DESIGN AND DEVELOPMENT OF SINGLE PHASE TO THREE PHASE CONVERTER FOR INDUSTRIAL INDUCTION MOTOR

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Abstract

In this project we worked on design and development of a single-phase to three-phase converter for industrial induction motors. Indirect matrix converters are now available on the market, and they are beneficial in high-power energy generating systems like solar energy, wind energy, and systems for unified power quality control. This study suggests using Matlab and hardware to simulate and implement space vector modulation for a three-phase indirect matrix converter.

INTRODUCTION

In many industrial applications, three-phase power systems are widely used due to their advantages in terms of efficiency, power capacity, and motor control. However, in certain settings such as residential areas or small-scale commercial establishments, only single-phase power is available. This limitation poses a challenge for industries that rely on three-phase motors and equipment.

To overcome this challenge, a single-phase to three-phase converter is designed and employed. A single-phase to three-phase converter is a power electronic device that transforms single-phase power into a simulated three-phase power supply. It enables the operation of three-phase motors and equipment using single-phase power sources, eliminating the need for costly infrastructure upgrades or the installation of dedic- ated three-phase power lines.The primary purpose of a single-phase to three-phase converter is to replicate the characteristics of a true three-phase power system. This includes generating three-phase voltage waveforms with the correct phase sequence, magnitude, and frequency.. By doing so, the converter enables the seamless operation of three-phase motors, ensuring optimal performance and efficiency [1].

The design of a single-phase to three-phase converter involves a combination of power electronic circuits, control strategies, and feedback mechanisms. The converter system typically consists of rectifiers, capacitors, inverters, and control circuits. The rectifier section converts the incoming single-phase AC power into DC power, which is then filtered and smoothed using capacitors. The inverter section utilizes this DC power to generate three-phase AC power with the desired voltage and frequency. The control circuits govern the operation of the converter, regulating the output voltage and frequency to ensure compatibility with the connected three-phase. It is seen that single phase to three phase converter was designed in Simulink For 5kW load and 4 kW

Squirrel Cage Induction Motor was connected as load. Output voltage of Three Phase Inverter is 415V (AC), 50Hz .3-Phase. DC Link Voltage simulation result is 400V DC. It was proposed a single-phase to three-phase control alter system with parallel rectifier and course of action inverter to oversee with single-phase to three-phase asymmetry. Such converter ensures both diminish inside the input current taken care of by the rectifier circuit (due to the parallel affiliation) and diminishment of the surrender voltage arranged by each inverter (due to the course of action affiliation). In appear abhor toward of proposing a topology with highlights not be that as it may observed inside the specialized composing, this paper shown a comprehensive appear of the proposed converter, adjust method, and a common comparison with the conventional setup [1].

OBJECTIVE

The objective of this project is to provide a cost-effective solution for powering three- phase induction motors in industrial settings where only single-phase power is avail- able. The report outlines the design considerations, system architecture, simulation and experimental results, as well as the challenges encountered during the develop- ment process. The final design demonstrates the feasibility and effectiveness of the converter in efficiently driving three-phase induction motors using single-phase power sources.

LITERATURE REVIEW

2.1 Power Electronics Switching Devices

The following are the switches used in power applications. All of these power switches have varying voltage and current carrying capacities. As a result, the selection of these switches varies per application.
1. Power Diodes (Uncontrollable)
2. Thyristors (Controllable)
3. Power Transistors, BJT, MOSFET, GTO, IGBT having controlled turn on and off characteristic
4. BJT, MOSFET, IGBT need continuous gate signal

5. SCR, GTO needs pulse at gate
6. SCR, GTO withstanding voltage capability is Bipolar
7. BJT, MOSFET, GTO, IGBT withstanding voltage capability is Unipolar
8. TRIAC having Bidirectional current capability
9. SCR, GTO, BJT, MOSFET, IGBT having Unidirectional current capability

2.2 Converters

A converter is a device or circuit that converts one form of electrical energy into another form. It is commonly used to transform voltage levels, frequency, or waveform shape to match the requirements of a particular application or device.

