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Economic Single-Phase to Three-Phase Converter for Low Power Motor Drives

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Abstract- **In his paper, a economical single-phase to three-phase converter is proposed to operate three-phase motors in single-phase supply with variable voltage and fixed frequency .In conventional single-phase to three-phase converters the number of switches are very high which increase its cost. In the proposed converter the numbers of switches are less which makes it economical. The paper also presents the output voltage control of economic single-phase to three-phase converter using triac which provides soft starting capability to the three-phase motor. This converter helps to run three-phase motors which are more efficient compared to single-phase motors. Here we are using two close loop controllers: one for controlling the dc link voltage and the other one for controlling the inverter output voltage. The proposed converter uses four switches (IGBT, MOSFET), two capacitors, one triac for the conversion. This paper explains two sequence of operation of economical single-phase to three-phase converter: one is positive sequence operation and other one is negative sequence operation.**

Index Terms- Induction motor; Three-phase motor; Single-phase motor; High frequency switches; Triac

1. INTRODUCTION

The main applications of single-phase to three-phase motors are in huge countries like Brazil where the single-phase grid is quite common due to the large area to be covered. This converter helps to run three-phase motors using single-phase supply. On the other hand the 3 phase motors have more advantages over single-phase motors hence this converter will act as a good bridge between a single-phase supply and three-phase load.

In the past, single-phase to three-phase conversion systems were obtained by the connecting passive elements (capacitors and reactors) with autotransformer, such types of conversion system have well-known disadvantages and limitations. In those days, power electronic components like SCR and thyristors was just emerging. During that days Power electronics, with gas tube and glass-bulb electronics, was known as industrial electronics. The power electronics with silicon-controlled rectifiers and transistors began emerging in the market from the early 1960s.

There are various solutions for the conversion of single-phase supply into three-phase supply including rotary converters, phase shifters and static converters where static converters have more advantages when compared to other types of converters.

The paper presents a low cost single-phase to three-phase converter topology with less number of switches and moderate performance.

2. CONVENTIONAL SINGLE-PHASE TO THREE-PHASE CONVERTERS

There are various types of static single-phase to three-phase converters with different number of switches. The cost of converter reduces with the reduction in number of switch used for conversion.

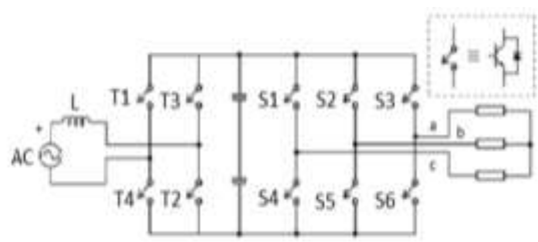

Fig 1: conventional single-phase to three-phase configuration with 10 switches (controlled rectifier in the input side).

The fig 1 shows the conventional single-phase to three -phase configuration. Here the first four switches will act as a controlled rectifier which will convert ac voltage into controlled dc voltage. Here the inductor helps to remove the current harmonics.

To convert ac voltage into pulsating dc the switches T1, T2 and T3, T4 will switch alternatively and the capacitors helps to convert pulsating dc into constant dc. The voltage across the capacitor can vary by adjusting the switching of T1, T2, T3, and T4.

In this single-phase to three-phase converter the switches S1, S2, S3, S4, S5 and S6 will act as inverter which converts variable dc voltage into three-phase ac voltage. The switch S1, S2, S3 helps to make positive polarities at c, b, a respectively and the switches S4, S5, S6 helps to make negative polarities at c, b, a terminals respectively. Here by adjusting the switching frequency we can adjust the output three-phase voltages. The efficiency of this converter is high compared to economical single-phase to three-phase converter and the main advantage of this converter is here we can control the output frequency by adjusting the switching frequency of the inverter.

