Software Controlled Multimode Single Phase Inverter

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Abstract

As the prices of the power electronic devices are getting cheaper, inverters are widely used in various applications like induction motor controllers, in relay testing equipments, uninterrupted power supplies (UPS) etc. especially in applications like in induction motor controllers and in relay testing equipments not only the frequency, but the magnitude of the voltage need to be varied. For these kinds of applications pulse width modulated (PWM) inverters are more suitable. In PWM inverters to change the magnitude of the voltage only the value of the duty factor of the switching signals need to be varied.

Popularity of these PWM inverters has been supported by the availability of few types of them namely as sinusoidal, Harmonic elimination, Square wave, Regular sampled, Distortion minimization etc.

PWM inverters available in the market have only one mode of operation and they are fairly expensive too. If someone is going to build a multimode inverter by using discrete components it would be very expensive and the size of the inverter circuit would be very large. The aim of this project is to build a multimode inverter in which the switching of the power switches is done by software. It will reduce the hardware requirements considerably. It is expected to implement this inverter to supply variable voltages and frequencies

1.0 INTRODUCTION

An Inverter can be considered as equipment, which converts a Direct Voltage into an Alternating Voltage with a desired frequency.

Most domestic inverters use a low voltage DC supply and after inversion it is stepped up to 230V or 110V using a transformer. But in industrial application like in induction motor controllers the mains AC supply is converted to a DC voltage and then inverted it back again to an AC voltage with a desired magnitude and frequency. In our project also we use a 230V DC power supply for inversion. The user can select the mode of inversion, the magnitude and the frequency of the output voltage using a software interface.

2.0 BASIC OPERATION

Basic block diagram consists of the user interface, Switching pattern generation unit, Driver circuit, Power supply and Power circuit, and the output unit.

The user can select the mode of operation out of square wave, regular sample and Harmonic elimination. In square wave and regular sample modes the user can input the output voltages and the frequency.
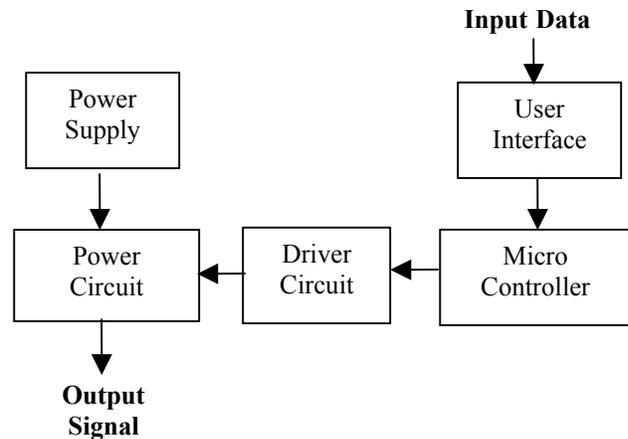

Figure 1 – Basic Block Diagram of the s/w controlled Inverter

In harmonic elimination mode the user can the harmonics to be eliminated from the output while setting the magnitude of the fundamental voltage. In order to keep the convenience of the program, selection of harmonics to be eliminated and the voltage magnitudes were restricted to limited number of combinations. According to the combination input by the user, appropriate switching time is calculated within the software program. Mathematical model that was used to calculate these switching times can be expressed as follows.

3.0 MAIN COMPONENTS

The heart of the hardware is the power circuit, which consist of a H-bridge. The power switches are driven by a driver circuit, which will switch according to the switching signals generated by the switching signal generating unit.
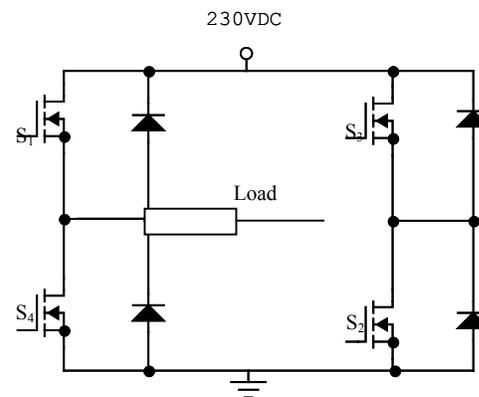
3.1 Power Circuit

Figure 2 - H-Bridge

The power circuit is a H-bridge consisting four N-channel Enhancement MOSFETs. The MOSFETs used here are International Rectifies IRF740, which can hold a maximum drain to source voltage of 400V and can pass a maximum current of 10A. The MOSFET can switch with a maximum switching frequency of about 16MHz. Although the manufacturer integrated an inverse parallel diode to the MOSFETs external inverse parallel diodes are used for added safety. Because of the on-state resistance of the MOSFET there will be a conduction loss. The on-resistance isn't the only cause of power dissipation in the MOSFET. Another source occurs when the MOSFET is switching between states. For a short period of time, the MOSFET is half on and half off. The longer that the MOSFET is in the state where it is neither on nor off, the more power it will dissipate. Because of this power dissipation to avoid the MOSFETs being damaged by heat, heat sinks are used.

