AC CHOPPER USING SINUSOIDAL PULSE WIDTH MODULATION (SPWM) TECHNIQUE

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Abstract—**This paper is concerned on development of AC Chopper using Sinusoidal Pulse Width Modulation (SPWM) switching technique. The IGBTs are used as switching devices. The Power System Block set with Matlab/Simulink environment is used to study the behavior of the purpose converter. The switching frequency of the converter is being varied and being fed to the R load circuit. The modulation index also is being varied to study the output voltage of the converter. Selected simulation and experiment results are presented.**

Keywords- Sinusoidal Pulse Width Modulation (SPWM), AC-AC Converters, Insulated Gate Bipolar Transistor (IGBT), Matlab/Simulink (MLS).

I. INTRODUCTION

In recent years, AC-AC converters or commonly known as AC Chopper is widely used in many application such as in heating industry, lighting control, AC motor controller, starting of induction motor and also to control the speed of the fan and pump. In AC Chopper, the input signal that is being provided is an AC signal and the output that supposed to come out is the AC signal. To convert from AC to AC signal basically undergoes AC-DC-AC conversion. Rectifier-inverter system with dc link using an indirect AC-DC-AC conversion method has been the most popular circuit. Basically in a traditional technology, many of the application use thyristor which have the advantages of simplicity in the circuit and large power capability. However, these have the inherent drawbacks that power factor decreases when firing angle increases and that, since the content of the line current harmonics is relatively large, the size of the passive filter circuit becomes bulky. These can be overcome by using the Sinusoidal Pulse Width Modulation (SPWM) AC Chopper. By using the SPWM, the chopper has sinusoidal current waveforms, better power factor, fast dynamics and smaller input/output filter. The use of SPWM type of switching algorithm in AC Chopper will result with possible switching spikes being developed during switch turn-off or during commutation [1].

A direct Ac-Ac converter with thyristors is placed of new electromagnetic compatibility (CEM) standards that limit the admitted perturbations in the power supply system [2]. Before the 90s, PWM Ac chopper were made by four quadrants switches [3]-[5]. Their application was delayed due to the commutation problems. To ensure safe commutation without high voltage spikes, some PWM control principle were developed [4]-[5]. After 1990, different AC Chopper topologies using a reduce number of switches [6]-[7] were developed. This is to reduce the switching losses. To increase the converters stability, a simple DC snubbers consisting of a capacitor is implement to the circuit [8]-[9].

This paper presents the development of Sinusoidal Pulse Width Modulation (SPWM) switching technique to synthesis the output of the AC-AC converter. The propose switching technique being investigate is by varying the switching frequencies which are 5kHz, 7kHz and 9kHz to a R load circuit. The modulation index also is being varied from 0.1 to 1 to study the output voltage of the converter. Prior to hardware implementation, simulations were performed to predict the behavior of the output being produced by the conversion process.

II. AC CHOPPER USING FOUR SWITCHES

There are some kinds of AC voltage regulators that were used previously such as auto-transformer and thyristor phase-controlled voltage regulator. For the auto-transformer voltage regulator, its voltage regulator speed is low whereas for the thyristor phase controlled voltage regulator, it has a relatively fast response. However, for both of the topology have some disadvantages which are the low input power factor and large amount of the low-order harmonic currents. For the AC Chopper using four switches, basically it composes of four semiconductors and LC filters. The input filter capacitor is divided into two parts as shown in Figure 1.

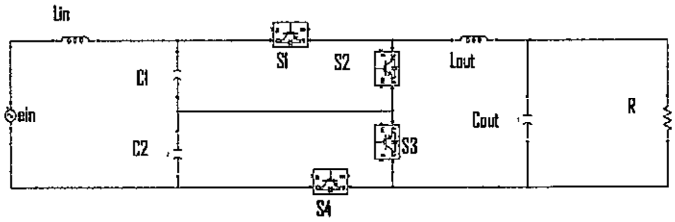


Fig 1. AC Chopper using four switches

The four switches are basically four IGBTs connected as show in the figure 1. The gates of the IGBTs are fed by a PWM signal which is given by comparison with a triangular wave and reference DC voltage. The switching patterns for the four switches chopper are critical and an alternate path has to establish in dead-time period. In this topology, it uses DC regenerative snubber capacitor [10]-[12].