2.2.1 Types of Converters

There are various types of converters used in electrical and electronics systems, each serving a specific purpose. Some common types of converters include:
1. Controlled Rectifier (AC to DC)
2. DC Chopper (DC to DC)
3. AC voltage regulator (AC to AC)
4. Inverter (DC to AC)
5. Static Switches
6. Rotatory base Converters
7. Transformer based Converters

2.2.2 Single Phase to Three Phase Converters

A single stage to three stage converter could be a machine that can create three stage control supply from an existing single-phase source stage converter may be a gadget that changes over electric control given as stage to different stages or bad habit versa [1]. The majority of stage converters are utilized to create three-phase electric control from a single-phase source [2].

2.2.3 Applications of Single Phase to Three Phase Converters

1. Small switching power supply for computers to big electric utility applications for bulk power transportation [3].
2. Micro-grid systems and huge industrial machinery are examples of high voltage sensitive loads/systems [4].

3.	This converter can power a three-phase induction motor, which is significantly more efficient than a single-phase motor(A three-phase 5hp Induction motor) [5].

4.	Conversion to Three-Phase Power The three-phase induction motor is turned on. They are perfect for future workshops, small industries, and major structures [5].

5.	Residential homes, Small entrepreneur workshops [6].

6.	Larger current-consuming electrical equipment, such as air conditioners, heat- ers, motors, pumps, farming equipment, and heavy machinery, need a three- phase power supply [6].

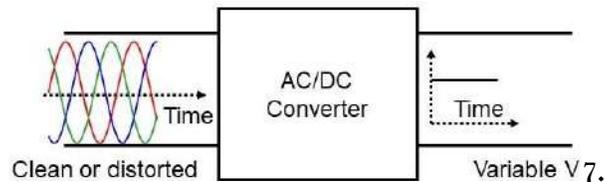The motor coupled to the converter has a rating of 2.2 KW / 3 HP, 415 V, 4.6

Figure 2.1: AC-DC Converter

A, and 50 Hz. The other load motor's specifications are 0.75 KW / 1 HP, 415 V, 1.88 A, and 50 Hz. [6].

## 2.2.4	AC to DC Converter

An AC to DC converter, specifically a controlled rectifier, is a power electronic circuit that converts alternating current (AC) input voltage into direct current (DC) output voltage. It consists of semiconductor devices such as diodes,

thyristors (such as silicon- controlled rectifiers or SCRs), or other controlled switches. The primary function of a controlled rectifier is to control the flow of current in a desired manner from the AC source to the DC load. By adjusting the switching times or angles of the controlled rectifier devices, the output voltage and current waveform can be modified [7]. The AC to DC converter is shown in Fig. 2.1.
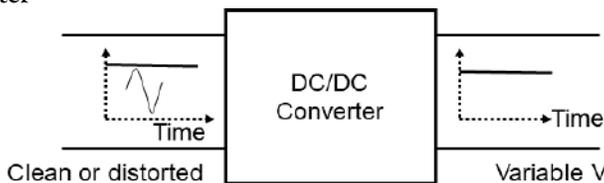
## 2.2.5	DC to DC Converter

Figure 2.2: DC-DC Converter

These converters may convert a constant DC input voltage to a variable DC voltage and vice versa. The duty cycle is used to manage the DC output voltage. The converter is shown in the Fig. 2.2.

## 2.2.6	AC to AC Converter

These converters may convert a set alternating current input voltage to a variable alternating current output voltage. The output voltage is regulated by altering the TRIAC's firing angle. These converters are referred to as AC voltage regulators [7]. A simple AC to AC Converter is shown in Fig. 2.3.
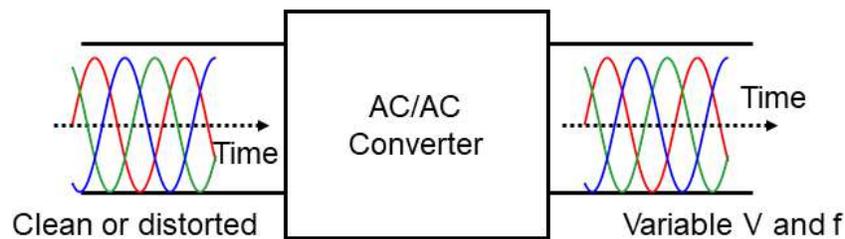
Figure 2.3: AC-AC Converter

Methodology

Implementation of Single Phase to Three Phase Converter

All the theory that we have covered in previous chapter is put into practise in this chapter.This chapter acts as a thorough instruction manual for turning the conceptual model into a working system. The focus shifts in this stage from impersonal ideas to the practical application of those ideas.

