Study of Single Pulse Width Modulated Inverter and Sinusoidal Pulse Width Modulated Inverter using Low Pass Filter and Comparison of the Respective Total Harmonic Distortion of Output Voltages using FFT Technique.

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Abstract- **This paper highlights the problems associated with single pulse width modulation, the most important being high harmonic content in output voltage. A comparative study with Sinusoidal Pulse Width Modulation Technique is done highlighting the reduction in Total Harmonic Distortion of the output voltage waveform.**

Keywords- **Sinusoidal Pulse Width Modulation(SPWM), Total Harmonic Distortion(THD), Fast Fourier Transform(FFT) Analysis, Carrier Wave Frequency, Modulating Index(MI), Low Pass Filter(LPF).**

I. INTRODUCTION

The DC to AC power converters are known as inverters. In other words, an inverter is a circuit which converts a DC power into an AC power at desired output voltage and frequency. The conversion is achieved by controlled turn-on and turn-off devices like BJT's, MOSFET's, IGBT's, etc or by forced commutated thyristors, depending on applications.

Some of the important industrial applications of inverters are as follows:

- Variable speed AC motor drives.
- Aircraft power supplies.
- Uninterruptible power supplies (UPS).
- Induction heating.
- Battery vehicle drives.
- Regulated voltage and frequency power supplies, etc.

The output voltage waveform obtained from an inverter contain harmonics which is undesirable. The presence of harmonics reduces the power quality and hampers sophisticated electronic devices.

II. PULSE WIDTH MODULATED INVERTER

For internal control of an inverter, we use Pulse-width modulation technique [1]. It uses a switching scheme within the inverter to modify the shape of the output voltage waveform.

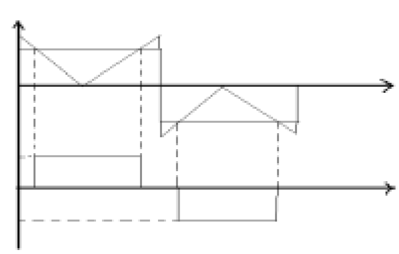
Advantages:

- The advantage of using Pulse-width modulation technique is that the lower order harmonics in the output voltage gets eliminated [1].
- The filtering requirements are minimized as higher order harmonics can be filtered easily [1].
- The output voltage can be controlled easily by modifying the width of the pulses.

There are various pulse width modulation technique (PWM) among which sinusoidal pulse width modulation (SPWM) is discussed here.

III. SINGLE PULSE WIDTH MODULATION

In Single-pulse width modulation, the gating signals are generated by comparing a rectangular reference signal with a triangular carrier wave thus producing only one pulse per half cycle of the output voltage.



Output Voltage Waveform

Advantages:

- Single pulse width modulated inverters are relatively cheap.
- It can work with ordinary light bulbs, fans.

Disadvantages:

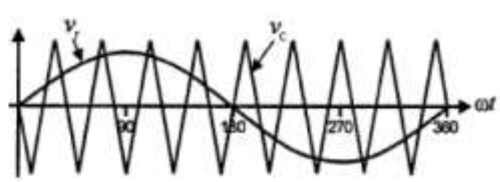
- The main drawback in this type of voltage control scheme is the introduction of harmonics in the output voltage.

Because of the above disadvantages of single pulse width modulation, Sinusoidal Pulse Width Modulation Technique is adopted. The harmonics content in the output voltage is reduced.

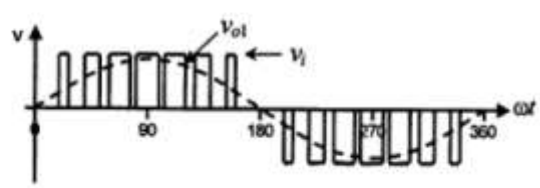
IV. SINUSOIDAL PULSE WIDTH MODULATION

In sinusoidal pulse width modulation, several pulses per half cycle are used. Instead of maintaining the width of all the pulses the same, the width of each pulse is varied proportionally to the amplitude of a sine wave [1]. Sinusoidal pulse width modulation technique is the most advanced control technique for Pulse Width Modulation.

Sinusoidal pulse width modulation technique is adopted in order to reduce the harmonic content of output voltage and to obtain an electrical near sinusoidal output voltage. Near sinusoidal output voltage is very desirable especially in high power applications. In SPWM technique, the carrier signal is a high frequency triangular wave and it is compared with the reference sinusoidal signal. By comparing, the gating pulses are generated which are then applied to the switching devices.



Where Vc is the high frequency carrier wave.
Vr is the reference sinusoidal signal.



Vo1 is the fundamental component of output voltage of frequency 50Hz.

Vi is the instantaneous output voltage.

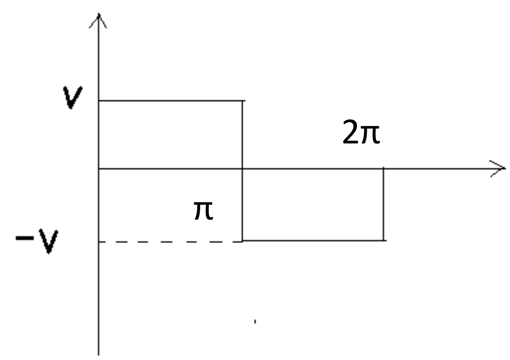
Advantages:

- The output voltage obtained is near sinusoidal.
- The harmonic content in the output voltage is reduced.

