Comparison of Hybrid Modulation Techniques for a Single Phase Rectifier

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Abstract
The objective of this paper is to control a single phase power rectifier using Hybrid PWM (Pulse Width Modulation) to get a required output. Nowadays PWM control technique has become an integral part of the most power electronics system. This technique is the most suitable one for controlling the output voltage of a power rectifier. In this paper the performance of the proposed module is analyzed for various Hybrid modulation techniques and the most suitable technique is identified on the basis of Total Harmonic Distortion present in the supply current waveform. Hybrid PWM technique is used to control Gate signal of power switches of single phase power rectifier. By this way, ON and OFF time of circuit MOSFETs can be controlled to obtain the desired DC output voltage. The performance of the power rectifier with the Hybrid PWM technique is promising and attractive for harmonics free power supply applications.

1. Introduction

Many power electronic systems need DC voltage sources. It is not very convenient to rely on batteries for such requirements. Circuits that are used to convert AC to DC are called rectifiers or AC to DC converters. In rectifier type of converters only fixed DC voltages are required. Power conversion is achieved by diode bridge rectifiers which are simple and highly reliable.

Nonlinear loads used in industries introduce current harmonics at the utility. This causes poor power factor, poor utilization of the distribution system and overheating which causes reduction of life expectancy of equipments. Further this causes low efficiency, disturbances to other consumers and interference with communication networks. Hence a technique towards reduction of harmonics using analysis of voltage and current waveforms in the presence of nonlinear loads is essential.

2. Topology of Single Phase PWM Rectifier

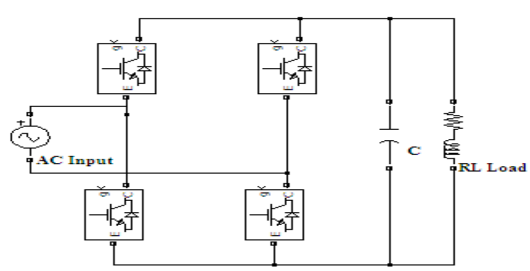

Fig: 1. PWM Single Phase Rectifier Simulation Circuit

With the recent development in the field of power electronics, more and more power electronic appliances are widely used for meeting industrial, commercial and consumer needs. In rectifier type of converters, power conversion is achieved by diode bridge rectifiers which are simple and highly reliable where only fixed DC voltages are required. Whenever the DC voltage has to be controlled, thyristors are used in place of diodes. The topology of the single phase rectifier adopted in this paper is shown below.

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3. Sinusoidal Pulse Width Modulation

Sinusoidal Pulse Width Modulation (SPWM) utilizes both amplitude modulation and pulse width modulation and therefore improving the quality of the input waveform of the rectifier with low distortions. The operating principle of this method is based on the comparison of reference voltage signal with the triangular carrier signal. As a result rectangular signal is generated. The width of the generated rectangular signal is proportional to average value of the reference signal. The carrier signals have the same amplitude A_c and frequency f_c. here are several SPWM schemes available of which the carriers may be shifted vertically or horizontally. The various SPWM schemes such as Alternative Phase Opposition and Disposition (APOD) scheme, Single Carrier Sinusoidal Pulse Width Modulation (SCSPWM) scheme, Phase Shifted Carrier Pulse Width Modulation (PSCPWM) scheme and Carrier Based Space Vector Modulation (CBSVM) scheme for single phase rectifier.

3.1 APOD PWM Strategy

In case of alternative phase opposition and disposition strategy every carrier signal is 180 degree phase shifted with respect to its neibouring carrier signal. The unipolar waveform pattern comprises of two triangular carrier signals with a sinusoidal reference signal. The waveform representation is shown in Fig.3.1 for an amplitude modulation index of m_a = 0.9 and frequency modulation index of m_f = 30. The high frequency PWM is obtained by the comparison of the rectified modulation waveform with corresponding phase disposition carrier signal. Here the two carriers are not sharing any common band as they are contiguous level shifted.

