Use of Advanced Unipolar SPWM Technique for Higher Efficiency High Power Applications

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***Abstract*—In high power applications like SONAR, PWM techniques are essentialto control high power as well as to reduce switching losses. The primary reason for preferring sinusoidal PWM is that our final need is a sinusoidal output. Hence, we use sinusoidal wave as reference wave. Sampling it with triangular wave of high frequency would ensure nearly sinusoidal wave on output side. The unipolar PWM which is one of the two commonly used types of SPWM is better suited for the applications mentioned. However, it faces problem of dead short circuit as two switches of same leg would be ON simultaneously. A modification under the name of advanced unipolar PWM technique is introduced and presented. The simulation and hardware implementation of same is also depicted using MATLAB while a microcontroller board (Arduino Uno, in this case) is used to implement the embedded code generation. The use of the microcontroller board further adds to the advantages when compared to the conventional method. The modified technique has been explained in the paper.**

***Keywords*—Unipolar SPWM, Dead band, Advanced Unipolar PWM, Sinusoidal Pulse Width modulation, Total harmonic distortion.**

I. INTRODUCTION

In a highly competitive world of constantly improving efficiencies and reducing costs, what may have once seemed as revolutionary would soon seem obsolete. As a result, the onus falls upon today's engineers to either come up with new technologies that can outmatch their current counterparts or build upon the current technology to improve their performance. Inverters, both single and three phase, have now become an indispensable part of our households as well as industries. Thus, any scheme that improves the output attained and specialises it according to specific applications will always be welcome. Advanced Unipolar SWPM, introduced in this paper is one such method.

II. NEED FOR PWM

A. History of PWM

Many applications require us to control the output voltage levels by supplying partial power from a fixed input power source. This was conventionally accomplished by using a rheostat in series to dissipate the excess power. This technique worked satisfactorily well for low power applications but would result in high losses for large systems. Thus, an efficient and cheaper method was required for switching that could better control and adjust the power levels.

Pulse-Width Modulation served as a solution. We could now control the width of the gate pulses of switches to control the output power as per our requirement.

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B. Introduction to PWM

PWM is basically adjusting the on and off periods of pulses of constant amplitude, in order to gain inverter output voltage control and to reduce its harmonic content. The main factors for PWM control are:

- Duty Cycle
- Frequency

Duty cycle is the ratio of the high (on) time of a pulse in a cycle to the total time period of that cycle. Frequency is the measure of how quickly the PWM completes one cycle. If the frequency and the duty cycle are high enough, the output appears as an analog signal.

In general, the longer the on period of a switch, the higher the power supplied to the load and vice versa. A plus point for PWM is that the power lost in switching is fairly low. When the switch is on, the voltage across it is ideally zero, while when it is off, the current flowing through it is negligible. Thus, the product of current and voltage, which amounts to the power loss, is almost equal to zero.

PWM signals are used in a variety of control applications. It is generally used for DC motors, but can be used to control valves, pumps, fans etc. as well as in communication circuits for encoding to convey information. The frequency and duty cycle of the PWM signals depend on the response and the desired performance of the application.

C. Advantages of PWM

The advantages of using the PWM technique are:

- Lower power dissipation,
- Relative ease of implementation and control
- The output voltage control can be obtained without any additional components

- Lower order harmonics can be eliminated or minimized along with its output voltage control.
- As higher order harmonics can be filtered easily, the filtering requirements are minimized.

The prime disadvantage of this method is that the switches used must have low turn-on and turn-off times and losses making them expensive. [1]

III. TYPES OF PWM

A. Broad classification

PWM signals are pulses of constant amplitude and varying widths. Various types of PWM can be used depending on the THD limits and the output voltage profile needed. Broadly, they are classified as:

- Single-pulse modulation,
- Multiple pulse modulation,
- Sinusoidal pulse width modulation (Carrier based Pulse Width Modulation Technique),
- Space vector pulse width modulation

Single pulse modulation contains only one pulse per half cycle and the width of the pulse can be used to control the output voltage. In multi-pulse modulation, multiple pulses are supplied per half cycle to reduce the harmonics in the input current and to get a smoother output voltage waveform. Space vector PWM is a relatively modern technique that uses a vector control for pulse modulation of three-phase inverters.[2]

B. Sinusoidal PWM

Sinusoidal PWM includes comparing the input sine wave (called the modulating wave) with a triangular wave (called the carrier wave) to obtain triggering pulses. The average of the pulses so obtained closely follows the input waveform because of which the harmonic content is fairly low. There two widely used techniques of SPWM, namely:

- Bipolar
- Unipolar

A bipolar SPWM technique uses a single triangular carrier wave and compares it with the desired sinusoidal. As the waveform switches between both the positive and negative V_{dc}(Where V_{dc} is the DC input given to the inverter.), this scheme is called bipolar modulation.