The main disadvantage of this converter is that here the number of switches are very high which increases the size and cost of the converter

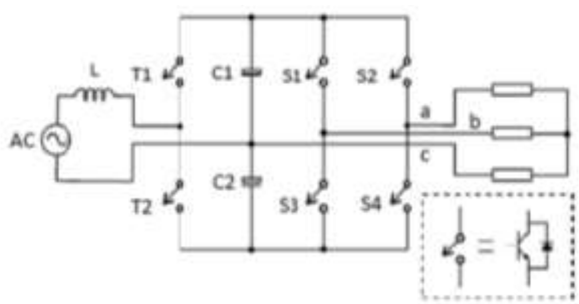

Fig 2: conventional single-phase to three-phase converter with six switches.

The fig2 shows conventional single-phase to three-phase configurations with six switches. The first two switches will as controlled rectifier which converts single-phase ac into controlled dc. The capacitors C1, C2 are used to store the dc voltage. Here during positive half cycle the switch T1 gets turned on then the capacitor C1 gets charged. During negative half cycle the switch T2 gets turned on then the capacitor C2 get charged. The capacitors C1, C2 helps to remove the ripples in the pulsating dc. Here the inductor helps to remove the current harmonics from the supply. The dc link voltage stored in the capacitor can be adjusted by adjusting the switching pulses to the switches T1, T2.

In this economical single-phase to three-phase converter the switches S1, S2, S3 and S4 will act as inverter which helps to make a three-phase supply from a constant dc voltage. Here the switches S1 and S2 help to make positive polarity at b, a terminals respectively and the switches S3 and S4 help to make negative polarity at b, a terminals respectively. The switches S1, S2 and S3, S4 should not turn on simultaneously which causes capacitors to get shorted.

The main advantage of this six switch conventional converter is that here the no of switches are low which helps to reduce the cost and switching losses. Here we are directly using the given single-phase supply in the output which helps to reduce the number of switches. Due to the presents of input single-phase supply in the output we cannot adjust the frequency of three-phase supply which means we have to adjust the inverter switching frequency into the input frequency.

In this six switch conventional single-phase to three-phase converter the switches S1, S4 help to make ac supply with 120 degree lag with respect to input single-phase voltage and the switches S2, S3 helps to make ac supply with120 degree lead with respect to the input single-phase voltage. The main advantage of this converter is that here the number of switches are less which helps to reduce cost, size of the converter. The main disadvantage of this converter is that here we cannot adjust the output three-phase voltage frequency due to the direct involvement of input supply in the output.

3. ECONOMIC SINGLE-PHASE TO THREE-PHASE CONVERTER

The cost of a single-phase to three-phase converter can be reduced by two different approaches.

1) Topological approach
2) Control approach

In topological approach the cost reduction is obtained by reducing the number of switches. While reducing the number of switches the cost, size of the converter reduces and the switching losses also get reduced. In control approach the cost reduction is obtained by various control techniques.

There are some disadvantages for converters with lees number of switches.

1) The switches need high voltage rating
2) VA rating of the capacitor should be high

In converters with less number of switches we have to use DC midpoint type configurations where we have to use two capacitors with series connection to store the dc link voltage. Hence the voltage across the switches will be double the operating voltage hence we have to use switches with high voltage ratings. The VA rating of capacitors used in converters with less number of switches should high due to the low frequency harmonics.

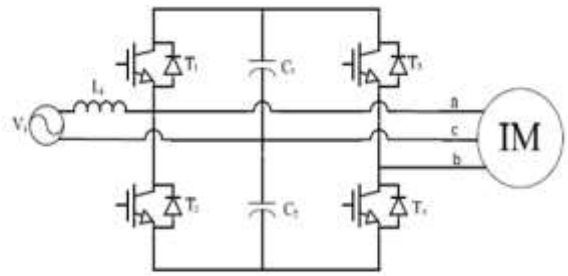

Fig 3: economical single-phase to three-phase converter

The fig 3 shows economical single-phase to three-phase converter. Here the cost reduction of converter is obtained by reducing the number of switches. The direct utilization of input supply in the three-phase output helps to reduce the number of switches. By reducing the number of switches we can reduce the gate triggering circuit.

The proposed converter uses four high frequency switches (IGBT, MOSFET), four diodes, two capacitors, one inductor.