This type of snubber is used to realize safe commutation and enhance efficiency.

The disadvantages of using this topology are the complexity of the topologies and also the control strategies which are related to the phase of the input voltage, input current or inductor current. Furthermore, there are voltage spike across the power switches during the commutation process. The switching devices are easy to be destroyed for the lack of protection to the power switches.

III. PROPOSED AC CHOPPER USING SINUSOIDAL PULSE WIDTH MODULATION (SPWM)

In this proposed AC Chopper topology, it uses a DC link which act as a storage device. The DC link provides decoupling between the rectifier and the inverter in order to provide an excellent input and output performances. The topology used for the rectifier part is the boost rectifier which performs the function of power factor correction and boost ac-dc conversion. For the inverter, the topology being used is the buck inverter topology which performs the function of buck dc-ac conversion with output voltage of variable amplitude and frequency. The circuit consists of 4 IGBTs connected as inverter and also four diodes connected as rectifier as shown in Figure 2. The switching sequence of the IGBTs in this proposed is controlled by SPWM switching technique.

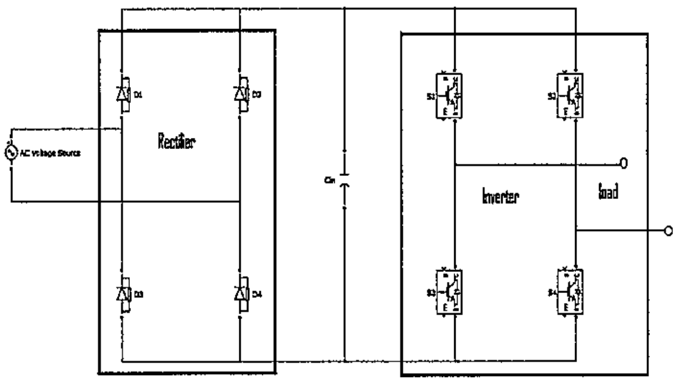


Fig 2. AC-AC chopper with DC link

A.) Sinusoidal Pulse Width Modulation (SPWM)

A sinusoidal pulse width-modulated (SPWM) AC Chopper as shown in Figure 3 has been suggested as an alternative to an ac voltage controller. In a SPWM AC chopper, single or multiple pulses per half cycle can be employed. The AC Chopper circuit employs forced commutated devices [13] or self-commutating devices [13]–[16]. System performance is further improved by using various harmonic elimination techniques in the AC Chopper [14]-[15]. It is shown in these works that the SPWM AC Chopper inherits several advantages over an ac voltage controller such as improved power factor, elimination of low-order harmonics, wide voltage control range, etc. A variable-speed single-phase capacitor-run induction motor driving a residential fan exhibits improved performance characteristics when supplied from an ac voltage controller than from a single PWM (SPWM) ac chopper. The harmonic components are merely shifted into the higher frequency range and are automatically filtered due to inductances in the ac system. Thus the harmonic in the system can be cancel. The system can also be improved by using the Space Vector switching technique where a higher modulating index can be obtained.