3.2 Driver Circuit

To turn a power MOSFET on, the gate terminal must be set to a voltage at least 5 volts greater than the source terminal.This is comfortably above the $V_{gs(th)}$ parameter.

One feature of power MOSFETs is that they have a large stray capacitance between the gate and the other terminals. The effect of this is that when the pulse to the gate terminal arrives, it must first charge this capacitance up before the gate voltage can reach the 10 volts required. The gate terminal then effectively does take current. Therefore the circuit that drives the gate terminal should be capable of supplying a reasonable current so the stray capacitance can be charged up as quickly as possible. The best way to do this is to use a dedicated MOSFET driver chip.

Since the operating voltage of the H-bridge is 230V when the high side MOSFETs are conducting the voltage at the source would be almost 230V.Therefore to keep the high side MOSFETs in the saturation region of conduction gate must be at least at 235V. If the MOSFET driver chips to be used it should be capable of providing this high voltage at the gate. Because of the expensiveness of the high voltage MOSFET driver chips, they were not used here.A method, which use three separate power supplies is used in this project.

Two separate power supplies power driver circuit1 and driver circuit2, while driver circuit3 and driver circuit4 are powered by a common power supply.

The switching signal generated by the Micro controller (μC) is amplified by a buffer IC and the output from the buffer is fed to an opto isolator. The function of the opto isolator is to switch the external power supply given to the driver circuit appropriately in order to provide the required Gate to Source voltage of the MOSFET.
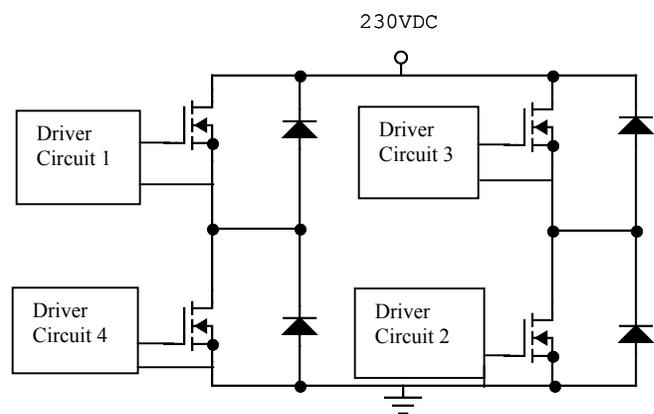

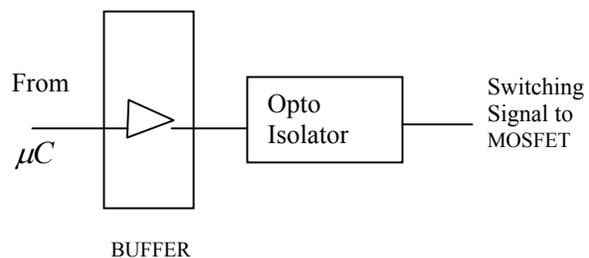*Figure3 - Schematic Diagram of the H-Bridge & Driver Circuits*

Figure4 - Block Diagram of the DriverCircuit

3.3 User Interface

Implementation of software control for the inverter brings few vital advantages for the user. One Important feature is that the hardware requirement is reduced to a great degree. Therefore, the cost is reduced. The software simulation can replace almost all the switching and control operations performed by hardware units. It is safe and offers the user more options for the controlling. On the other hand remote operation is possible with the option of connecting the software to a web server. Accessing hardware may not be possible in some cases therefore we believe that this option will be a good alternative for that. Another advantage is that for different modes of operation no hardware changes are required but only the switching pattern change, which is done by the software. Thus it is another way of reducing cost.