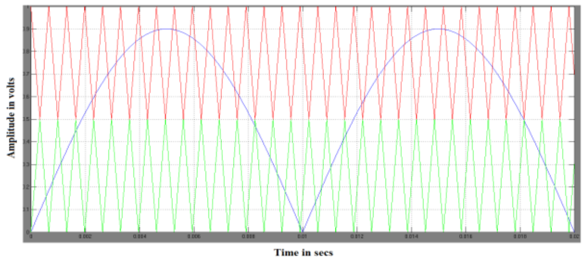

Fig: 2. Waveform pattern for APOD scheme

3.2 SCSPWM Strategy

In single carrier sinusoidal pulse width modulation strategy two modulating signals are compared with a single carrier signal. One of the unipolar modulating signals is level shifted down by a value of 1. The high frequency PWM is obtained by the comparison of the single triangular carrier with the two unipolar reference signals. The waveform representation of the SCSPWM strategy is shown in Fig.3.2 for an amplitude modulation index of m_a = 1.5 and frequency modulation index of m_f = 30.

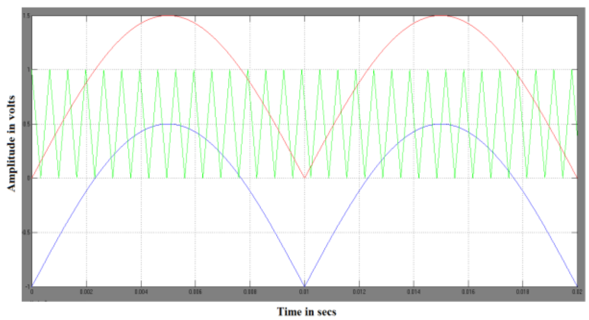

Fig: 3. Waveform pattern for SCSPWM scheme

3.3 PSCPWM Strategy

In this strategy each carrier is 90 degree phase shifted with respect to its adjacent carriers. The unipolar wave pattern for a single phase rectifier comprises of a rectified sinusoidal reference signal with two triangular carrier signals shifted by 90 degree. The high frequency PWM is obtained by the comparison of the modulation waveform with phase shifted carrier signals. The waveform representation is shown in Fig.3.3 for an amplitude modulation index of m_a = 0.9 and frequency modulation index of m_f = 30.

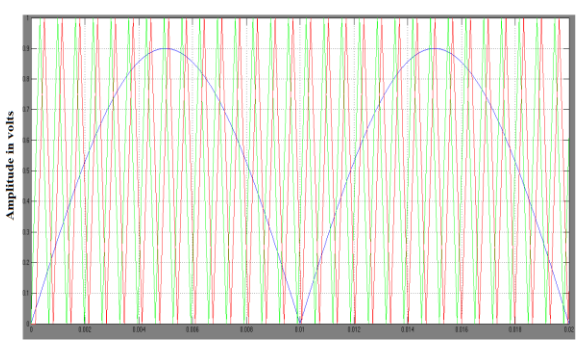

Fig: 4. Waveform pattern for PSCPWM scheme

3.4 CBSVM Strategy

Space vector modulation is a digital technique that incorporates vector calculations and switching state selection. Implementing this technique becomes complex, therefore the SVM technique is reduced to carrier based SVM. This technique incorporates two triangular carrier signals and one unipolar reference signal. Here instead of using pure sinusoidal waveform as modulating signal an offset voltage injected reference signal is employed. This offset voltage injection centers the active space vector in the corresponding switching interval. The high frequency PWM is obtained by comparing the modulating waveform with level shifted carrier signals. The waveform representation is shown in Fig.3.4 for an amplitude modulation index of m_a = 0.9 and frequency modulation index of m_f = 30.

