High Speed Voltage Switching Converter from Single Phase to Three Phase: A Design and Implementation Process

By Abdul Rehman & Muhammad Shakeel Faridi

University of South Asia Lahore, Pakistan

Abstract - A single phase to three phase converter topology for domestic use and for small industries is presented in this project. Phase converter, included in this project, is a device that supplies three phase power from a single phase source to power inductive, resistive and capacitive loads with distinct advantages over any existing converter device. Three phase converters are finding increased applications in industrial environment with greater demand for high voltage, high power processing techniques with improved efficiency. The essential advantage is the improvement in the improvement in the output voltage signal quality using devices of low voltage rating with lesser switching frequency, thereby increasing the overall efficiency of the system. This converter is applied to drive the motor.

GJRE-F Classification : *FOR Code: 290901*

HIGHSPEEDVOLTAGESWITCHINGCONVERTERFROMSINGLEPHASETOTHREEPHASEADESIGNANDIMPLEMENTATIONPROCESS

Strictly as per the compliance and regulations of :

High Speed Voltage Switching Converter from Single Phase to Three Phase: A Design and Implementation Process

Abdul Rehman [α] & Muhammad Shakeel Faridi [σ]

Abstract - A single phase to three phase converter topology for domestic use and for small industries is presented in this project. Phase converter, included in this project, is a device that supplies three phase power from a single phase source to power inductive, resistive and capacitive loads with distinct advantages over any existing converter device. Three phase converters are finding increased applications in industrial environment with greater demand for high voltage, high power processing techniques with improved efficiency. The essential advantage is the improvement in the improvement in the output voltage signal quality using devices of low voltage rating with lesser switching frequency, thereby increasing the overall efficiency of the system. This converter is applied to drive the motor.

I. Introduction

This type of converter is required in those areas where the three phase electric power is not present. Most of these areas include domestic areas because most of the domestic use appliances are powered by single phase electric power. One of the reasons of not giving three phase electric power to the domestic customers is its high cost of connection installation. But still, if any customer wants to run a three phase appliance on a single phase electric power, the single phase to three phase converter can be used. The reason of using three phase power is that three phase appliances are available in high ratings as compared to appliances available in single phase. For example [1,2,3]

1) In case of loads, three phase motors are more compact and less costly than a single phase motor of same voltage and rating. Moreover single phase AC motors above 10 HP (7.5 kW) are rarely available. Three phase motors have self-starting torque because they can produce rotating magnetic field whereas single phase motors requires a special starting winding.
2) From generation point of view, the three phase AC generators are smaller in size as compared to single phase generators. The kVA rating of three phase generator is 1.5 times greater than that of single phase AC generators.

In single phase AC electric power system, the power falls to zero three times during one complete cycle i.e. at the interval of $0, \pi$ (180°) and 2π (360°) as shown in fig. 1 below. Whereas in three phase electric system the power never falls to zero and a continuous same power is delivered to the load at all time as shown in fig. 2 below.
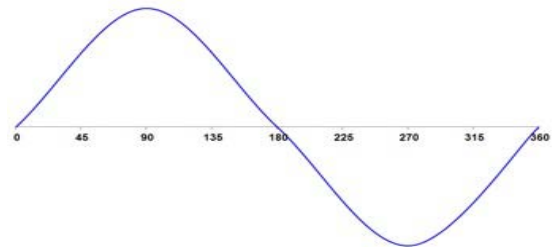

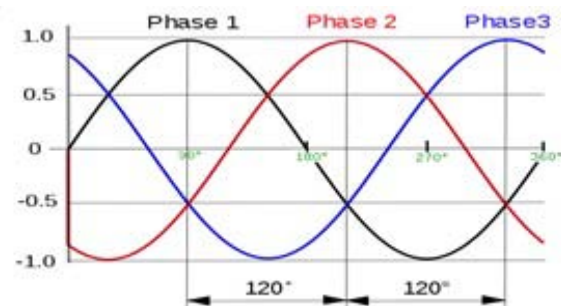*Fig. 1 :* One complete cycle of single phase voltage

Fig. 2 : One complete cycle of three phase voltage

Most motors and equipment's need this continuous power to run properly.

The above discussion emphasis on a strong need of efficient and cost effective static single phase to three phase voltage converter. Previous work done in this regard has created a wide variety of possible circuits that could be used for single phase to three phase voltage conversion but these works have some disadvantages as well for example in [4] thyristors are used in combination with L-C components. The disadvantage of this conversion technique is that the L-C values must be matched with the load impedances. Furthermore in [5] the technique proposed has a disadvantage that only two semiconductor devices are used for the conversion purpose therefore the conversion would not be that much accurate i.e. phase difference between each phase cannot be exactly 120°.