We used Visual Basic to design the software. According to the mode of output signal user has to input the relevant parameters. For example for the regular sampled mode the reference signal frequency has to be entered as a basic parameter. However there should be a freedom for the user to select the carrier signal frequency, carrier signal amplitude and thereby the modulation index etc. There are advanced options for the user to do so.
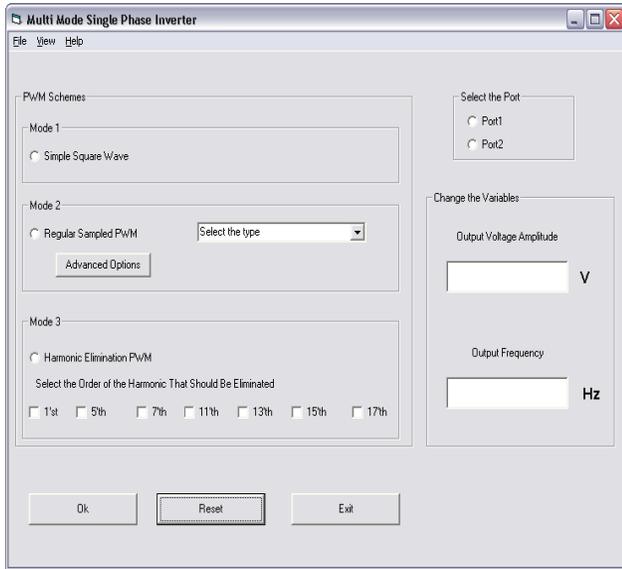
Since VB is not much control oriented there were barriers in transmitting the switching patterns to the driver circuit with that. It was impossible to keep correct delay times in switching using parallel port data transmission. Therefore our option was to introduce a micro controller between driver circuit and the user interface. Thereby the set of data for each selection is fed into the micro controller by serial transmission and thereby final switching pattern is generated by the micro controller.

3.4 Mathematical Models

Mathematical models used to calculate the delay times for each mode of operation are illustrated as follows.

3.4.1 Regular Sampled PWM

$\tau = [1 + m \sin(360^0 * k/P)]/ 2p*f_r$

Where   p = carrier ratio
               m = modulation index
               f_r = frequency of the output voltage
               k = sampling point

Values of τ and T_c at each sampling point are then stored in an array and transmitted to the micro controller.
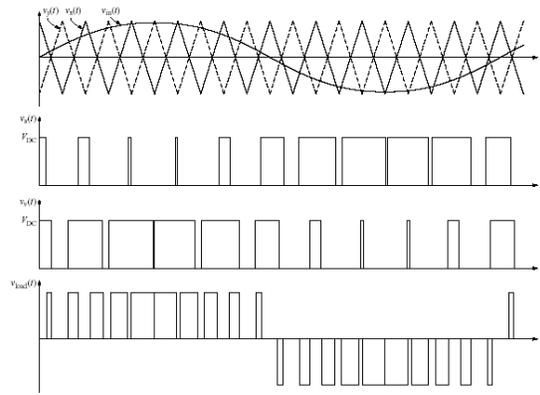
3.4.2 Harmonic elimination PWM

Only odd harmonics exist, Fourier Coefficients given by:

$$a_n = \frac{4}{n\pi}\left[\sum_{k=1}^{N}(-1)^{k+1}\cos(n\alpha_k)\right]$$

$$b_n = 0.$$

The non-linear equations to eliminate N-1 lower-order harmonics such as 3, 5, 7 etc. are in the form of

$$\begin{bmatrix} \cos \alpha_1 & -\cos \alpha_2 & (-1)^{N+1}\cos \alpha_N \\ \cos 3\alpha_1 & -\cos 3\alpha_2 & (-1)^{N+1}\cos 3\alpha_N \\ \vdots & \vdots & \vdots & \vdots \\ \cos(x_3)\alpha_1 & -\cos(x_3)\alpha_2 & (-1)^{N+1}\cos(x_3)\alpha_N \end{bmatrix} = \begin{bmatrix} \frac{\pi a_1}{4} \\ 0 \\ \cdot \end{bmatrix}$$

where

$$x_3 = 2N - 1.$$

Non-linear equations are solved using suitable numerical methods. We used the MathCAD 2000 professional software for this purpose. The values which were used in the database of the program has the following values.

