Single Phase to Three Phase PWM Converter with Induction Motor

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Abstract— There are many applications in industry which require different voltage level and frequency. The power electronics converter which converts fixed ac voltage in to pulsating dc voltage known as rectifier. The power electronics converter which gives DC power to AC power at required output voltage and frequency level is known as inverter. Three are mainly Voltage source inverter and current source Inverter is used for DC to AC power conversion. .Here single phase to three phase PWM converter simulation are done in PSIM software. Simulation of single phase to three phase PWM converter with ten switches, seven switches, and six switches are done

Key words: DC, PWM

I. INTRODUCTION

In industrial applications, two forms of electrical energy are used: direct current (dc) and alternating current (ac). Usually constant voltage constant frequency single-phase or three-phase ac is readily available. However, for different power applications, different forms, magnitudes and frequencies are required. One of the first and most widely used application of power electronic devices have been in rectification. Rectification refers to the process of converting a fixed ac voltage or current source to pulsating dc voltage and current. In Rectifiers are specially choosen to power electronic converters where the electrical power flows from the ac side to the dc side. In situations the same converter circuit may carry electrical power from the dc side to the ac side so they are called to as inverters.

A. Introduction of Rectifier:

A rectifier is an electrical device that converts alternating current (AC) to direct current (DC), or in other meaning a fixed ac voltage to a variable pulsating voltage this process known as rectification. Rectifiers have many uses including as components of power supplies and as detectors of radio signals. Rectifiers may be made of solid state diodes, vacuum tube diodes, mercury arc valves, and other components.

B. Introduction of Inverter:

An inverter is an electrical device that converts direct current (DC) to alternating current (AC); with variable voltage and variable frequency. The resulted AC can be e transformers, switching, and control circuits.

Static Inverters have no moving parts and are used in a wide range of applications, from small switching power supplies in computers, to large electric utility high-voltage direct current applications that transport bulk power. Input supply uses for Inverters are battery, solar cell or batteries fuel cell.

C. Advantages and Disadvantages of Half Wave Rectifier [1]:

1) Advantages of half wave rectifier: - Simple circuit and low cost:

2) Disadvantages of half wave rectifier are listed below:

1) The efficiency is low (40.6%).
2) Ripple factor is high (121%).
3) The circuit has low transformer utilization factor (28.7%)

D. Advantages and Disadvantages of Single Phase Full Bridge Rectifier [2]:

1) Advantages and disadvantages of single phase full bridge rectifier [2]:

1) No centre tap is required on the transformer
2) No terminal is grounded
3) Average or DC output Voltage and average or DC load current are twice of a half bridge rectifier
4) Ripple factor is less

2) Disadvantages of Single Phase Full Wave Rectifier:

1) Output voltage half of the secondary winding
2) It requires four diodes
3) The peak inverse voltage of the diode is two times the half wave rectifier
4) It is expensive

Table 2 Comparison table of rectifier

E. Classification of Inverters [3]:

1) Classification According To the Nature of Input Source:

1) Voltage source inverters.
2) current source inverters.

2) Classification According To the Nature of Output Voltage:

1) Square- wave inverter
2) Qusi- square wave inverter
3) Pulse width modulated PWM inverter

A square wave inverter produces a square- wave ac voltage of a constant magnitude. The output voltage of this type of inverter can only be varied by controlling the input dc voltage. Square- wave ac output voltage of an inverter is adequate for low and medium power applications. However, the sine-wave output voltage is the ideal waveform for many high power applications. Two methods can be used to make the output closer to a sinusoidal. One is to use a filter circuit on the output side of inverter; this filter must be capable of handling the large power output of inverter, so it must be large and will therefore add to the cost and weight of the inverter. Moreover, the efficiency will be reduced due to the additional power- losses in the filter. The second method, pulse- width modulation (PWM) uses a switching scheme within the inverter to modify the shape of the output voltage waveform.

3) Classification According To the Method of Commutation

1) Line commutated inverters:- in case of ac circuit when the current in the scr goes to through a

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natural zero, the device is turned off. This process is known as natural commutation process and the inverters based on this principle are known as line commutated inverters.