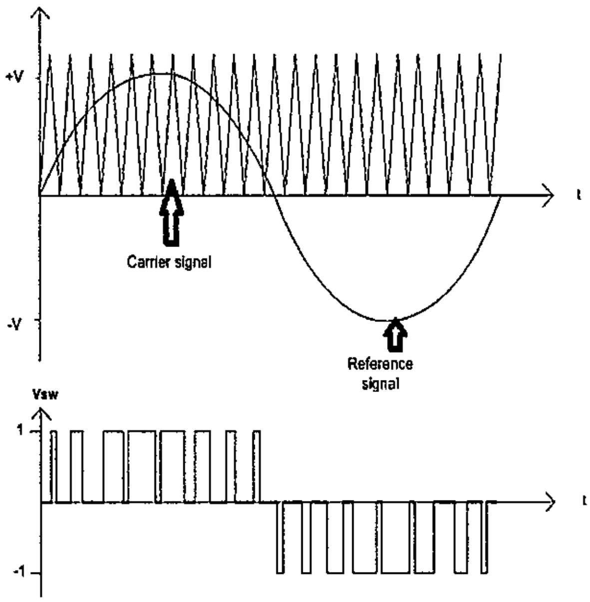
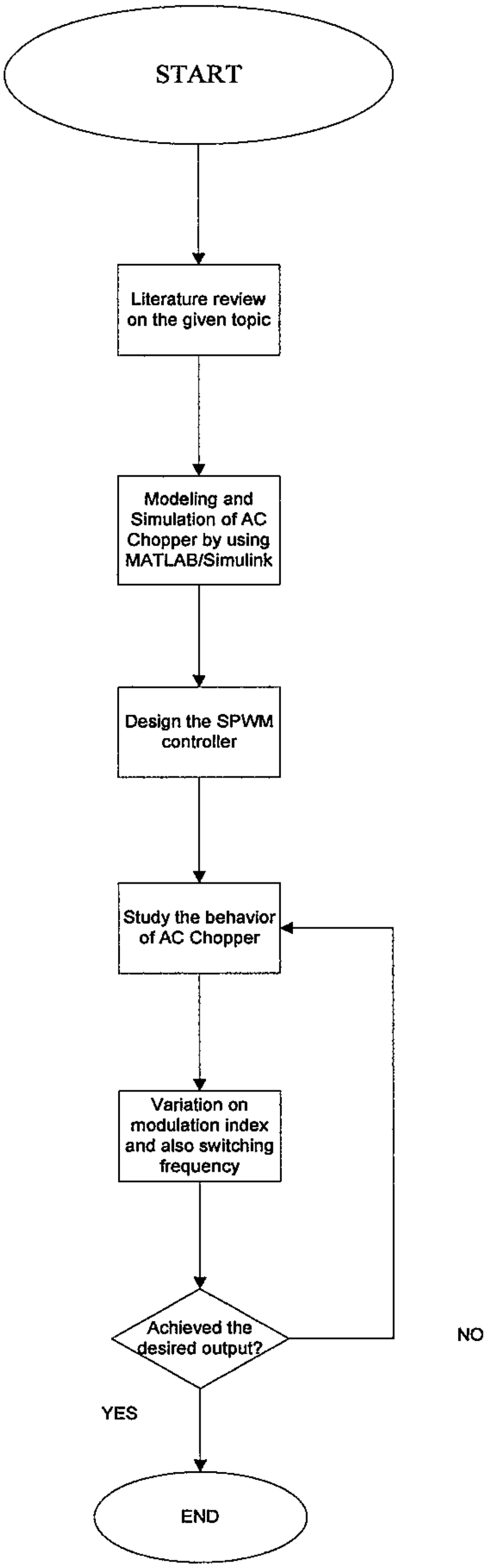


Fig 3. SPWM waveform

B.) METHODOLOGY

The methodology involve in this proposed paper is the testing the AC Chopper simulation.

For simulation, MATLAB simulation is use to simulate the SPWM AC Chopper switching technique circuit. From this simulation, the operation of the AC Chopper operation is being observed. The behavior and characteristic of the AC Chopper is also being studied. The switching frequency of the Space Vector SPWM is also being observed. The modulation index of the SPWM is being varied. The output voltage and also the total harmonic distortion (THD) are also being observed. If the expected result is the same as the desired one, the simulation will be used to develop hardware for this research.