Author α : Department of Electrical Engineering, University of South Asia Lahore, Pakistan. E-mail : engr.armughal@gmail.com
Author σ : Department of Computer Science, University of Agriculture, Faisalabad, Pakistan. E-mail : shakeelfaridi@gmail.com

In response to above two mentioned techniques the technique mentioned in this paper will nullify the above mentioned disadvantages.

II. PROPOSED THREE PHASE CONVERTER

The converter proposed in this project converts the single phase electric power to three phase electric power in two steps:

1) POWER CIRCUIT: Conversion of single phase A.C voltage to D.C voltage i.e. from 220V, 50Hz single phase A.C supply to 400V D.C supply.
2) CONTROL CIRCUIT: Conversion of D.C voltage to three phase A.C voltage i.e. from D.C 400V to 380V, 50Hz three phase A.C supply by using PIC microcontroller.

Both of these steps are described in detail below

a) Power Circuit

The power circuit is that part of the converter in which rectification is done i.e. single phase A.C voltage 220V, 50Hz is converted to D.C voltage 400V. The reason of converting 220V A.C to 400V D.C is to get the three phase voltage of amplitude of 400V which is then switched with the help of hex-bridge and microcontroller in such a way to get a three phase voltage with phase difference of 120°. This rectification can be done by using a full bride rectifier which can be made either by using diodes or by using an I.C whose output voltages are equal to 400V. The full bridge rectifier circuit is shown in fig. 3.
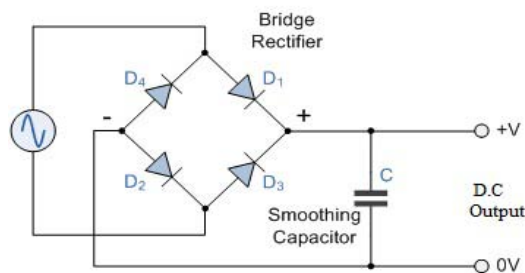

Fig. 3 : Rectifier

The smoothing capacitor is used to remove the ripples so that we can get a smooth D.C voltage. The value of this capacitor can be found out by Eq. 1

$$C = \frac{2\,(P_o)(T_h)}{(V_1^2 - V_2^2)\,(\eta)} \tag{1}$$

Where
C = Capacity of filtering capacitor
P_o = Output power of the rectifier
T_h = Hold-up time
V_1 = Input D.C voltage i.e.
    Input A.C voltage (rms) x $\sqrt{2}$
V_2 = Input D.C voltage which can hold output voltage
η = Efficiency

These 400V D.C produced will be given to the hex-bridge. The hex-bridge is the heart of three phase inverter. It takes a D.C voltage and uses six switches arranged in three legs for switching purpose. The hex-bridge used is shown in fig. 4
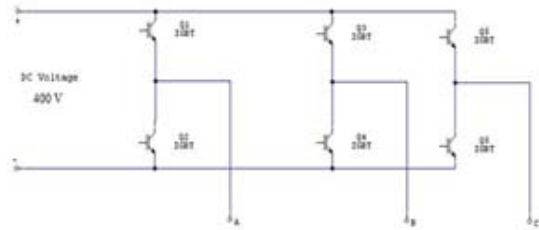

Fig. 4 : Hex-bridge

In fig. 4 Q1-Q6 are six switching devices and A, B, C are the three phase output terminals that will be connected to the motor terminals. There are two types of switching devices that could be used IGBT or MOSFET. In this project IGBTs are used instead of MOSFETs [6,7]. This selection is made on the conditions for which these two devices are to be used. Mostly the decision is made keeping two factors in mind
1) Switching frequency
2) Voltage bearing capability of device

The IGBT is chosen for voltages above 1000V, while the MOSFET is certainly chosen for voltages below 250V. Between 250 to 1000V, some technical papers prefer MOSFETs and some IGBTs this is shown graphically in fig. 5
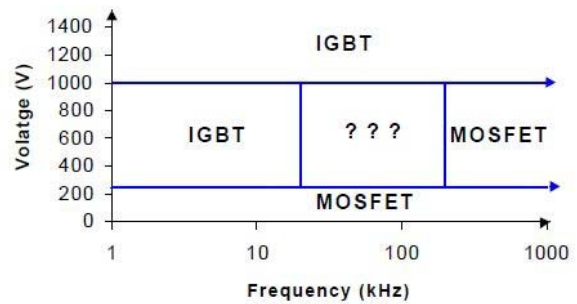