2) Forced commutated inverters:- In case of dc circuits the supply voltage does not go through the zero point some external source is require to commutate the device. This process is known as the forced commutation inverters.

4) Classification According To Connections:

1) Series inverters
2) Parallel inverters
3) Bridge inverter: - Half bridge and Full bridge.

1) Single Phase Two Leg Inverter:

1) It consist of four switches
2) Output voltages of only two levels +0.5Edc and -0.5Edc.
3) Lower voltage distortion.

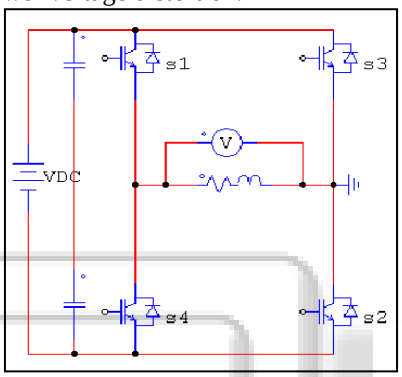

Fig. 1.5.1: Single Phase Two Leg Inverter

2) Three Phase Voltage Source Inverter:

1) It consist six switches.
2) Output voltages are +0.5Edc, 0, -0.5Edc.
3) Rms ripple voltage can be made lower than that two level inverter

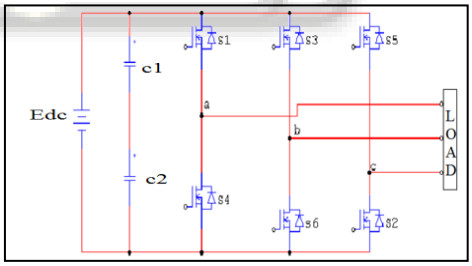

Fig. 1.5.2: Three Phase Voltage Source Inverter

F. Industrial Applications of Rectifier and Inverters are Listed Below:

1) Variable speed ac motor drives.
2) Induction heating.
3) Uninterruptible power supplies (UPS)
4) High voltage dc transmission lines.
5) Battery- vehicle drives.
6) Regulated voltage and frequency power supplies

G. Single Phase to Three Phase Converter:

Several solutions have been proposed when the objective is to supply three-phase motors from single-phase ac mains. It is quite common to have only a single-phase power grid in residential, commercial, manufacturing, and mainly in rural areas, while the adjustable speed drives may request a three-phase power grid. Single-phase to three-phase ac–dc– ac conversion usually employs a full-bridge topology, which implies in ten power switches, as shown in Fig.1.7 This converter is denoted here as conventional topology.[4]

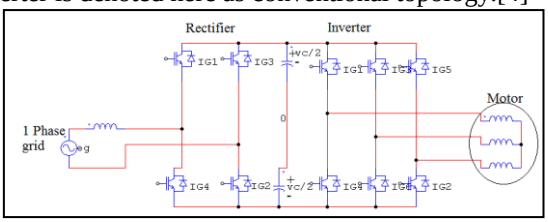

Fig. 1.7: Conventional Single-Phase To Three-Phase Drive System.

II. Single Phases to Three Phase PWM Converter

A. Introduction:

This is control scheme of single phase to three phase PWM converter. It is used in application for low power three phase induction motor drives. In many industry applications where a three phase power is not available then to run induction motor for three phase supply it is necessary to convert a single phase to three phase power conversion. And it would do by power converter like rectifier, inverter, and chopper. There is various control mechanism for AC to DC means rectifier and dc to ac means inverter using pulse width modulation technique.