Flow Chart of the AC Chopper

C.) Switching Strategy

For the operation mode of the Ac Chopper using SPWM is divided to two operation modes which are during the positive SPWM and also negative SPWM. During the initial mode, the Ac current flow from the source to the rectifier and through the dc link capacitor where it is being charged. This is where the ac current being converted to dc current. After the capacitor has been charged, it flows to the inverter where the SPWM topology is implemented. During the positive SPWM, switch S1 and S4 are controlled by SPWM while the switch S2 and S3 are turned off. The dc current flows through S1 to the resistor and S4. During the negative SPWM, switch S2 and S3 are controlled by the SPWM and switch S1 and S4 are turned off. The current flows to the S2 switch and flow through the resistor and S3.The same topology continues for the next cycle. A suitable value of capacitor which acts as a filter is used to obtain an excellent output waveform with less harmonics and distortions. The final output obtained is an ac current and ac voltage.

IV. MODELLING AND SIMULATION

The circuit is design and simulate by using MATLAB/Simulink software. The model of the design can be seen in Figure 4. From this simulation, the operation and behavior of the AC Chopper is being studied and the output characteristic of the chopper is being observed.

For this MATLAB simulation, the parameter of components in the design is shown in the table below:

Parameter	Value
AC voltage source	230V
Dc link capacitor , C_{in}	50μF
Resistor, R	50Ω
Filter capacitor, C	50μF

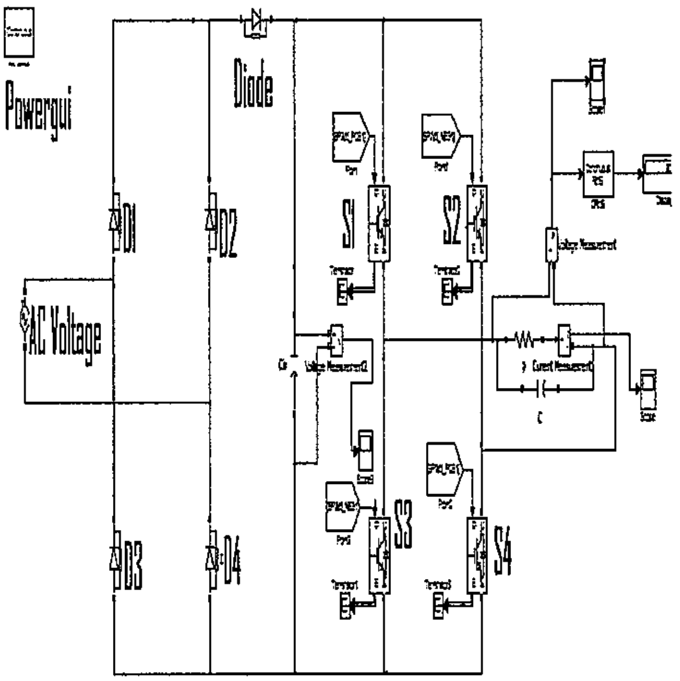


Fig 4. Model of AC Chopper (MATLAB)

Based on figure 4, to generate SPWM pulse for the switching technique, sinewave signal is compared with the triangular wave. In MATLAB simulation, it is done by using the sinewave block with the repeating sequence where the switching frequency and the amplitude of the triangular wave is set. For the sinewave, the amplitude use is 1 and the frequency in rad/sec is 100π. For the triangular wave, the switching frequency is set to 5000Hz. The modulation index is also created and set by using the constant block which is 'Modulation Index' and 'Modulation Index1'. This is where the modulation index is varies to obtain a desired output voltage. The 'Sinewave' block represent the sinusoidal modulating index for the first cycle and the 'Sinewave1' block represent the modulation index for the second cycle. The circuit for the SPWM controller using MATLAB can be seen in figure 6. Based on figure 6, the controller is being fed to the gate terminal of the IGBTs in the inverter part. The Modulation Index is being multiply with the Sine Wave by using the 'Product' block diagram. Then is is being compare with a triangular wave generated by 'Triangular Wave' block diagram by using a 'Relational Operator'. The result is being multiply with a 'Pulse Generator' block diagram. The 'Pulse Generator' block diagram is use to generate the pulse signal and also to set the delay of the pulse which in this case study the delay is set to 0.01sec with an amplitude of 1. The final product generated is the SPWM pulse signal.