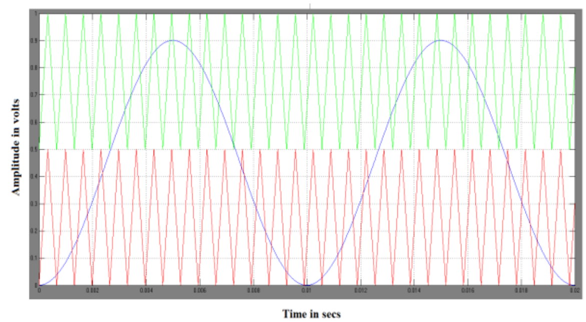

Fig: 5. Waveform pattern for CBSVM scheme

4. Hybrid Pulse Width Modulation

Hybrid pulse width modulation is the combination of Fundamental frequency Pulse Width Modulation (FPWM) and Sinusoidal Pulse Width Modulation (SPWM). The low frequency FPWM has low switching losses but poor harmonic performance where as the high frequency SPWM has good harmonic performance and very high switching losses. So as to have the advantages of both the techniques hybrid modulation strategy has been developed. Thus hybrid modulation is the consolidation of fundamental switching frequency and high switching frequency PWM. The high switching frequency PWM scheme includes APODPWM, SCSPWM, PSCPWM and CBSVM scheme. Implementing this hybrid modulation technique to a single phase rectifier results in the operation of four switches of the module at two different frequencies, two switches being commutated at FPWM and while the other two switches are modulated at SPWM. Thus the resultant switching pattern inherits the quality of both FPWM and SPWM.

4.1 Sequential Switching Hybrid Modulation

Sequential switching strategy is incorporated with the hybrid modulation in order to sweep away the unequal switching losses of the power components. A base PWM circulation scheme is also introduced to have uniform power loss dissipation among the power components. The scheme of .proposed sequential switching modulation comprises of three basic modules to generate the new modulation pulses. The three basic building blocks for the sequential switching hybrid modulation scheme are as follows.

a) Base modulation generator
b) Base PWM circulation scheme
c) Hybrid modulation controller

4.1.1 Design of Base Modulation Generator

In order to design the base modulation generator three modulation pulses are needed. Pulse (A) is a square wave signal having frequency equal to half the value of fundamental frequency. This square pulse (A) makes the power switches to operate in such a manner so as to have uniform power losses among the devices. Therefore pulse (A) is termed as the sequential switching pulse. Pulse (B) is also a square wave signal having frequency equal to that of fundamental frequency which is synchronized with the modulating signal. Therefore pulse (B) is the FPWM pulse. The pulses (C) and (D) are the SPWM pulses. The block diagram representations of the base modulation generator for four different SPWM schemes are shown in the figure that follows.