In larger power converters there is tendency to increase the number of switches in order to supply the increased current demand, while in smaller power converter the emphases is on low cost so that any reduction in the number of necessary is beneficial. Number of low cost topologies has been suggested for both fixed and variable speed drives in the low power range. Such system is supplied from single phase sources. [5]

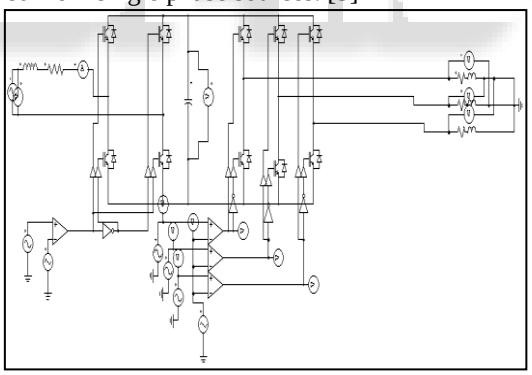

Fig. 2.2: Single Phase to Three Phase PWM Converter

Which has four switches for rectifier and six switch for inverter gives good performance such as unity power factor control, bidirectional power flow. But it requires ten switches so it is expensive.

Single phase to three phase converter with dc boost chopper shown in below fig 2.3

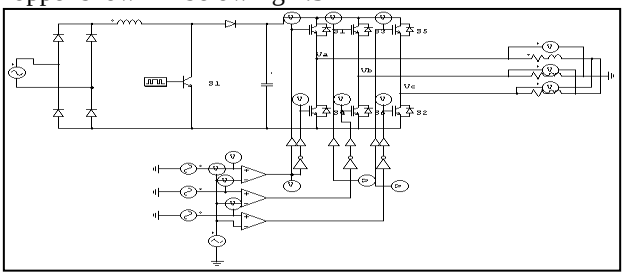

Fig. 2.3: Single Phase to Three Phase Dc Boost Chopper

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In above fig four diode works as rectifier and six IGBT switches work as inverter, in between rectifier and inverter dc boost chopper employed.

Advantages of boost topology are high efficiency, high power density and inherent power quality improvement at input and output.

In single phase half bridge rectifier plus two leg three phase PWM converter fig show below. Which has two switches for rectifier and four switches for inverter, both rectifier and inverter sinusoidal pulse width modulation control technique is used. In this converter number of switches reduced then conventional ten switch converter, cost also reduced then conventional ten switches converter. Its merit same as conventional single phase to three phase PWM converter.

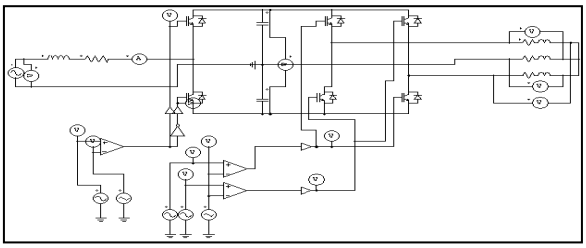

Fig. 2.4: Single Phase Half Bridge Rectifier plus Two Leg Three Phase PWM Converter

A six power switch converter has advantages over conventional converter are listed below. [6]

1) Active input current shaping for sinusoidal input current
2) Line regulation
3) Bidirectional flow of power
4) Close to unity power factor operation
5) Simple control scheme
6) Reduces number of power electronic devices implies that it is cheaper

This converter makes use of only six switches and two capacitors with their midpoint grounded; the switches of the converter were controlled by PWM.

The PWM switching pattern controls the switching of the power devices for input current wave shaping so that it almost becomes harmonic free and in phase with the source voltage, thus producing a nearly sinusoidal supply current at unity power factor.[7]

III. Speed Control for Single Phase to Three Phase PWM Converter for Induction Motor Drive

AC machines are preferable over DC machines due to their simple and most robust construction without any mechanical commutators. Induction motors are the most widely used motors for appliances like industrial control, and automation; hence, they are often called the workhorse of the motion industry [8].

Variable speed operation of a single phase induction motor has been obtained through voltage control using triacs or back to back thyristors, however these suffer from large harmonic injection into the supply and low power factor, in addition to a limited speed range. To minimize the harmonic injection, this solution uses only IGBTs to control the induction motor. [9,10]

The development of speed control system using frequency control has been designed by combinations of PWM control circuit, driver circuit and inverter which makes the

system simple, robust and compact open loop PWM controller circuit to control single phase induction motor and single phase induction motor can be driven to variable speed and frequency.[11], But it is desirable to replace the single phase induction motor drives by three phase induction motor drives in residential appliances, farming and low power industrial applications [12].