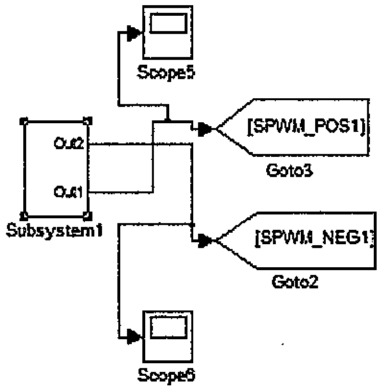


Fig 5. Top Model of SPWM Controller

To further simplify the circuit, the SPWM controller circuit is converted to a subsystem block. By using this, the connection of the circuit look more simplify and more systematic as shown in Figure 5. The overall SPWM controller in the subsystem block is shown in Figure 6.

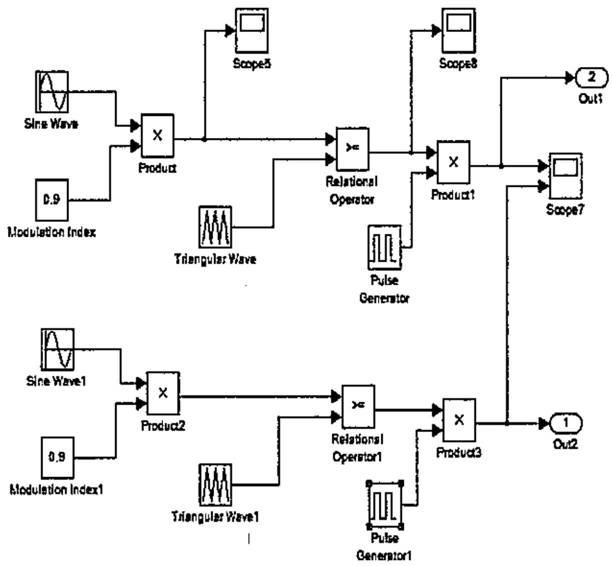


Fig 6. SPWM Controller using MATLAB

Figure 7 and Figure 8 shown below is the current flow from the source voltage to the DC link capacitor. This is the converter mode of the circuit. The positive and negative cycle of the current flow will charge the capacitor. When the capacitor is charged, the current will flow to the inverter mode of the circuit.

