with both output pulse. Now use all the different type of combinations of pulses and ANDed them we got the output pulse for positive and negative converter as shown in output waveform.

4. Converter Group Selection:

The load current is allowed to flow through the P converter or the N converter through suitable logic. D is the delay during which period; the firing pulses to both the converters are inhibited. The delay is not introduced in some control schemes where a small circulating current is permitted during the cross over instants of the fundamentals load current only. The scheme is still recognized as the non-circulating current operation since during a major portion of the output cycle, it operates in the non-circulating current mode.

The function of this circuit is to see that only one converter operates at a time depending upon the polarity of the current. The positive converter is operated when the load current is positive and then negative converter is operated when the load current is negative. The converter group selection is not straight forward primarily due to non-ideal nature of the output current waveform. Since the actual load voltage waveform itself is far from sinusoidal, the load current is also non sinusoidal. Depending upon load circuit parameters, converter pulse number, the load current may become zero before the fundamental half period. If the group selection and blanking circuit were to operate at each current zero instant, it may cause erratic switching of converters. The result of this is to further distort the output voltage. One possible solution to this problem is to see that the blanking circuits operate at the zero crossings of the fundamental current.

The function of each of the positive and negative firing pulse generators is to produce firing pulse for the thyristors of the associated converters. The phase of threes firing pulse is controlled in accordance with the analog input voltages, so that the mean output voltage of the associated converter is directly proportional to the respective voltage.

Each of the firing pulse generators have equal and opposite fixed bias voltages applied to their inputs. The polarities of these voltages are such as to tend to retard the converter firing angles, and thus to bias off the converters, with respect to one another, thereby preventing the flow of circulating current.

IV. SIMULATION OF CYCLOCONVERTER WITH SPLIT PHASE I.M

Here simulation of cycloconverter is done using non linear load and output waveforms are observed. The waveforms of Input voltage, output voltage, output current, rotor speed and electromagnetic torque is observed and waveforms are collected as below.