The speed of machine of machine is controlled by converting fixed voltage and frequency to adjustable values on machine side. The three phase inverter circuit changes the DC input voltage to three phase variable frequency variable voltage output. The three phase Ac is rectified into DC and then filtered to minimize the ripple current. This controlled dc is converted into controlled pulses by means of voltage to frequency converter. These controlled pulses are fed to Inverter Bridge for producing variable voltage variable frequency output. This output is fed to induction motor for controlling it's speed. [13]

A. The Reasons For The Popularity of the Induction Motors Are:

1) Induction Motors are cheap compared to DC and Synchronous motor. Due to its economy installation and use, the Induction Motor is usually the first choice for an operation.
2) Squirrel-Cage Induction Motors are rugged in construction. There robustness enables them to be used for long durations of time.
3) Induction Motors have high efficiency and also they are very reliable.
4) Because of their simplicity of construction, Induction Motors have very low maintenance costs.

B. Working of Induction Motor:

When the stator winding is energized by a three-phase supply, a rotating magnetic field is set-up which rotates around the stator at synchronous speed Ns. This flux cuts the stationary rotor and induces an electromotive force in the rotor winding. As the rotor windings are short-circuited a current flows in them. Again as these conductors are placed in the stator's magnetic field, this exerts a mechanical force on them by Lenz's law. Lenz' law tells us that the direction of rotor currents will be such that they will try to oppose the cause producing them. Thus a torque is produced which tries to reduce the relative speed between the rotor and the magnetic field. Hence the rotor will rotate in the same direction as the flux. Thus the relative speed between the rotor and the speed of the magnetic field is what drives the rotor. Hence the rotor speed Nr always remains less than the synchronous speed Ns. Thus Induction Motors are also called Asynchronous Motors.

C. Speed Control Is A Necessity For Induction Motors Because Of The Following Factors:

1) It ensures smooth operation..
2) It provides torque control and acceleration control.
3) Different processes require the motor to run at different speeds.
4) It compensates for fluctuating process parameters.
5) During installation, slow running of the motors is required.

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D. Different Method of Speed Control:

A three phase induction motor is mostly a constant speed motor so it's fairly not easy to control its speed. The speed control of induction motor is done at the price of reduce in efficiency and low power factor. Before discussing the methods to control the speed of three phase induction motor one should know the necessary formulas of speed and torque of three phase induction motor as the methods of speed control depends upon these formulas [14]

Synchronous speed, Ns = $\frac{120f}{P}$

Where f = frequency and P is the number of poles The speed of induction motor is given by, N = Ns (1-s)

Where, N is the speed of rotor of induction motor Ns is the synchronous speed S is the slip

Stator and Rotor both side changed the speed of Induction motor. [14]

1) The Stator Side Speed Controls of Induction Motor:

1) V/F control or frequency control
2) Changing the number of stator poles
3) Controlling supply voltage
4) Adding Rheostat in the stator circuit

2) The Rotor Side Speed Controls Are Further Classified As:

1) Adding external resistance on rotor side
2) Cascade control method
3) Injecting slip frequency emf into rotor side

E. V/F Control for Induction Motor:

Of the above mentioned methods, V/f Control is the most popular and has found widespread use in industrial and domestic applications, in areas where precision is required, V/f Control are not used.

The various advantages of V/f Control are as follows:

1) It provides good range of speed.
2) It gives good running and transient performance.
3) It has low starting current requirement.
4) It has a wider stable operating region.
5) The acceleration can be controlled by controlling the rate of change of supply frequency.