Clear explanations of the tools, technologies, and platforms used in the implement- ation process will be provided. Additionally, All algorithms created for the project and methodology that have been used will be thoroughly explained. This chapter aims to present a clear view of how the theoretical underpinnings are converted into a practical, workable solution.

To implement the single phase to three phase converter first we have to decide the converter topology. There are different topologies through which we can implement our project but we have to look for the most efficient method which gives the optimal outputs and results. Also we have to choose the components accordingly to the load for which we are designing the converter. The different topologies which can be used for the implementation are as follows:

i.   Voltage Source Inverter (VSI) with Phase Shifting Transformer
ii.   Cycloconverter
iii.   Matrix Converter
iv.   Static Frequency Converter
v.   Rotary Converter

Optimized Methodology

We have opted Space Vector Modulation technique for the implementation of single phase to three phase converter. There are different techniques which can be used but we are using Space Vector Pulse Width Modulation(SPWM) because of the following reasons:

i.   It is most widely used technique in the field of Power electronics.

ii.   As we are using VSI so it is most suitable technique in the VSI methodology.

iii.   SPWM has better voltage utilization in comparison with Sinusoidal Pulse Width Modulation.

iv.   It provides reduced Harmonic Distortion in the final output waveform of voltage in comparison with sinusoidal PWM. The vector voltages generated are con- trolled more accurately and has less distortion on the output waveform.

v.   Because of improved voltage utilization and reduced harmonic distortion SPWM gives higher overall efficiency. It has less energy waste and do not produce unwanted harmonic components which results in improved energy conversion and efficiency.

vi.   The magnitude and frequency of the output voltage can be freely controlled with SPWM. The normal yield voltage can be accurately observed by changing the term of each exchanging state, permitting for fine direction of engine speed, torque, or other yield highlights.

vii. It reduces the acoustic noise in the motor due to smoother voltage waveforms.

viii. As we are converting single phase to three phase so the SVPWM is more suited for the three phase supply and make it ideal for controlling three phase output voltage.

Block Diagram of Proposed Project

In the Fig. 3.1 we have proposed a block diagram of the circuit. In the start we will deliver single phase AC input supply of 220V to the converter. After that it will go in the rectifier bridge which will convert the AC supply into pulsating DC supply, then it will go to the input filter which will smoothens the waveform and pass the supply to the Inverter. The inverter will change the pulsating dc into three phase 440V AC supply. A micro controller(Arduino,FPGA) will be used to drive the inverter. The microcontroller will be powered by a power supply. After the conversion of single phase supply into three phase the output will be filtered again to get the smooth waveform. After that the converter will be attached to the three phase load.
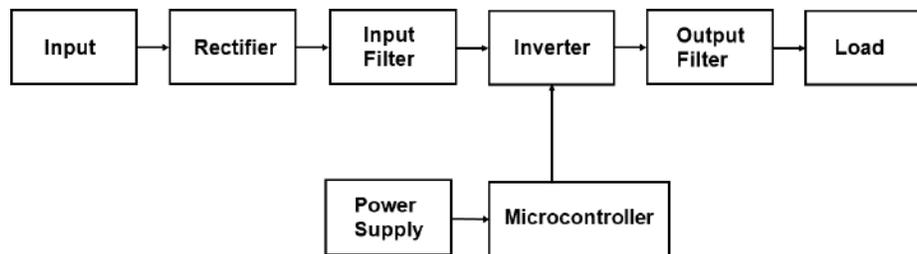