The main advantage of this converter is that the reduction in cost due to less number of switches the main disadvantage of this converter is that here we need switches with high voltage rating and we need capacitors with high VA rating due to the current harmonics. The voltage across c1 and c2 gets added and which will be present across the switches hence we need switches with high voltage rating.

In this proposed converter the inductor Li helps remove the current harmonics. The switch T1, T2 will act as rectifier which converts single-phase ac into controlled dc voltage. By controlling the switching pulses we can control the dc link voltage across the capacitors. To convert single-phase ac to controlled dc the switches T1, T2 will turn on alternatively when the T1 is on the capacitor c1 get charged and when T2 is on capacitor c2 get charged. Here the switches T3 and T4 help to adjust the three-phase output voltage. We can use diodes instead of T1, T2 to reduce the number of switches but in that case we cannot control the dc link voltage stored in the capacitors c1, c2.

During positive half cycle the switch T1 will turn on and the current pass through inductor Li, switch T1, and capacitor c1 hence the capacitor c1 gets charged. During negative half cycle the switch T2 turned on and the current passes through the capacitor c2, switch T2, inductor Li hence the capacitor c2 get charged during negative cycle. In this rectification the inductor Li helps to remove the current harmonics. So the controlled dc voltage stores in the capacitor from fig 3 we will get the voltage across the capacitors c1 and c2 gets added which is present across the switches. Turning on the switches T1, T2 simultaneously causes capacitors to get shorted hence the switches T1, T2 should not switch on at the same time. Here the capacitors help to remove the ripples in pulsating dc voltage

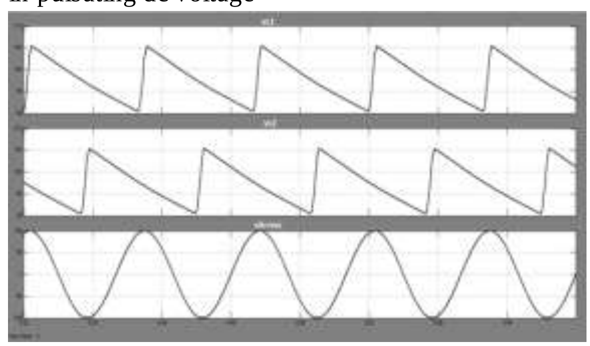

Fig 4: voltage across capacitor c1, voltage across capacitor c2, input voltage

The fig 4 shows the wave forms of voltages across the capacitors c1, c2 and the input voltage. In the figure the descending slop represents the capacitor discharging. The ascending slop represents the charging of capacitors. From the figure it is clear that the voltage across the capacitor is same as that of input voltage vi and the voltage across the switches is 2*vi. As the capacitance of c1 and c2 increases we will get constant dc voltage with fewer ripples across the capacitor.

In this proposed converter the switches T3, T4 will act as inverter which helps to convert controlled dc voltage into three-phase voltage. Actually the T3, T4 will act as a square wave inverter. When is T3 on we will get positive square pulse and when T4 is on we will get negative square pulse as output. By controlling the switching pulses to the switches T3, T4 we can adjust the pulse width of sure wave. If the switching time of T3 is high then the duty ratio of the square pulse will be more. If the switching time of the switch T4 increases the duty cycle reduces.

In this economical single-phase to three-phase converter T3, T4 switches helps to produce controlled square wave. When the switch T3 is turned on the current passes through T3, motor terminal b and motor terminal c. during this time the capacitor c1 gets discharged. Hence we will get a positive square pulse as output. From the figure 3 it is clear that the motor terminals a, c are connected directly to the single-phase supply. And the terminal b is connected to the inverter output.

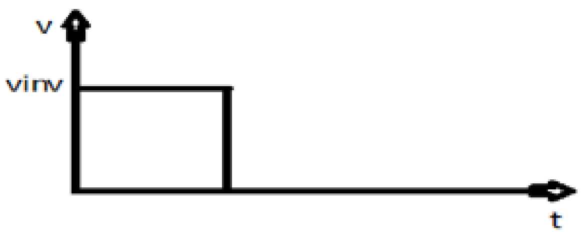

Fig 5: Inverter output voltage when switch T3 is on

The figure shows voltage across the terminals b and c (Vbc) which is equal to inverter output voltage (Vinv).