					Volltage step		57.742	60.851	61.672	62.459	63.208	63.906	64.53
Angle	0	0.1	0.2	0.3	0.4	α7 0.5	79.846	79.009	0.8	76.969	75.906	74.796	73.61
α1	17.129	19.647	19.274	18.882	18.472	18.044	79.894	80.128	86.053	82.963	18.299	84.845	85.81
α2	17.129	20.33	20.635	20.911	21.151	21.35	21.498	21.578	21.565	21.398	20.778		
α3	38.228	39.34	38.648	37.922	37.161	36.36	35.524	34.66	33.624	32.492	30.878		
α4	38.228	40.625	41.213	41.757	42.25	42.677	43.019	43.237	43.265	42.938	41.51		
α5	57.742	59.119	58.205	57.254	56.26	55.21	54.086	52.857	51.462	49.758	47.056		

Table 5.1 Database for the Harmonic Elimination PWM Mode

3.5 Serial transmission of data to the micro controller

In a serial link the transmitter, send bits one at a time, in sequence. A link with just two devices may have a dedicated path for direction or it may have a single path shared by the both. One signal required by all serial links is a clock, or timing reference, to control the flow of data. The transmitter and receiver use a clock to decide when to send and read each bit. Two types of serial data formats are available namely as synchronous and asynchronous and they use clocks in different ways. We used asynchronous data format.

In asynchronous serial data transmission, the link doesn't include a clock line, because each end of the link provides its own clock. Each end must agree on the clock's frequency and all the clocks must match within a few percent. The programming required to send and receive data in asynchronous format is made simpler by the component UART. (Universal Asynchronous Receiver / Transmitter).

3.6 Microcontroller

In order to Generate the switching pattern according to the set of input data PIC 16F873 microcontroller was used. Some of the salient features of 16F873 can be summarized as follows.

- High-performance RISC CPU
- Only 35 single word instructions to learn
- All single cycle instructions except for program branches which are two cycle
- Operating speed: DC - 20 MHz clock input and DC - 200 ns instruction cycle
- Up to 8K x 14 words of FLASH Program Memory,
- Up to 368 x 8 bytes of Data Memory (RAM)
- Up to 256 x 8 bytes of EEPROM data memory
- Only single 5V source needed for programming
- Has 3 ports called A,B and C and each port can be set for input and output using pins individually or all at once.
- Timer0: 8-bit timer/counter with 8-bit prescaler
- Timer1: 16-bit timer/counter with prescaler can be incremented during sleep via external crystal/clock
- Timer2: 8-bit timer/counter with 8-bit period register, prescaler and postscaler
- Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI) with 9-bit address detection

4.0 CONCLUSION

With the implementation of the software controlled inverter it was possible for us to experience a vast amount of knowledge about programming, especially the difference in ordinary user friendly programming and control oriented programming, design aspects of power electronic circuits, complex mathematical calculations etc.
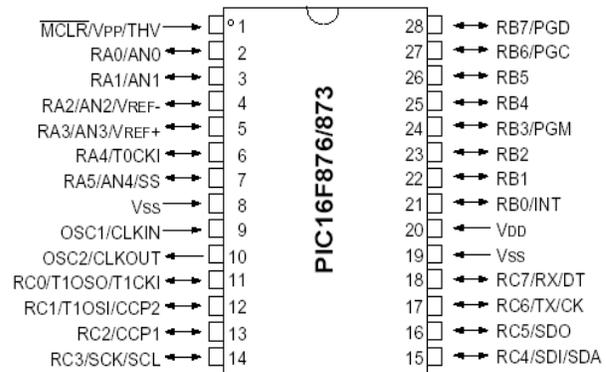

Figure 7 – Pin Diagram of 16F873

As described earlier this type of an inverter could perform in a wide and a cost effective manner to serve for applications like motor control.

Initially our purpose was to design this inverter to serve loads up to 24V DC. While continuation we had the idea that if this inverter circuit was designed to serve loads of about 230V DC that would be more useful. One main barrier faced in this project were that being unable to generate accurate switching patterns using the software. Therefore, the Analog to Digital Converter part had to be skipped from the block diagram as the micro controller performed accurate open loop accuracy of the output parameters. For the power circuit, transistors were tested first but it was given up due to the reason of not serving medium and high power applications. On the other hand, we could not go beyond Mosfets because of the cost considerations.

We have included the most important modes of PWM inverters like regular sampled PWM, harmonic elimination PWM. To increase the accuracy of the output methods like increasing the number of sampling points and thus p and m can be done. In harmonic elimination mode if the calculations can be done real-time by linking to a math software that would allow the user to select the exact reference frequency.

Further improvements that we see in this project are replacing Mosfets with IGBT's to serve more power, extending the program for other types of PWM like Current controlled PWM, Distortion minimization PWM etc., feedback to the program from the output for controlling and interfacing.

REFERENCE

Microchip 16 F 87x datasheet for 28/40-pin 8-Bit MOS FLASH Microcontrollers