Fig. 5 : Regions where IGBTs and MOSFETs are preferred

As working voltage for the hex-bridge is 400V D.C and switching frequency is between 20-25 kHz, so IGBTs are used.

b) Control Circuit

The control circuit is that part of the converter in which electrical components are used to control the switching of the six IGBTs to generate three phase 380V, 50Hz voltage with exact phase shift of 120°. To see the control circuit at a glance, block diagram of control circuit is shown in fig. 6
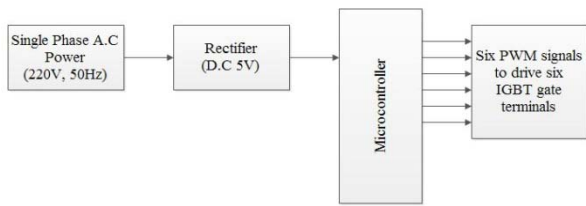
Fig. 6 : Block diagram of control circuit

As mentioned earlier that a microcontroller is used to control the switching of the six IGBTs connected in hex-bridge. Any one output port of the PIC microcontroller can be used for output signals. Total six microcontroller pins will be used for output purpose. These pins will then give signal to each gate terminals of six IGBTs connected in hex-bridge while travelling through bridge driving IC. The method used to generate control signals through microcontroller is pulse width modulation (PWM) as shown in fig. 7.
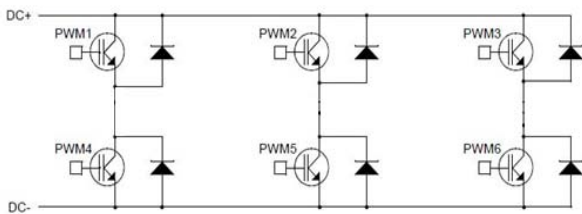

Fig. 7 : PWM connected with hex-bridge

The reason of using PWM technique is that a switching wave of constant magnitude and frequency is required. The PWM signals are generated in such a way that three IGBTs will conduct at a time i.e. either one upper or two lower or two upper and one lower. Upper and lower IGBTs of the same limb are not made conductive at the same time otherwise the D.C bus supply would become short circuited. There is a time delay given between switching the upper IGBT ON and lower IGBT OFF and vice versa. This time delay is called dead time. To control the switching of the upper three IGBTs three PWMs are required. For switching the lower three IGBTs the inverted PWM signals of the corresponding upper IGBTs are used. The three PWMs used for the three phase sine wave generation are shown in fig. 8
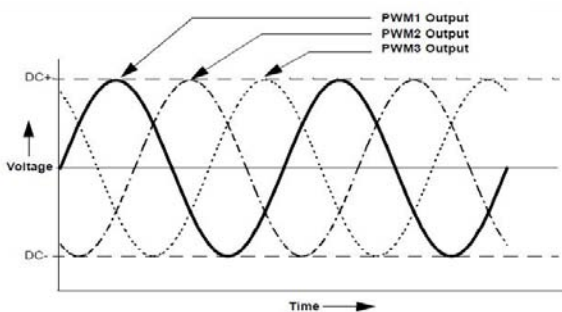

Fig. 8 : Generation of three phase sine wave using PWM

In the used PWM technique the duty cycle of the square wave will determine the phase voltages. To control this duty cycle a sine table is created in the program memory which is then transferred to the data memory upon initialization. A phase shift of 120° is maintained between phases by using three offset pointers to the sine table. So a voltage of each phase will be calculated as

For phase 1: Sine table value + offset1
For phase 2: Sine table value + offset2
For phase 3: Sine table value + offset3

Above explained generation of three phases with phase shift of 120° is shown graphically in fig. 9
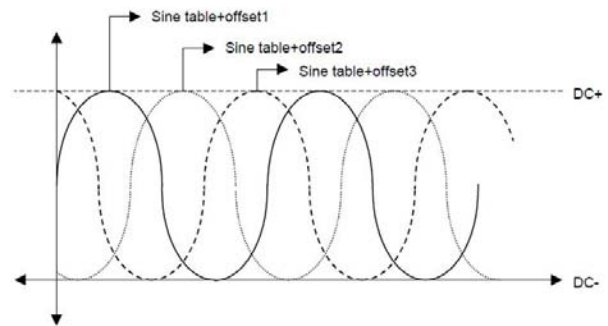