V. SQUARE WAVE INVERTER

A square wave inverter produces a square-wave AC voltage of a constant magnitude. In case of single pulse width modulation, taking the modulating index as 1, results in a square wave output voltage.

The output voltage waveform of a square-wave inverter is shown below.



Advantages:

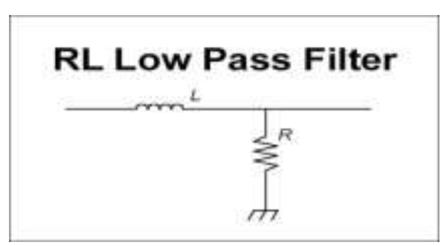
- Square wave AC output voltage of an inverter is adequate for low and medium power applications.
- Square wave inverters are comparatively cheaper than other advanced type of inverters. So it is suitable for medium and low power applications with considerable reduction in cost.

Disadvantages:

- The main drawback of this type is that the output voltage can only be varied by controlling the input DC voltage. Thus internal control of the inverter is not possible. Moreover, the output voltage waveforms of an ideal inverter should be sinusoidal.
- The output voltage contains undesirable harmonics.

VI. LOW PASS FILTER

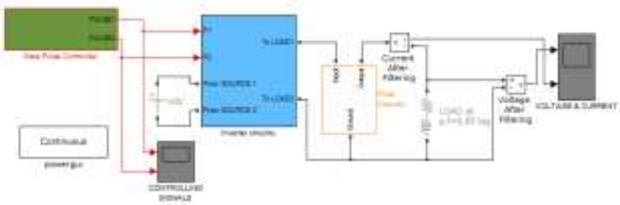
The Low Pass Filter – the low pass filter only allows low frequency signals from 0Hz to its cut-off frequency, f_c point to pass while blocking those any higher.



Here a resistor inductor low pass filter driven by a voltage source is used to reduce the harmonics.

VII. CONTROL TOPOLOGY

Matlab Simulink model for Single Pulse Width Modulated Inverter(for MI=1):



Output Waveforms:

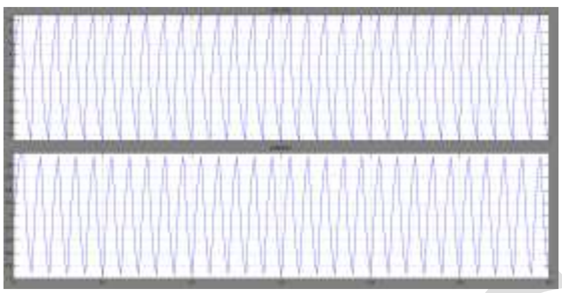


Fig1.: Voltage & Current w.r.t. time for Single Pulse Width Modulated Inverter with Passive Filter.

Control Signals for SPWM Inverter:

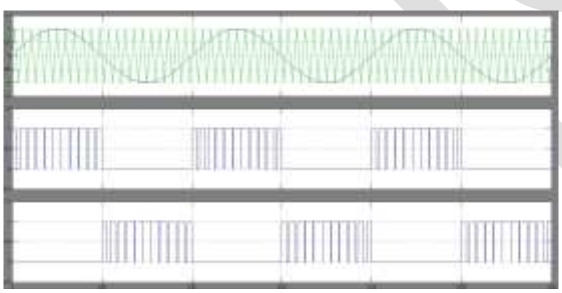
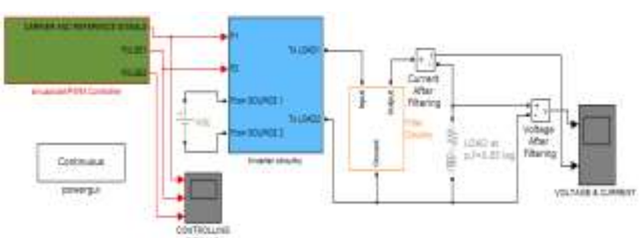


Fig.2: i) Carrier Triangular Signal(Green) & Reference Signal(Blue).

ii) Gating Signal to Mosfets 1 and 3.

iii) Gating Signals to Mosfets 2 and 4.

Matlab Simulink model for Sinusoidal Pulse Width Modulated Inverter with Low Pass Passive Filter(with cut-off frequency=50Hz) :



\ Output Waveforms:

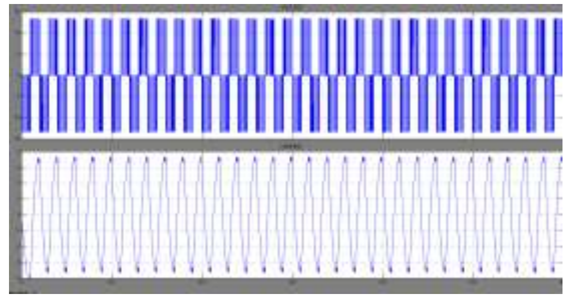


Fig.3: Output Voltage & Current Waveforms w.r.t. time Without using Filter.