Whenever three phase supply is given to three phase induction motor rotating magnetic field is produced which rotates at synchronous speed given by in

$$Ns=\frac{120f}{P}$$

in three phase induction motor emf is induced by induction like to that of transformer which is given by

$$E = 4.44\emptyset KT$$

Now if we modify frequency, synchronous speed changes but with reduce in frequency and flux will increase and this vary in value of flux causes saturation of rotor and stator cores which will further cause increase in no load current of the motor , its key to maintain flux Φ constant and it is only achievable if we change voltage . i.e if we reduce frequency, flux increases but at the same time if we decrease voltage, flux will also decease causing no vary in flux and hence it remains stable.

Here we are keeping the ratio of V/F as constant. Hence its name is V/F method. For controlling the speed of three phase induction motor by V/F method we have to supply variable voltage and frequency which is easily obtained by using converter and inverter set.

IV. Simulation of Single Phase to Three Phase PWM Converter

A. Simulation of Single Phase to Three Phase Ac/Dc/Ac PWM Converter:

1) Operation of the System:

Below fig4.1 has four IGBT switch work as rectifier which are connected to the main AC source which convert ac voltage in to pulsating dc output voltage. Here Ls and Rs work as filter for rectifier which are remove ripple from the input current, Ls which is boost up of the rectifier. When Sa1 and Sa2 are switches on at that time Sb1 and Sb2 switches off, these both switches are operate in complimentary type. When these both switch operates at same time or switches on at same time no current flow in the circuit. In this case, the input voltage source is short-circuited through inductor L. Here for control mechanisms we have to use a sinusoidal pulse width modulation technique.

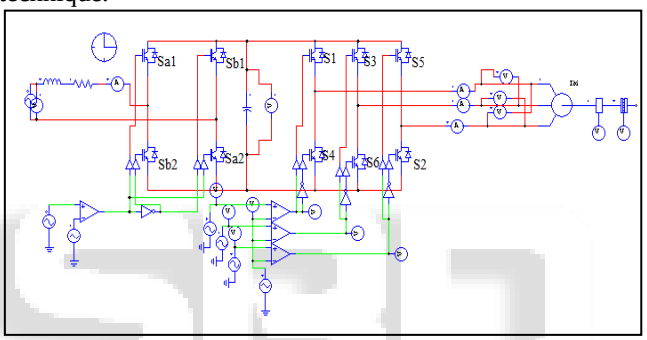

Fig. 4.1: Single Phase Ac/Dc/Ac to Three Phase PWM Rectifier

According to the modulating signal intersect carrier wave from this PWM converter changes its width from one pulse to other pulse from this output voltage obtained.

Here capacitor uses for balance output voltage which is act for filter for inverter and act as dc link voltage sources for inverter, six IGBT switches act as inverter which is convert pulsating dc voltage in to ac output voltage. S1, S2, S3 switches are upper switches and according their S4, S6, S2 switches are complimentary lower part of the switches. If input 100 then upper switches S1, S6, S2 on and other switches off. Here sinusoidal pulse width modulation techniques used. Switching state are shifted from 120° to each other.

B. Simulation Result Wave Form:

1) Carrier and Reference Wave:

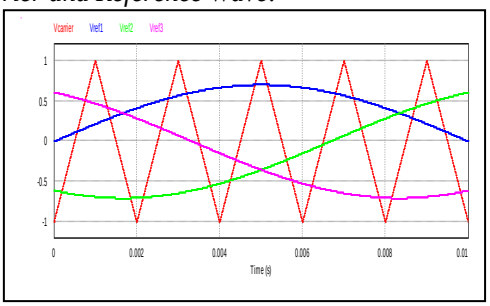

Fig. 4.2.1: Carrier and Reference Wave for Inverter

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2) Gate Pulse for Switches:

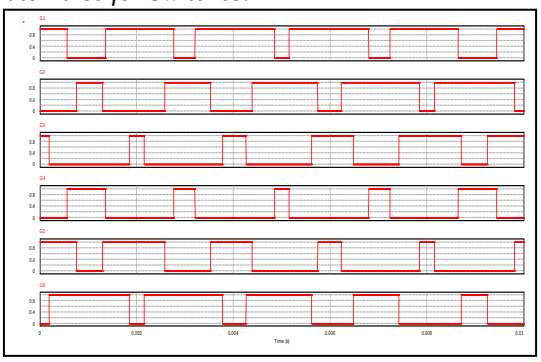

Fig. 4.2.2: Gate Pulses for Inverter

3) Output Current Waveform:

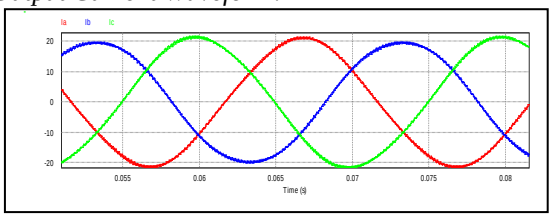

Fig. 4.2.3: Three Phase Current Waveform [I=20 Amp]

4) Torque Graph:

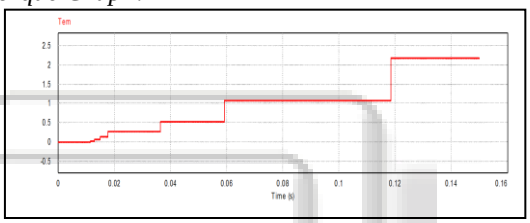

Fig. 4.2.4: Torque Characteristics' [TL=2.4Nm/Div]

C. Simulation of Single Phase Half Bridge Rectifier plus Two Leg Three Phase PWM Converter:

Single Phase half bridge plus two leg three phase circuit diagram shown in below fig 4.2.1

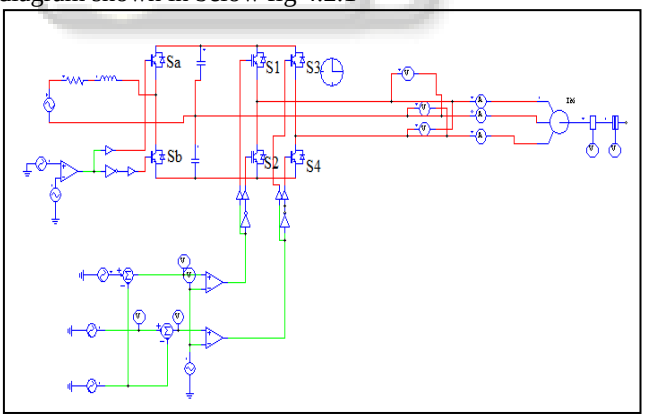

Fig. 4.2.1: Single Phase Half Bridge plus Two Legs Three Phase PWM Converter

1) Operation of the System:

Above circuit diagram two IGBT switches Sa and Sb for rectifier which convert ac voltage in to pulsating dc output voltage, which are work in complimentary type. When Sa switch on at that time switch Sb off. Here rectifier is working on two operating mode of charging and discharging.

Input side inductor and resistor which are work as filter for rectifier. Inductor remove ripple from the input current and boost up rectifier. There are Two dc link capacitor required for balance the inverter output voltages. Pulse width modulation technique applied for rectifier.

Four IGBT switches for inverter S1, S4 and S2, S3, which are convert dc voltage in to ac voltage. When Switch S1 is on at that time switch S2 is off .switches work on PWM pattern to give shape to the input current. The center point of the dc link capacitor form the third phase for inverter can be operated as voltage control. To generate balanced three output voltage should be shifted by 120° and-120°. Vcb and Vca phase shifted according to the output phase sequence.

PWM control scheme is applied for inverter. According to the modulating signal tract the carrier signal from this pulse width change from one pulse to the other pulse.