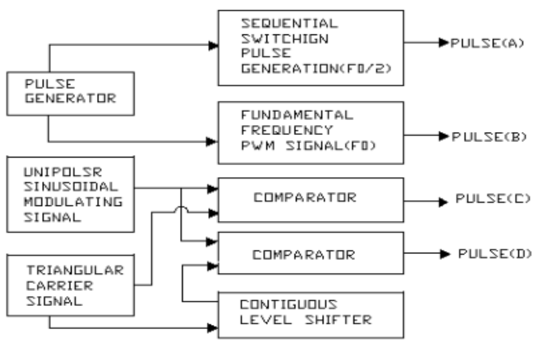

Fig: 6. Base modulation generator – HSCSPWM

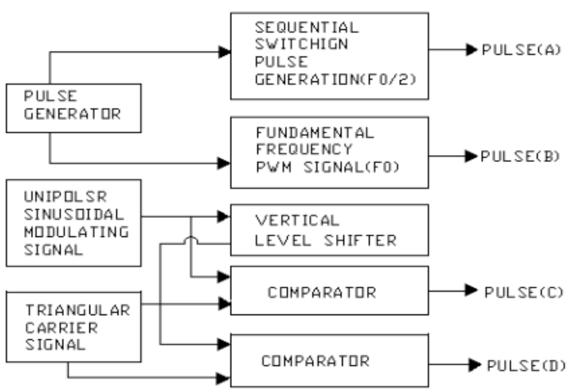

Fig: 7. Base modulation generator – HSCSPWM

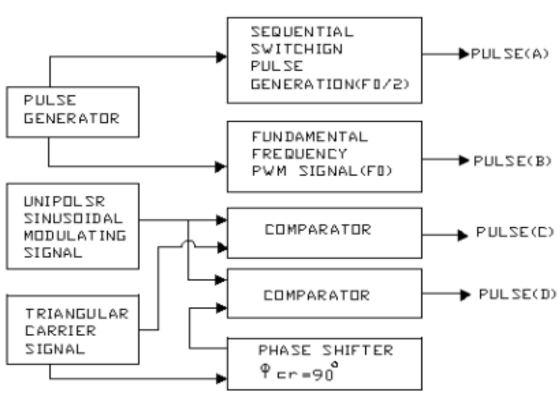

Fig: 8. Base modulation generator – HPSCPWM

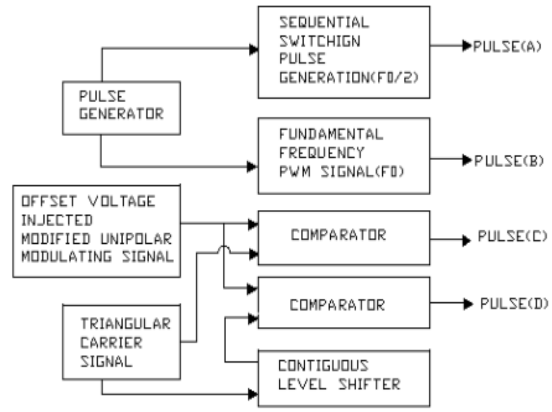

Fig: 9. Base modulation generator – HCBSVM

4.1.2 Scheme of Base PWM Circulation

The base PWM circulation scheme is developed to have hybrid pulse width modulation among the power components so as to establish uniform power loss dissipation. The base PWM circulation scheme comprises of a 2:1multiplexer. The multiplexer selects any one of the two PWM signals applied to its terminals depending on the control signal of the multiplexer. The control signal is a clock input whose frequency is equivalent to f_0 /4 which makes the base time period for the PWM circulation among all the power components.

4.1.3 Design of Hybrid Modulation

The hybrid modulation controller is a logical operator module that combines sequential switching pulse (A), FPWM pulse (B) and SPWM pulses (C) and (D) for the generation of the switching pulses required by the power semiconductor switches. Thus the gating pulse for the power switches includes both FPWM and MSPWM. The logical function for a single phase rectifier is depicted as follows,

$S1 = ABE + \bar{A}B$
$S2 = A\bar{B}E + \bar{A}\bar{B}$
$S3 = \bar{A}\bar{B}E + A\bar{B}$
$S4 = \bar{A}BE + AB$

Depending on the sequential switching pulse (A) the switches are operated at SPWM and FPWM sequentially. If the sequential switching pulse (A) is kept at level 1 then the switches S_1 and S_2 are triggered with MSPWM and S_3 and S_4 are triggered with FPWM. If the pulse (A) is kept at level 0 then the switches S_1 and S_2 are triggered with FPWM and S_3 and S_4 are triggered with MSPWM. Since the pulse (A) is a sequential switching pulse the average switching frequency of all the four switches are equalized. Thus the dv/dt and di/dt stress on all the switching components are normalized. The primary building block of this hybrid modulation controller is the logical gates that are intended to perform the OR and AND operations required for the switching pulse generation. Thus the power semiconductor switches are operated in a balanced condition. This represents the implementation of base PWM circulation scheme.