Vbc=vinv

When the switch T4 is turned on we will get a negative square pulse as output. The direction current flows through terminal c, b, switch T4. During this time the capacitor c2 gets discharged.

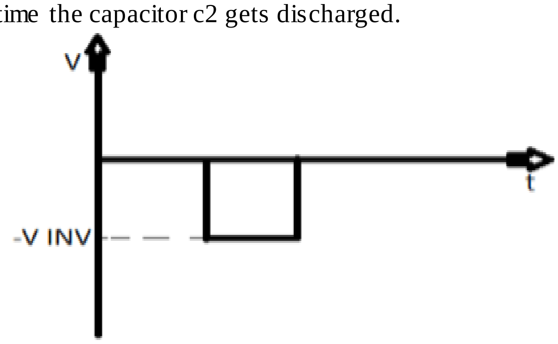

Fig 6: inverter output voltage when T4 is on.

From the figure it is clear that the inverter voltage is negative when T4 is on.

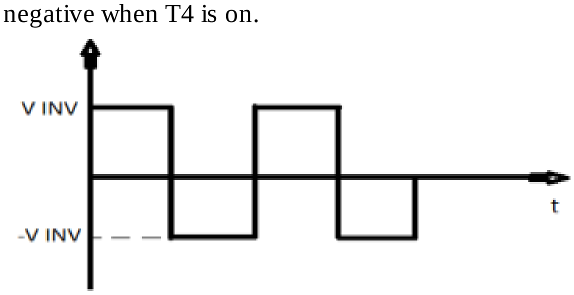

Fig 7: inverter output voltage.

So we can simplify the proposed converter as

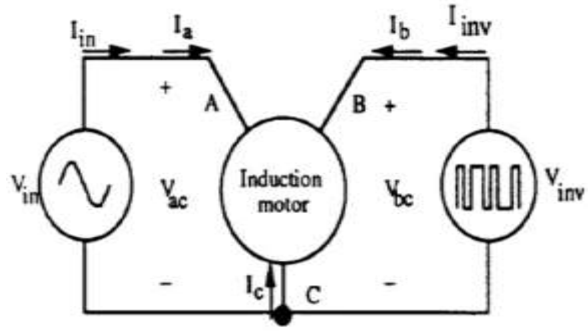

Fig 8: simplified equivalent circuit

In this figure, it is clear that input current (Iin) is equal to Ia and inverter current (Iinv) equal to Ib and there is two voltages input voltage (Vin) and inverter voltage (Vinv).

To get a balanced three-phase operation we have to make 60 degree phase difference between inverter voltage and input voltage. There are two modes of operation for this converter one is positive sequence operation and other one is negative sequence operation.

In negative sequence operation inverter output voltage leads 60 degree with the input voltage

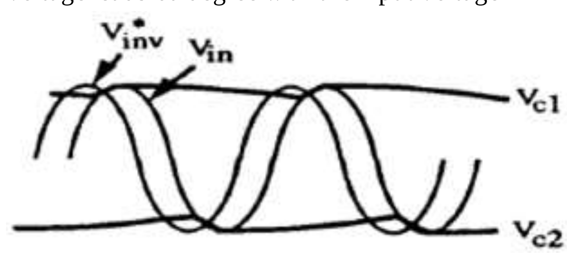

Fig 9: wave forms in negative sequence operation

The figure shows inverter output voltage, input voltage, voltage across capacitors c1, c2. The main disadvantage of negative sequence operation is that voltage distortion. Here the peak of inverter output voltage occurs just before the peak of input voltage and at this time the capacitor gets discharged which causes voltage distortions.