Figure 3.1: Block Diagram of proposed Project

Implementation of Space Vector Modulation

For the implementation of space vector modulation first we have to understand the basics of space vector modulation. It is basically based on the concept of voltage vec- tors.The voltage vectors can be used to get the desired output voltage approximately. There are two types inverter i:e Two-level inverter and three level inverter. There are six possible voltage vectors in Two level inverter and on the other hand there are eight possible voltage vectors in Three level inverter. As we are implementing on the Two level inverter so we will have six possible vector voltages. After the basics we have to determine the voltages, Reference voltages are the outputs that we wanted as a result output. It is represented in the form of axes such as two axes and three axes along with the components. After implementing the simulation on MATLAB we have generated the HDL code from MATLAB simulation and then converted all MATLAB files into Xilinx ISE for FPGA.

3.1.1 SVM Matlab Simulation

In Fig. 3.1 we have shown the Matlab implementation of space vector modulation. Firstly, we have converted the three phase voltage waveform into d-q plane using Clark's transformation.

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{3.1}$$

i. **Getting Reference Vector Vref and Calculating angle of Vref** After the transformation we have calculated the reference voltage and angle using formulas shown in (3.2) and (3.3) respectively.

$$V_{ref} = \sqrt{(V_d^2 + V_q^2)} \tag{3.2}$$

$$\alpha = \tan^{-1} \frac{V_q}{V_d} \tag{3.3}$$

ii. **Calculating Sector of Vref** When reference voltage is known the sector in which reference vector is situated can easily be determined . So, after the reference vector we have calculated the sector. As, there are six switches and six active vectors and two null vectors. Therefore, there would be total six sectors.

iii. **Calculating necessary Duty cycles of all switches** After calculating the sectors we have determined the necessary duty cycles of all switches correspond- ing each sector.

$$T_1 = \frac{\sqrt{3} \cdot T_z \cdot V_{ref}}{V_{dc}} \cdot \left[\sin \frac{n\pi}{3} \cos(\alpha) - \cos \frac{n\pi}{3} \sin(\alpha) \right] \tag{3.4}$$

$$T_2 = \frac{\sqrt{3} \cdot T_z \cdot V_{ref}}{V_{dc}} \cdot \sin \left[\alpha - \frac{n-1}{3} \pi \right] \tag{3.5}$$

$$T_o = T_z - T_1 - T_2 \tag{3.6}$$

$$T_z = \frac{1}{f_z} \tag{3.7}$$

where fz is fundamental frequency which is 50 Hz.

iv.   **Modulating with triangular wave** After generating necessary duty cycles modulated with carrier triangular wave of 5000Hz to get the switching sequence for all six switches shown in Fig. 4.1 in Chapter 4
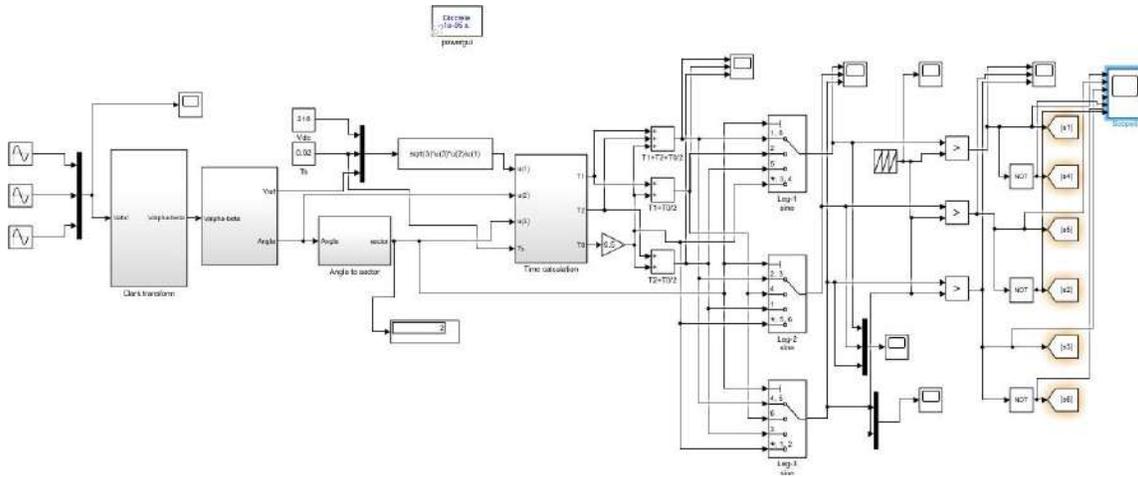