2) Carrier and Reference Waveform:

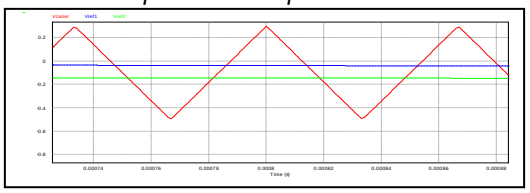

Fig. 4.2.2: Carrier and Reference Waveform

3) Gate Pulse of Inverter:

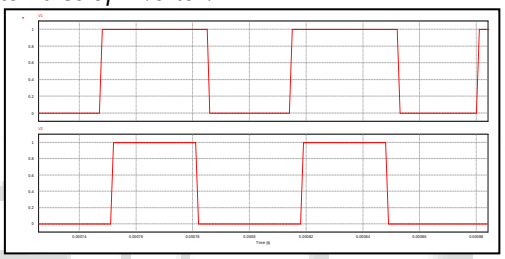

Fig. 4.2.3: Gate Pulse of Inverter

D. Output Current Waveform:

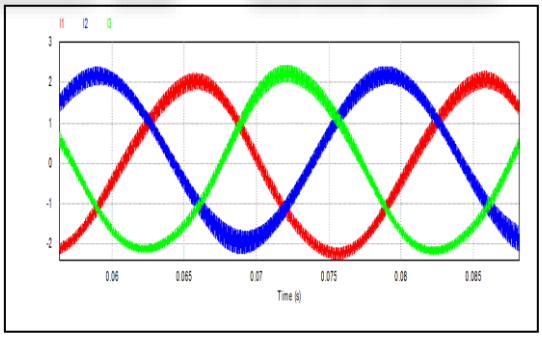

Fig. 4.2.3: Output Current Waveform [I=2.3amp]

E. Transient Response for Load Torque:

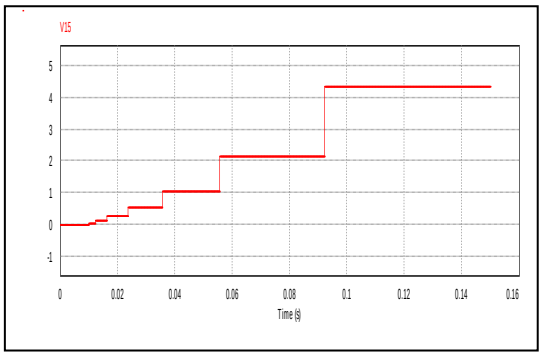

Fig. 4.2.5: Transient Response for Load Torque [TL=4.3Nm/div]

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F. Simulation of Single Phase to Three Phase Ac/Dc/Ac Dc Boost Chopper:

Single phase to three phase ac to dc then dc to ac boost chopper power circuit diagram shown below in fig 4.3.1

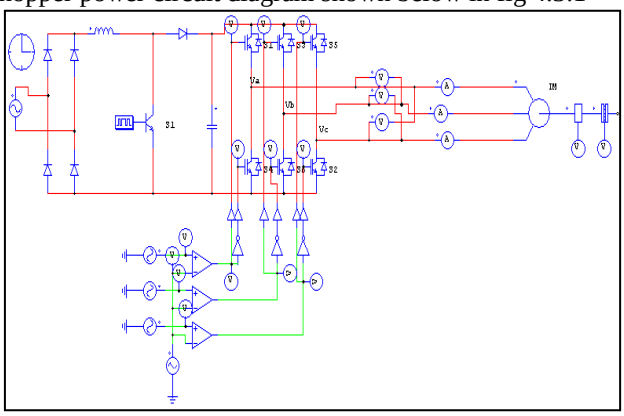

Fig. 4.3.1: Single Phase to Three Phase Ac/Dc/Ac Converter with Dc Boost Chopper

1) Operation of the System:

Above figure 4.3.1 show the power circuit of single phase to three phases PWM converter in which dc boost chopper inverted between rectifier and inverter. With four diode switches for rectifier which convert ac voltage in to dc voltage.

Switch S1 is chopper which can be used to produce higher voltages at the load then input voltage hence it is called dc boost chopper which convert constant dc voltage in to variable dc voltage.

When chopper switch S1 is on inductor is connected to the supply input voltage and inductor will stores energy during on period. When chopper Switch S1 is off during this time inductor current is flow through diode and load for time off period.

Diode connected between chopper switch and capacitor work as freewheeling diode. When chopper switch S1 is switch off at that time diode work as freewheeling diode and dc current flow from this diode. Capacitor is use for balance and work as filter for the inverter.