5. Simulation Output for Single Phase PWM Rectifier

Logical Simulation Diagram for Generating Gate Pulses

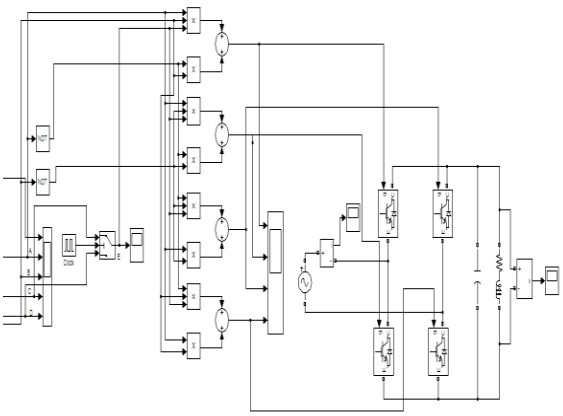

Fig: 10. Logical Simulation Diagram - Gate Pulses

DC Output Voltage and FFT Plot – HAPOD

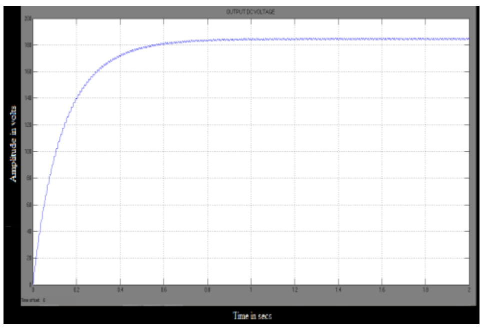

Fig: 11. DC Output Voltage

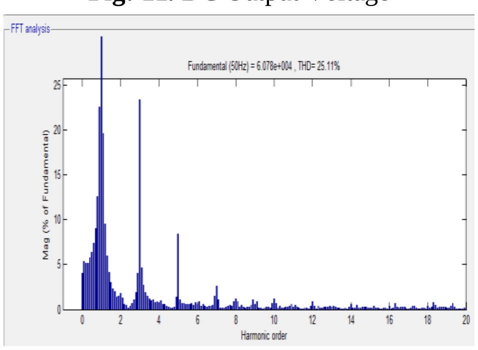

Fig: 12. FFT Plot

DC Output Voltage and FFT Plot – HSCSPWM

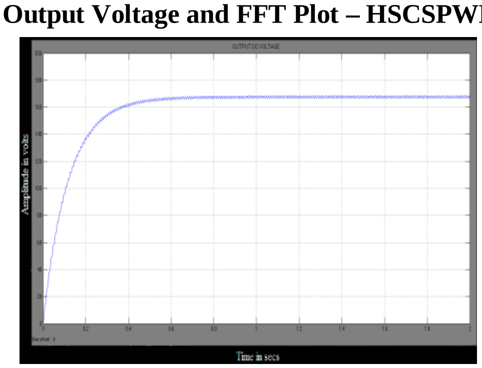

Fig: 13. DC Output Voltage

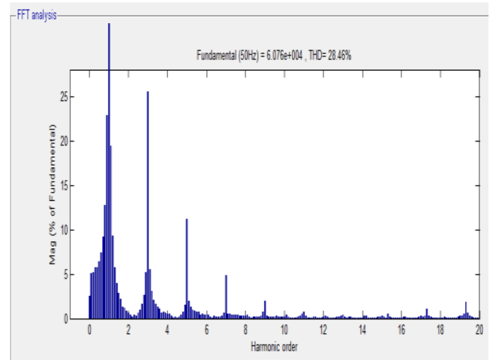

Fig: 14. FFT Plot

DC Output Voltage and FFT Plot – HPSCPWM

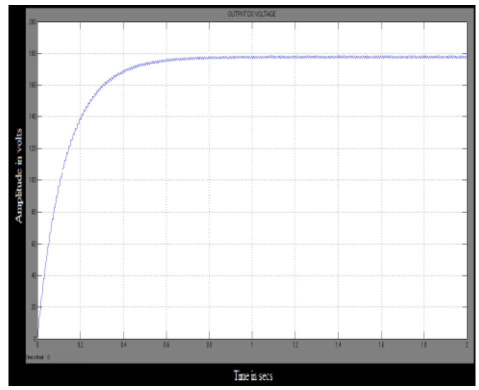

Fig: 15. DC Output Voltage

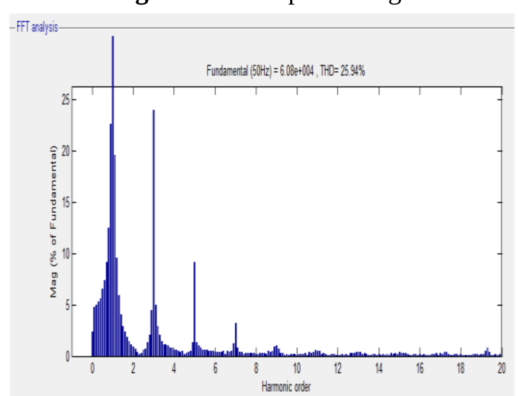

Fig: 16. FFT Plot

DC Output Voltage and FFT Plot – HCBSVM

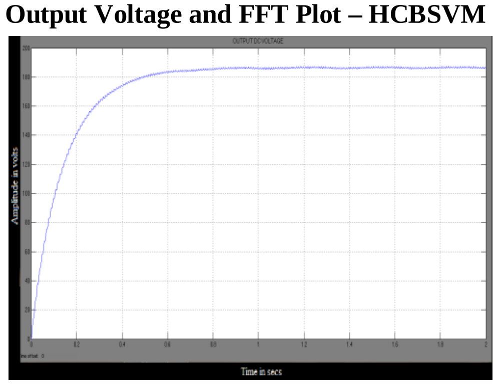

Fig: 17. DC Output Voltage

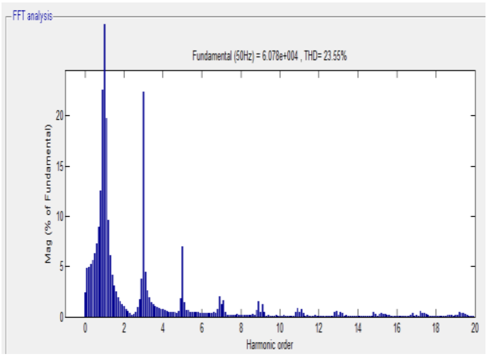

Fig: 18. FFT Plot

6. Results and Discussion

The triggering pulses for the four power semiconductor switches are created using MATLAB/SIMULINK. For hardware implementation these pulses are obtained from FPGA unit. The behavior of the single phase pulse width modulated rectifier is studied on the footing of percentage of total harmonic distortions.

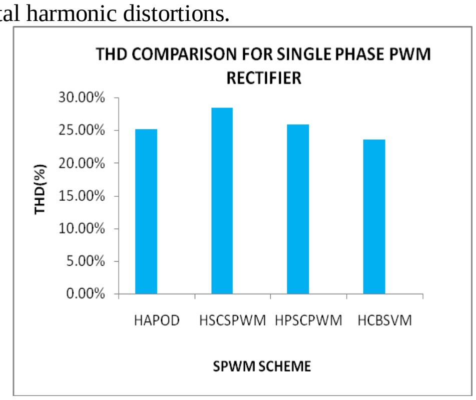

Fig: 19. THD comparison bar chart for SPWM schemes

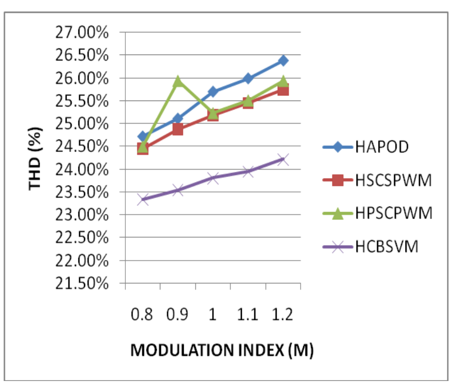

Fig: 20. Modulation index versus % THD

7. Conclusion and Future Work

Thus from the results of the simulation the appropriate SPWM scheme most suited for the single phase rectifier is identified as the HCBSVM strategy. This is evident from the percentage of Total Harmonic Distortion present in the input current waveform of the proposed single phase rectifier. Thus the analysis of the performance of the single phase PWM rectifier is done on the basis of THD. A comparison chart of all the four SPWM schemes with respect to their THD is shown in Fig.6.1

Here for the comparison of THD of various schemes a common modulation index is considered for all the four techniques. The level of THD present in the input current waveform of the single phase rectifier incorporating the specific SPWM strategy for the taken modulation index is depicted in the chart for comparative study. The comparison bar graph shown in Fig.6.1 clearly states that the harmonic content present in the input of the single phase rectifier operated with HCBSVM strategy is lesser compared to the other three SPWM schemes. And also the variation of THD with respect to the modulation index is shown in Fig.6.2.

The graph shown in Fig.6.2 depicts the variation of modulation index with the amplitude of THD. From the graphical representation it is inferred that for lower modulation indices the THD is higher for all the four SPWM schemes and as the modulation index approaches unity the THD starts decreasing. Therefore it is evident from the simulation results that the dynamic performance of the single phase rectifier increases when the proposed converter module is triggered with HCBSVM pulses. Thus the feasibility of the PWM based single phase rectifier has been analyzed for various hybrid modulation techniques, the most suitable technique is identified and the same has been planned to be implemented in the hardware using FPGA controller. FPGA offers run time configuration while generating the triggering pulses for the power semiconductor switches.

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