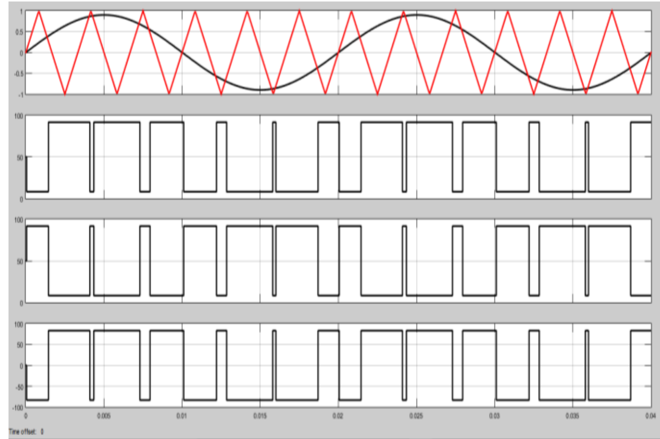

Fig 1 Bipolar SPWM Pulses

In figure 1, the first plot shows the modulating and carrier waves. The next two are the voltage waveforms between one load terminal and neutral. The final plot is the difference between the previous two, representing the actual voltage profile across the load.
The harmonics obtained are centred on the fundamental frequency (m_f) and their multiples. The harmonics lower than (m_f-2) are negligibly small. However, it faces a problem of high magnitude harmonics for amplitude modulation less than 0.8. [4] This problem can be solved using the unipolar scheme.
Unipolar SPWM uses a single carrier wave, a modulating wave and the inverse of the modulating wave to generate the PWM signals. Here, the pulses are in the same direction and hence the name, unipolar.

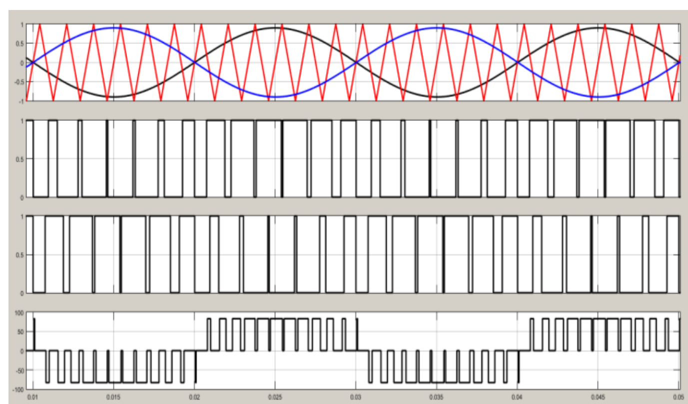

Fig. 2 Unipolar SPWM Pulses

In figure2, the first plot shows the waveforms to be compared. The second and third waveforms are the pulses generated by each arm (note that they are not identical as in bipolar). The last plot shows the output across the resistive load.
The harmonics in this case are centred on $2m_f$ and so the lowest dominant harmonics are of a higher order than those in

Carrier Frequency	Modulation frequency(m_f)	%THD(Unipolar)	%THD(bipolar)
150Hz	3	55.55%	203.10%
300Hz	6	63.63%	123.45%
600Hz	12	66.65%	123.55%
1200Hz	24	61.39%	112.76%
2400Hz	48	62.02%	124.31%

Table 1 Comparison of %THD of bipolar and unipolar schemes for Modulation index=0.9

bipolar. Hence, this technique has a better %THD and requires less bulky filters.

C. Problems with normal Unipolar

Even though the unipolar technique issuperior to various other PWM techniques, it suffers one major drawback. As can be seen from the waveforms of unipolar SPWM, there may be instances when two switches of the same leg may be ON at the same time. This will result in a direct short circuit across the source leading to potentially catastrophic results. In order to avoid this, we may need to provide a dead band. [3]

The dead band increases the reliability of the system but reduces the maximum achievableoutput and increases the total harmonic distortion which is undesirable. Thus, in order to deal with this issue without sacrificing the overall efficiency, a new technique called the advanced unipolar may be used instead.

IV. ADVANCED UNIPOLAR PWM TECHNIQUE

A. Introduction

As has been discussed earlier, for unipolar PWM technique, the main issue is the chance of dead short circuit becauseof two switches of the same leg. Hence, as a solution, advanced unipolar PWM technique is proposed. This technique makes sure that the overlap condition is avoided.

B. MATLAB Simulation

A simple H-bridge topology is simulated using advanced unipolar pulse width modulation technique.

In this PWM technique, two sinusoidal waves 180^o out of phase with each other are used as reference signals and a triangular wave as carrier signal is used. The carrier wave is compared independently with the two sine waves. The pulses obtained depend on two parameters viz. modulation index and modulation frequency.