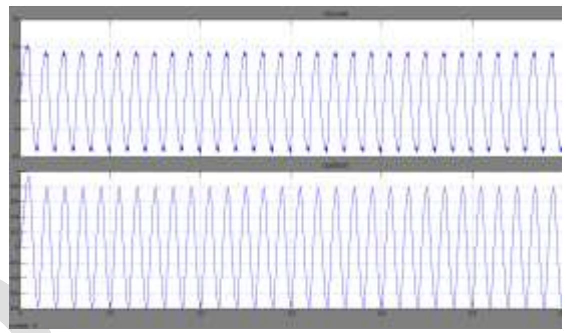


Fig.4: .: Output Voltage & Current Waveforms w.r.t. time With Filter Circuit.

VIII. RESULTS AND DISCUSSION

Harmonic Analysis of Output Voltage Waveform for SPWM Inverter without Filter:

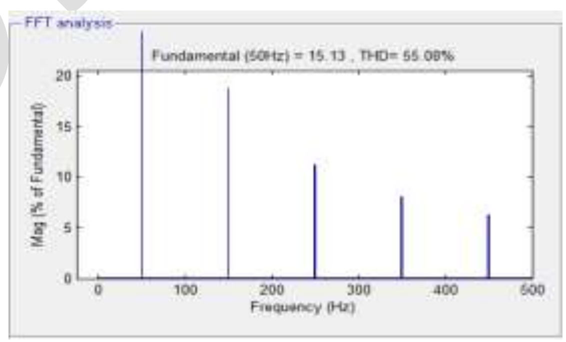


Fig.5: THD of Output Voltage Waveform for SPWM Inverter without Filter.

Harmonic Analysis of Output Voltage Waveform for SPWM Inverter with Filter:

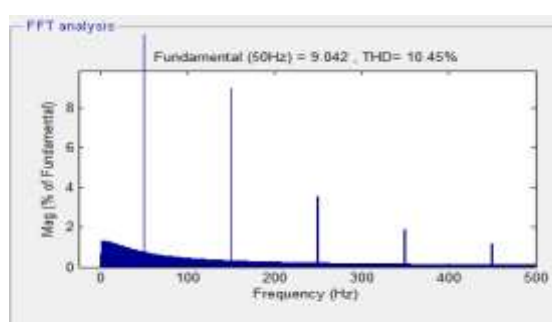


Fig.6: THD of Output Voltage Waveform for SPWM Inverter with Filter.

Harmonic Analysis of Output Voltage Waveform for Single Pulse Width Modulated Inverter:

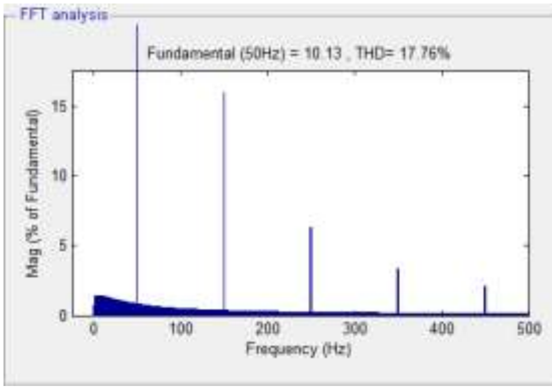


Fig.7: THD of Output Voltage Waveform for Single Pulse Width Modulated Inverter.

IX. REVIEW OF PREVIOUS WORK

Due to rapid growth of photovoltaic (PV) power generation, highly efficient and cost effective pure sine wave inverters are greatly demanded in the local market. In the referenced paper **[4],** based on the simulation result in PSIM software, a low ripple and almost 97% efficient single-phase pure sine-wave inverter for PV application has been designed and implemented which has a total harmonic distortion (THD) of less than 0.6%.

The referenced paper **[5]** focuses on design and development of SPWM three-phase voltage source inverter in MATLAB/SIMULINK. Pulse Width Modulation variable speed drives are mainly applied in many industrial applications that require better performance. In the referenced paper **[3]** simulation and analysis of sinusoidal PWM Inverter fed Induction motor is carried out. The THD and fundamental voltage is measured at varying modulation indexes.

X. FUTURE WORK

The future work of this project includes the following aspects:

- The hardware implementation of Sinusoidal PWM inverter for domestic loads.
- To compare the Total Harmonic Distortion (THD) of a Sinusoidal PWM inverter for carrier waves with different natures such as trapezoidal-triangular, inverse sine wave etc.

TYPE OF INVETER	FILTER USED	TOTAL HARMONIC DISTORTION(THD)
Single Pulse Width Modulated Inverter	Passive Low Pass filter	17.76%
Sinusoidal Pulse Width Modulated Inverter	None	55.08%
	Passive Low Pass Filter	10.45%

XI. CONCLUSION

Due to the presence of huge harmonic content in the output voltage waveform in the order of frequency of the carrier wave used, with the introduction of a low pass filter the THD is greatly reduced, unlike the case of single pulse width modulated inverter where the reduction is comparatively lower.

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