Six IGBT switches are act as inverter which are convert pulsating dc voltage in to ac output voltage. S1, S2, S3 switches are upper switches and according their S4, S6, S2 switches are complimentary lower part of the switches. If input 100 then upper switches S1, S6, S2 on and other switches off. Here sinusoidal pulse width modulation techniques used. Switching state are shifted from 120° to each other. Switches of the inverter are controlled by PWM signals and to obtain three phase sinusoidal ac voltages of the desired magnitude and frequency at the inverter output

2) Carrier and Reference Wave Form:

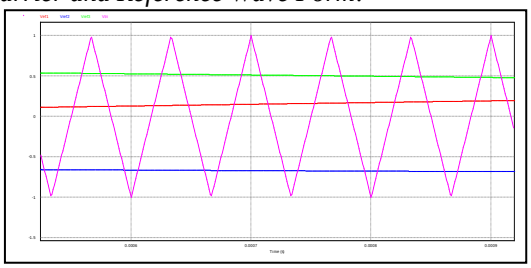

Fig. 4.3.2: Carrier and Reference Waveform

3) Gate Pulse Waveform:

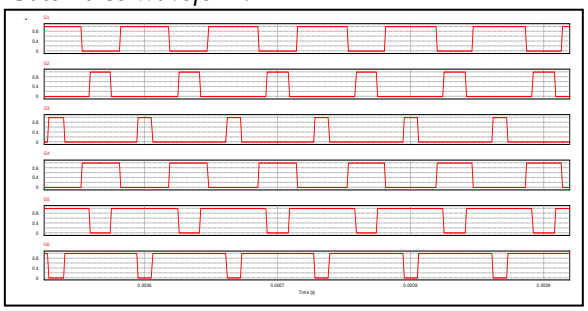

Fig. 4.3.3: Gate Pulse Waveform

4) Output Current Waveform:

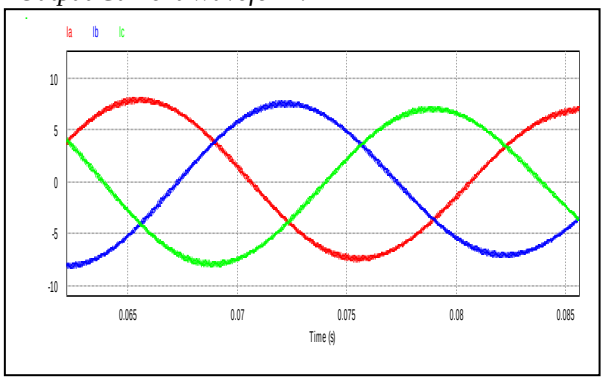

Fig. 4.3.4: Output Current Waveform For Seven Switches PWM Converter [I=8.20 Amp]

5) Torque Characteristics:

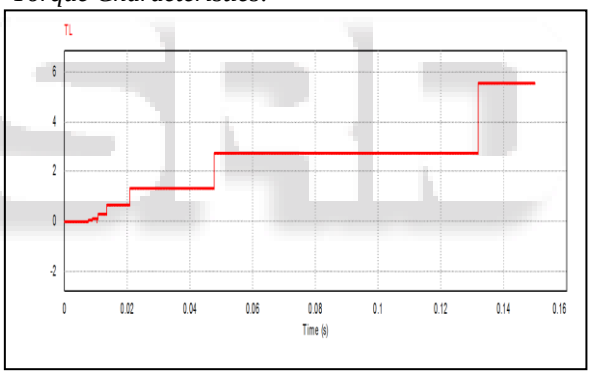

Fig. 4.3.5: Torque Characteristics [TL=5.55Nm/div]

V. Conclusion

From the simulation of the single phases to three phase different PWM converter, single phase half bridge rectifier plus two leg three phase PWM converter lower cost than conventional PWM converter. Lower output current is than other two PWM converter .Seven Switches PWM converter merit are same as Six switches PWM converter.

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