Modulation index is the ratio of magnitude of peak magnitudes of modulating waveform and the carrier waveform. Modulation frequency is the ratio of frequency of the carrier wave with respect to the frequency of the modulating waveform. On varying modulation index the pulse width varies in direct proportion. On the other hand, the change in modulation frequency leads to change in number of pulses.

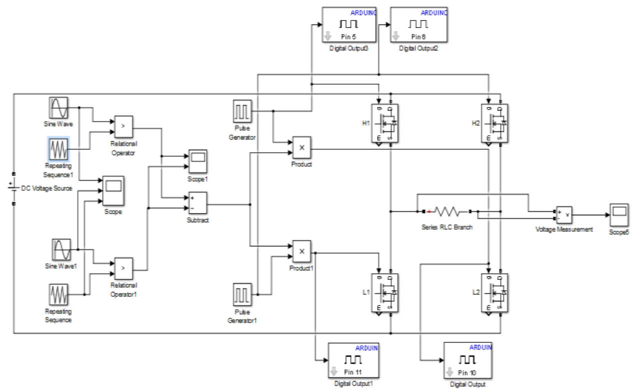

Fig 3 Simulation of H bridge inverter with advanced unipolar PWM technique in MATLAB

Now, after the pulses are generated they are given to a subtractmodule, whose output gives almost same output as that of unipolar PWM inverter with negative cycle being on the positive side. This is then multiplied with a square wave having 50% duty cycle for period of 20 millisecond. The same output is again multiplied with square wave with same parameters but having phase lag of 180^o. The pulses achieved after multiplication are given as gate pulses for lower two MOSFETs L1 and L2 respectively. The upper two MOSFETs H1 and H2 are provided square waves with 0^o and 180^o phase lag respectively.[5]

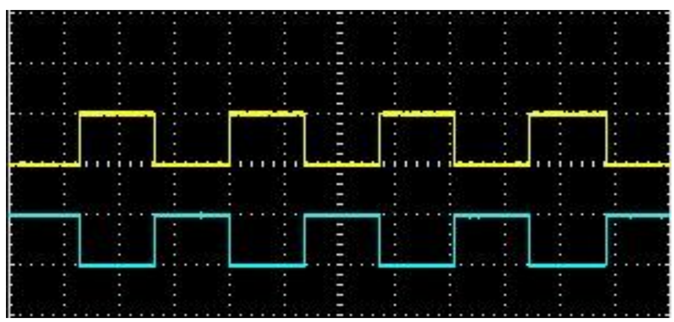

Fig 4 Square waves supplied to switches H1 and H2

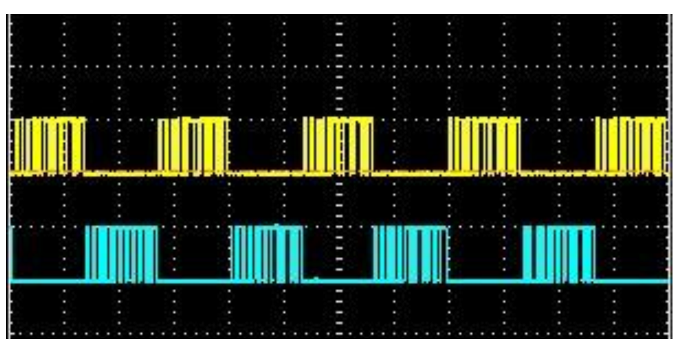

Fig 5 Pulses supplied to switches L1 and L2

When H1 is given square wave with 0^o phase lag and L2 is given multiplier output, then the load conducts through H1 and L2. Now, H1 and L2 turns off. Then similarly H2 and L1 are on and load conducts with reverse polarity. Hence, we get same output as that with unipolar PWM with problem of shorting of switches of same leg resolved. This technique eliminates the need of auxiliary dead band circuit which was must in Unipolar PWM technique.

C. Using microcontroller board to generate pulses

Here, in this simulation diagram Arduino Uno board is used to generate gate pulses for all 4 MOSFETs. There are certain advantages for using microcontroller boards:

- Flexible control of carrier frequency, reference wave magnitude just by changing the value in simulation
- Requirement of function generator, comparator ICs eliminated
- Higher accuracy over analog circuits
- Single board can be used for implementation other PWM techniques as well
- Reduced size of hardware

Generation of gate pulses using MATLAB Simulink can be explained as below here requires an additional support package for Arduino. This will then allow us to use output blocks as shown in simulation cuircuit.
The limiting factor for said method is that Arduino UNO board can generate pulses up to carrier frequency of 1 kHz only. If the frequency is increased above 1kHz, pulses will be missed, as sampling time of UNO board will not be sufficient enough. For higher frequencies we can employ Arduino DUE board.