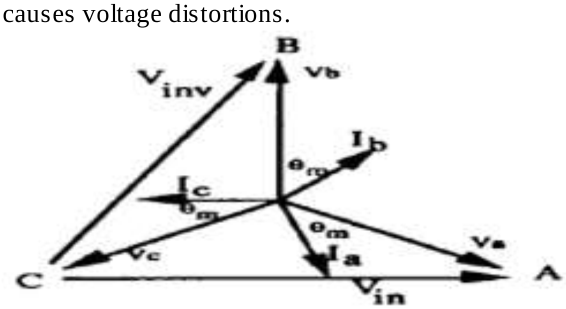

Fig 10: phasor diagram for the system operated in negative sequence operation.

From the figure we get that the inverter output voltage leads input voltage by 60 degree. By resolving Vbc (inverter output voltage) and Vac (input voltage) we will get Va, Vb, Vc as shown in figure 10. From the phasor diagram the inverter output power can be calculated as

$$P_{inv} = V_{inv}\, I_{inv} \cos\theta_{inv} = V_{bc}\, I_b \cos(\theta - 30°)$$

And input power can be calculated as

$$P_{in} = V_{in}\, I_{in} \cos\theta_{in} = V_{ac}\, I_a \cos(\theta_m + 30°)$$

Where Θin is the input power angle and Θm is the power angle of motor

In positive sequence operation the inverter output voltage lags behind input voltage by 60 degree.

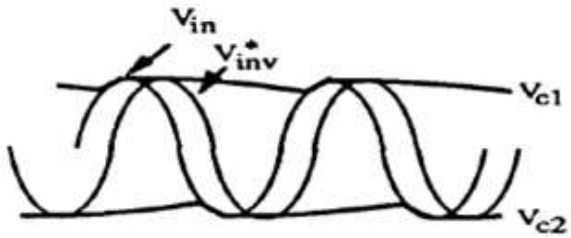

Fig 11: wave forms in positive sequence operation.

The main advantage of positive sequence operation is that there will not be any voltage distortions because the peak of inverter output voltage occurs just after the peak of input voltage at that time the capacitor charges. Hence there will not be any voltage distortions.

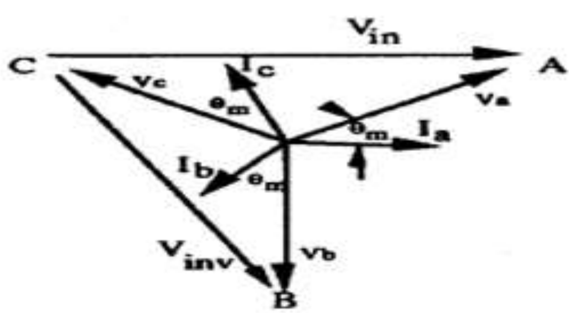

Fig 12: phasor diagram for the system operated in positive sequence operation.

From the figure it is clear that the inverter output voltage lags behind the input voltage by 60 degree. By resolving Vbc (inverter output voltage) and Vac (input voltage) we will get Va, Vb, Vc as shown in figure 12. From the phasor diagram the inverter output power can be calculated as.

$$P_{inv} = V_{inv}\, I_{inv} \cos\theta_{inv} = V_{bc}\, I_b \cos(\theta_m + 30°)$$

And input power can be calculated as

$$P_{in} = V_{in}\, I_{in} \cos\theta_{in} = V_{ac}\, I_a \cos(\theta_m - 30°)$$

Where Θin is the inverter power angle and Θm is the motor power angle.

4. ECONOMIC SINGLE-PHASE TO THREE-PHASE CONVERTER WITH MOTOR SPEED CONTROL

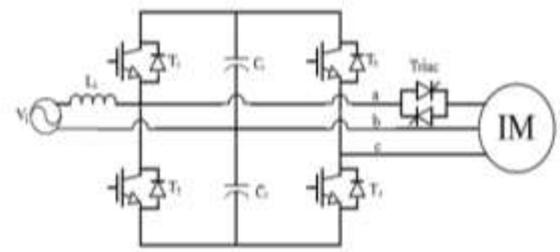

Fig 13: economic single-phase to three-phase converter with speed control.