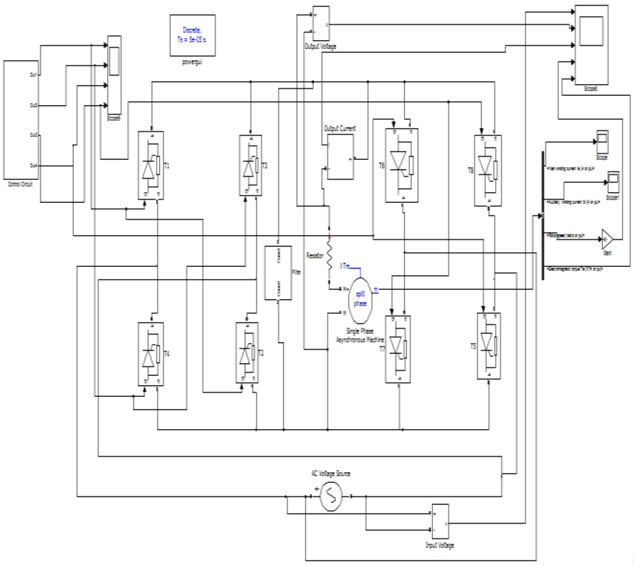


Figure 4. Simulation of cycloconverter using nonlinear load

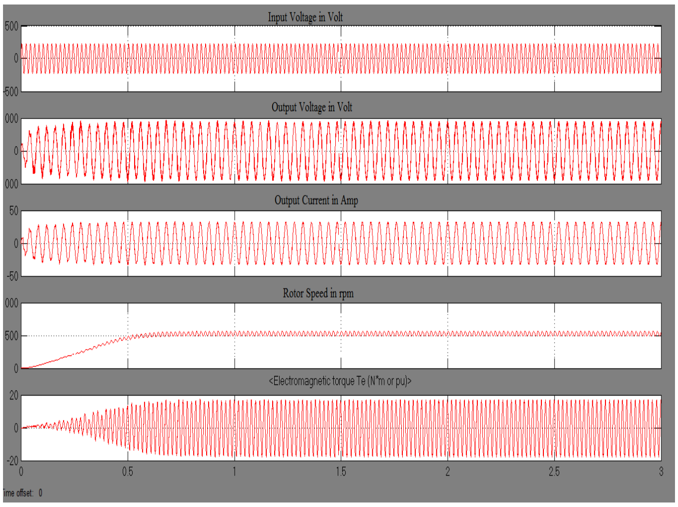


Figure 5. Waveform of Simulation of cycloconverter using nonlinear load

Initially the waveforms are somewhat distorted. After t=0.2 sec, the waveforms are quite similar to meet the actual ideal waveforms.

V. FFT ANALYSIS

Now as we know the cycloconverter will introduce harmonics in the output quantity so to eliminate that we need to install filter. The necessity of filters can be proved by simulating cycloconverter without filter and doing FFT analysis of output voltage as well as current waveform.

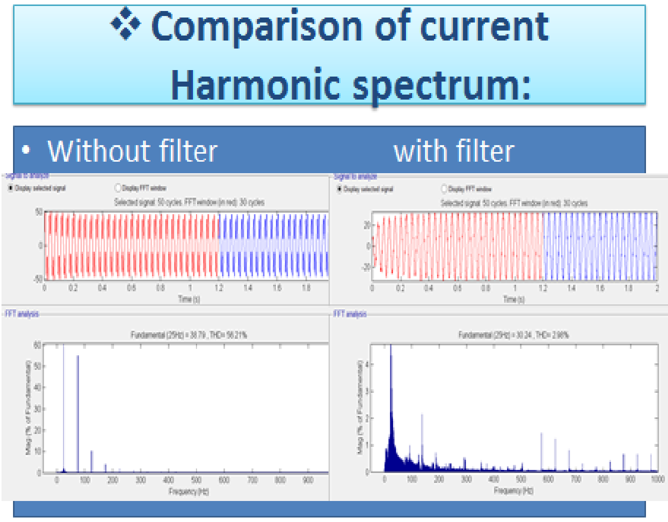


Figure 5. Comparison of voltage harmonic spectrum

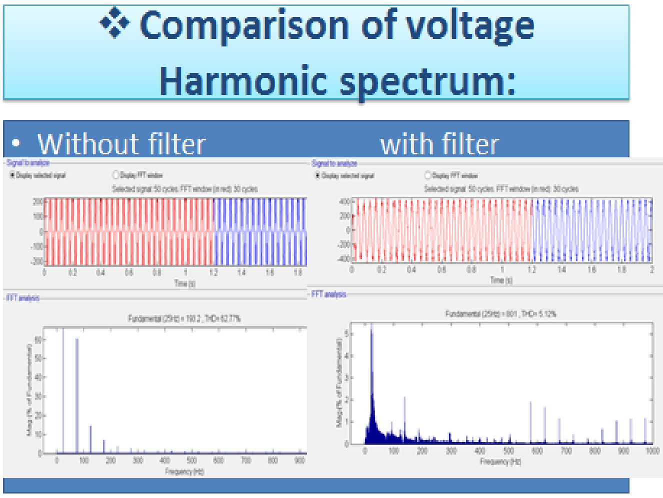


Figure 6. Comparison of voltage harmonic spectrum

VI. CONCLUSION

Due to the advance of power electronics & power semiconductor devices, the applications of direct frequency converters are becoming increasingly attractive.

By properly selecting a suitable converter an excellent performance and responsive controls can be expected. The simple control logic circuit makes the propose technique attractive, economical & practical. The frequency components in the input current and the output voltage are practically the same for ideal conditions except for some low frequency harmonics could vary depending upon operating conditions.

With the use of propose method the speed control of single phase induction motor can be achieved. Simulation results have covered the basic principles of cycloconverter theory and system consideration.

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