Fig. 9 : Generation of three phase waveform from the sine table

To control the values of the sine table + offset, three timers are used. These timers are Timer0, Timer1 and Timer2. The functions performed by each of these timers is given in table 1

Table 1 : Timers and their functions

Timers	Function
Timer0	Interrupt timer after which duty cycle changes
Timer1	Interrupt timer for the positive peak of A.C wave
Timer2	Interrupt timer for the negative peak of A.C wave

Another purpose of using these timer registers is that as the program for the microcontroller is written in software and then burned in hardware i.e. in microcontroller, so the hardware and software PWMs will be leading or lagging from one another. To control this problem and to get same PWM signals. The detailed working of the three timers from this point of view is discussed below.

1. Timer2

It is an 8-bit timer used to control the timing of hardware PWMs. The main processor is interrupted when the Timer2 value matches the PR2 value.

2. Timer1

Timer1 is used for setting the duty cycle of the software PWM. In Timer2 to PR2 match interrupt, the port pin designated for PWM3 is set to high. Also Timer1 is loaded with the value which corresponds to PWM3 duty cycle. In Timer1 overflow interrupt, the port pin for PWM3 is cleaned and as a result the hardware and software PWMs will have the same frequency.

3. Timer0

After every Timer0 overflow interrupt, the value pointed by the offset register on the sine table is read. The value is loaded to the PWM duty cycle registers and the offset registers are updated for next access.

After the three PWM signals are generated they are connected to the driver chip that will generate dead time of 200 ns between upper and lower switches of all phases.

III. Simulation & Experimental Results

If we simulate the above discussed method for the generation of three phase voltage waveform from single phase voltage then the waveforms obtained from MATLAB software when the scope is connected across the PWM generating pins of microcontroller are as shown in fig. 10
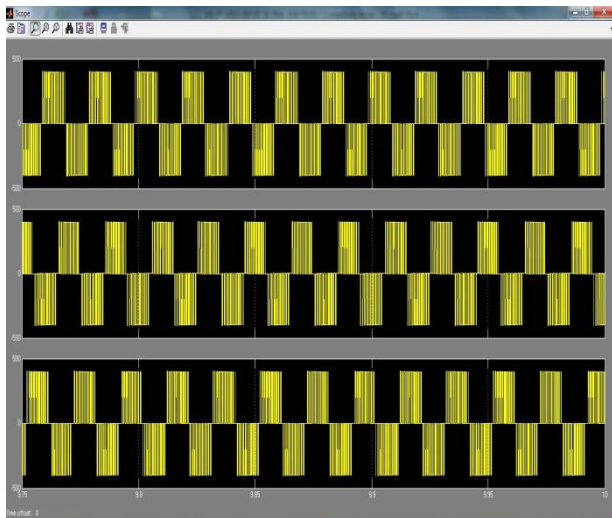

Fig. 10 : Waveforms of all three PWM

The waveforms shown in fig. 10 are switching waveforms that's why they are in the form of pulse these pulses can be created to the A.C waveforms

IV. Conclusions

The single phase to three phase voltage converter presented in this research by which three phase motor is driven is made up of six IGBTs and PWM technique is used for its switching purpose. The advantages of using this converter are as follows:

1) The IGBT has the output switching and conduction characteristic of BJT but is voltage controlled like MOSFET. In general it means that it has the advantage of high current handling capability with the ease of control of MOSFET.

2) The PWM technique used for the switching of IGBTs has the advantage that power loss in the switching device is very low because when the switch is OFF there is practically no current and when the switch in ON there is almost no voltage drop across the switch.

References Références Referencias

1. Jeff Keljik, Electricity 3: Power Generation & Delivery, 9th edition.
2. Irving L. Kosow, Electric Machinery & Transformers, 2nd edition.
3. Scott Landis, The Work Shop Book.
4. S. B. Dewan, M. Showleh, "Steady State Analysis of Static Single-Phase to Three-Phase Converters", IEEE IAS Conf. 1981, pp. 910-915
5. Prasad N. Enjeti, Ashek Rahman, and Ranjit Jakkli, "Economic Single-Phase to Three-Phase Converter Topologies for Fixed and Variable Frequency Output", IEEE Transactions on Power Electronics, Vol. 8, No. 3, July 1993.
6. Thomas L. Floyd, Electronic Devices (conventional current version), 7th edition.
7. http://www.irf.com/technical-info/whitepaper/choosewisely.pdf

36