Figure 3.1: SVM Simulation

3.2   Implementation of Rectifier
3.2.1   Software Implementation
We are using three leg two level inverter comprise of six switches. As we are using in-direct matrix converter technique. We'll convert single phase Ac supply into pulsating DC with the help of rectifier. As we can see in Fig. 3.1 there are four diodes attached in the rectifier circuit .It is basically full bridge rectifier circuit diode works only in forward direction. This module will convert the AC waveform into pulsating DC and at the end the oscilloscope is attached to observe the output waveform of the circuit. The PCB layout on proteus is shown in Fig. 3.2
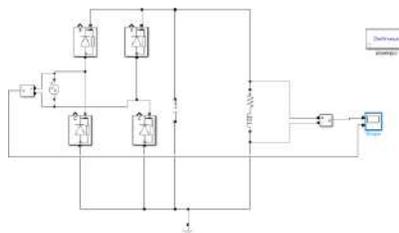

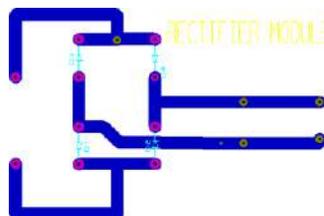**Figure 3.1: Rectifier Circuit on MATLAB**

Figure 3.2: PCB routing of Rectifier circuit

3.2.2 Hardware Implementation

In the hardware Implementation of the rectifier block we first made the circuit PCB layout on the software (Proteus) . After that we have printed it on the PCB board. After that we made connection according to the circuit. The rectifier patched circuit is shown in the Fig. 3.3.

Figure 3.3: Rectifier Module on hardware

3.3 Implementation of Inverter

3.3.1 Software Implementation

After rectification there exist our inverter block. The inverter is there to convert the dc supply coming from the rectifier block into 3 phase ac supply. The supply at the start is of single phase and it will be converted into three phase. The inverter consists of six IGBTS. It is basically used for switching the circuit. The inverter is driven by a microcontroller. We are using two microcontrollers one is Arduino and the other is FPGA Spartan 6.The inverter circuit is shown in Fig. 3.1.The voltage will also be converted into 440 three phase AC from 220 single phase AC. The circuit layout have been implemented on the Proteus software. The Layout is shown in Fig. 3.2
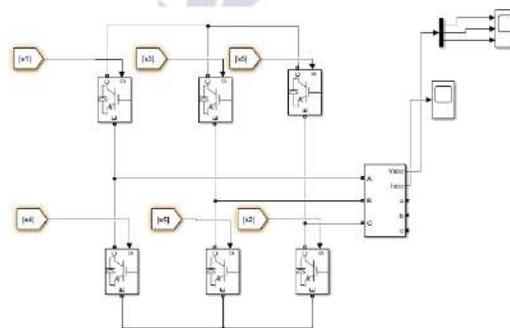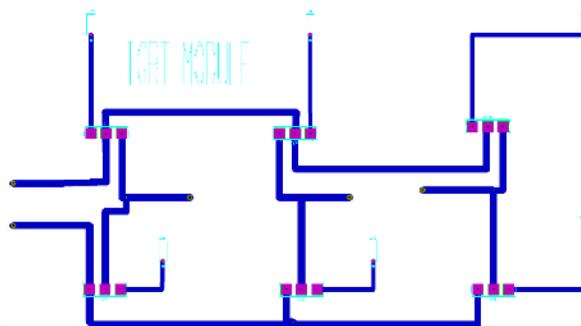