To control the speed of the motor we can use anti parallel thyristors. By controlling the switching pulses to the thyristors we can control the speed of the motor. The thyristors also provides soft starting capability to the motor.

The main advantages of conventional single-phase to three-phase converter is that in this converter we can adjust the dc link voltage and we can provide soft starting capability to the motor by adding anti parallel thyristors. The main advantage of this converter is that here the numbers of switches are very less and here we can maintain a balanced three-phase output voltage while controlling the speed.

5. SIMULATION RESULTS

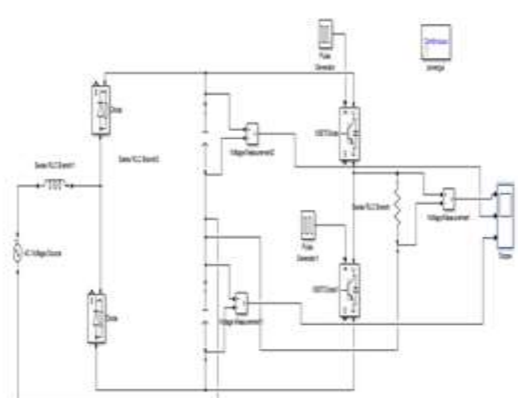

Fig 14: block diagram of single-phase to three-phase converter

The figure shows the circuit diagram for single-phase to three-phase converter. In this simulation diodes are used for rectification purposes and resistive load is there in the inverter output. The diagram is for measuring the voltages across the capacitors and voltage across the resistor which is connected the inverter output. Here the switches will turn on alternatively to make square wave output. The capacitors with 100 micro farads and resistor with 1000 ohm is used for this simulation. In this simulation high frequency IGBT switches are used in the inverter.

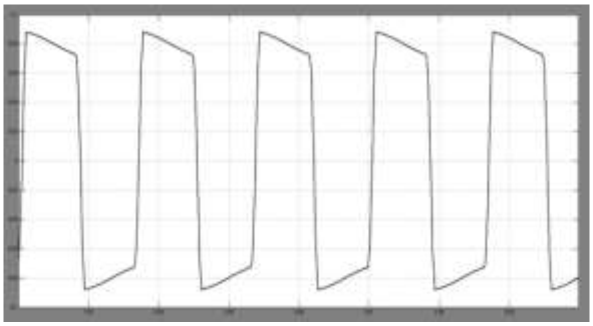

Fig 15 a: inverter output voltage

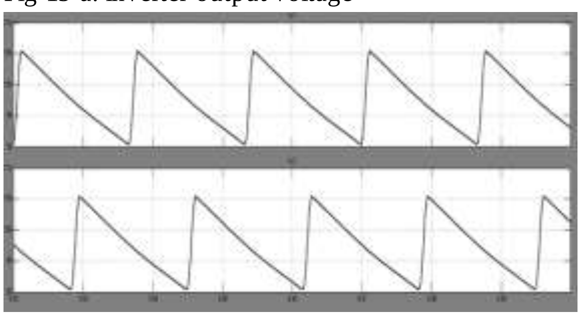

Fig 15 b: voltage across the capacitors.

Here the first waveform is the inverter output voltage. From the figure it is clear that it is a square wave. The last two waveforms show the voltage across the capacitors. Here we can adjust the width of square pulses by adjusting the switching pulses. In this figure the width of the square pulses are same hence here the duty cycle is 50%.

6. CONCLUSION

This paper presents economical single-phase to three-phase converter with speed control. The reduced number of switches makes this converter economical. The converter has four switches, four diodes, two capacitors and one inductor. This converter uses an inductor to reduce the current harmonics in the output. The main advantages of this converter is that

1) In this converter we can adjust the dc link voltage by adjusting the switching pulses to the rectifier switches.
2) It has low cost due to the reduction in the number of switches compared to conventional single-phase to three-phase converter.
3) It has speed controlling techniques to control the speed of the motor.
4) It provides soft starting capability to the motor
5) We can maintain a balance three-phase output voltage while controlling the speed.

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