D. Hardware circuitry and Output voltage waveform (using Arduino Uno board)

Here, in this hardware circuit there are basically three sections.

- Isolated DC power supply
- Gate driver circuit
- Power circuit

The left most section is for isolated DC power supply for gate driver IC. The input is 18V AC. With use of bridge rectifier, capacitor and constant voltage IC (7815) we get 15V at the output side.

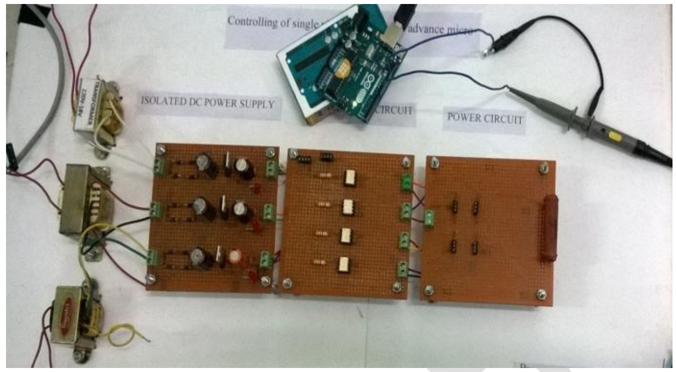

Fig 6Hardware Implementation

This output works as supply for gate driver IC (TLP 250 in this case). This IC serves two purposes. First, isolation between power and control circuit. Secondly, it amplifies the signals from Arduino UNO board from 5V to 15V to drive MOSFETs. One gate driver IC for each MOSFET is used. The input to gate driver ICs are pulses from Arduino UNO board with resistor (330Ω) in series to limit the current to photo LED of TLP250. The middle section at the uppermost side is having connectors for pulses from Arduino UNO board. The output of gate driver IC is given across gate and source terminal of each MOSFET.
In the last section i.e. Power circuit, the MOSFETs are connected in H bridge topology. Connector is provided for input DC voltage. Across the H bridge resistor of (100 Ω, 10W) is connected, across which output voltage waveform is observed in digital storage oscilloscope.
Output voltage waveforms for different frequencies of triangular wave are as follows.

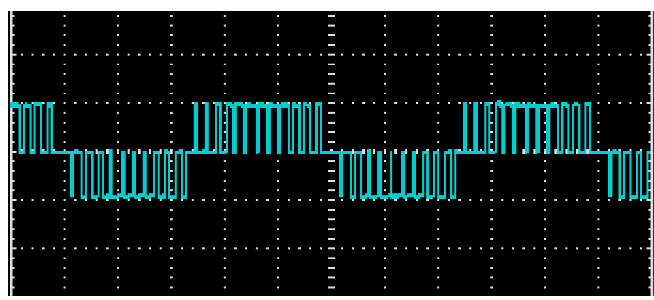

Fig 7. For carrier frequency 600Hz and modulation index 0.9

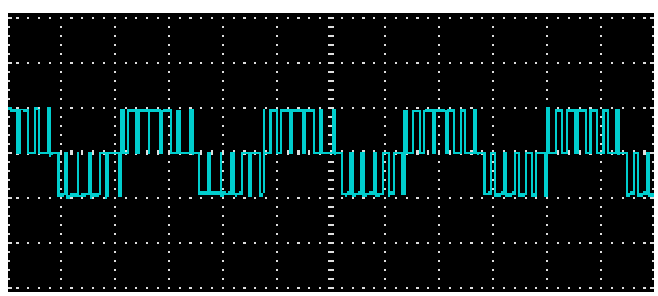

Fig 8.For carrier frequency 300Hz and modulation index 0.9

As can be observed, these are similar to the pulses obtained by conventional unipolar technique.

V. APPLICATIONS

As has been mentioned, for low power applications, the power loss and the lack of control due to inferior techniques such as using a rheostat or single pulse PWM do not significantly affect the output. Here, the main factor is the simplicity of design and overall cost reduction.

However, for sizeable applications where efficiency is one of the main parameters and small discrepancies in voltage control can lead to large losses, accurate and efficient methods such as advanced unipolar SPWM may be used. One such application is SONAR,[5] which is the SOund Navigation And Ranging used for underwater detection. Here, as high power tens of kilowatts are to be delivered by each unit, this method can be particularly useful. Furthermore, the ability to control parameters like output frequency, voltage and power would be an added bonus.

VI. CONCLUSIONS

We can now safely claim that advanced unipolar helps combine the advantages of conventional unipolar while taking care of the problem of dead short circuit. Thus, for systems that need a high level of efficiency and can afford the extra complexity and costs, this scheme is a viable option.

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