Figure 3.1: Inverter Circuit on MATLAB

Figure 3.2: PCB routing of Inverter circuit

Hardware Implementation

The layout of inverter block shows that there are six igbts that have been used for switching. After PCB layout the inverter block is printed on the PCB as shown in Fig. 3.3. After that it is patched accordingly to its components. The hardware circuit is shown below in Fig. 3.4. In Fig. 3.4 the fuse is attacted before the circuit so that if there is any surge it do not harm or burn the circuit but the gets burned. The fuse is used as a protective measure in this case.
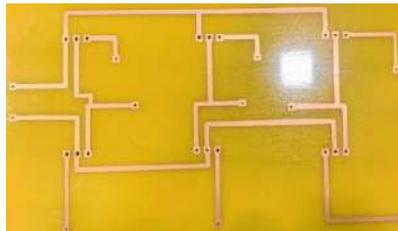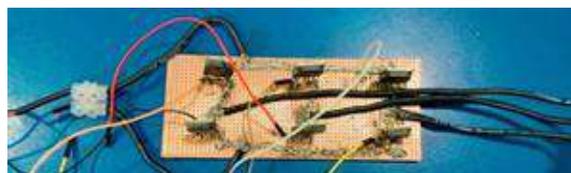

Figure 3.3: PCB layout of Inverter circuit

Figure 3.4: Inverter Module Patched Circuit

Simulation on PSIM

Power electronics-specific simulation platform PSIM is a specialised tool. With a spe- cialised library of parts and models tailored for converters, inverters, motor drives, and associated devices, it excels in designing, simulating, and analysing power electronic circuits and systems. PSIM's graphical user interface, in contrast to MATLAB's, is naturally created for the unique requirements of power electronics simulations, creating a setting favourable to effective circuit design and analysis. Due to these advantages over MATLAB, We have also implemented our proposed project circuit on PSIM which is shown in Fig. 3.1.
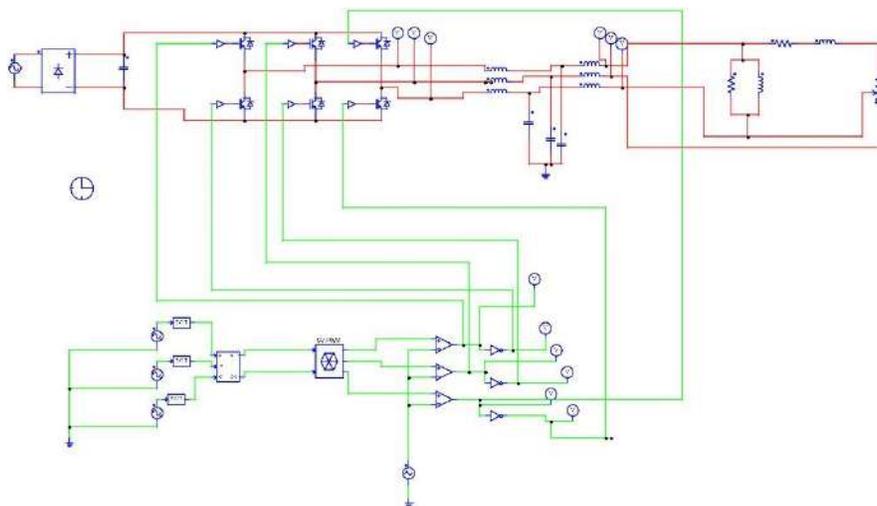

Figure 3.1: Sinlgle Phase to Three Phase Converter on PSIM

Conclusion

The compelling execution of the converter system underscores the noteworthiness
of a all enveloping and multi-platform approach in complex wanders. The combination of FPGA-based real-time dealing with, Arduino UNO's cost-effective adaptability, MATLAB's algorithmic refinement capabilities, and PSIM's specialized reenactment environment wrapped up in a solid and flexible converter system adjusted for a wide run of applications, from renewable imperativeness integration to mechanical control supply.

5.1 Recommendations

We can further move it to GAN transistor. As, It has better switching speed and less power losses as compared to IGBT and MOSFETs. Also, It is also reliable under high temperatures. Also, We can further work on FPGA for getting efficient output dealing with real time. As working on FPGA is a complex task and need better understanding of the Digital System Design. We can further move our project to the advancement and make it more efficient.

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