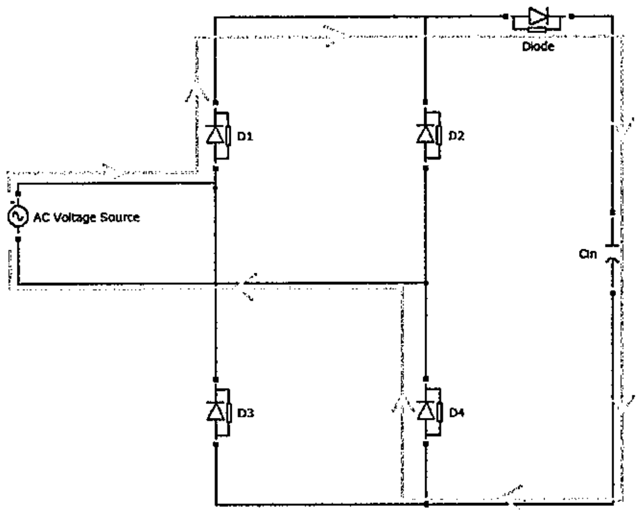


Fig 7. Positive Cycle of Current Flow from Source

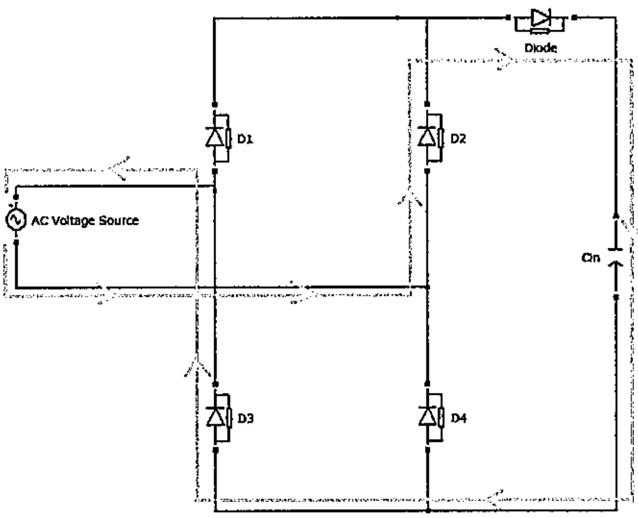


Fig 8. Negative Cycle of Current Flow from Source

The state of the IGBTS during current flow is as shown in the Table 1. The flow of current during State 1 and State 2 of the circuit are as show in the Figure 9 and Figure 10.

TABLE 1: SWITCHING SEQUENCE OF THE IGBTS

Cycle	S1	S2	S3	S4
State1	ON	OFF	OFF	ON
State2	OFF	ON	ON	OFF

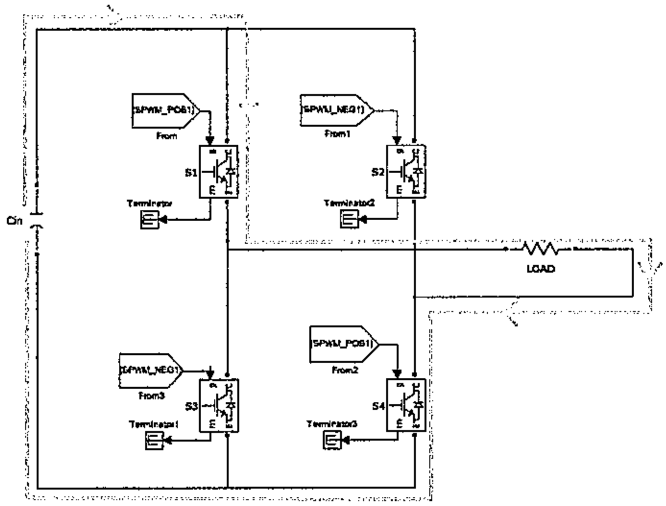


Fig 9. State 1 of Current Flow

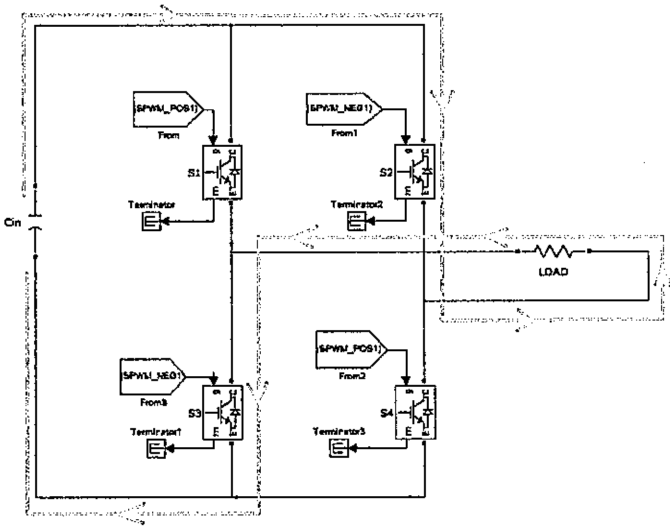


Fig 10. State 2 of Current Flow

V. RESULTS AND DISCUSSION

The operation and the characteristic of the Ac chopper are studied by using the Matlab simulation. Sample results are taken by varying the modulation index and switching frequency as shown in the Table 2.

TABLE 2: RESULT OF AC CHOPPER SIMULATE USING MATLAB SIMULATION

Modulating index, mi	Vout rms
0.1	77.82V
0.3	78.73V
0.5	79.36V
0.7	79.93V
1	80.37V

Matlab simulation with switching frequency of 5kHz

Modulating index, mi	Vout rms
0.1	78.24V
0.3	79.20V
0.5	79.74V
0.7	80.10V
1	80.43V

Matlab simulation with switching frequency of 7kHz

Modulating index, mi	Vout rms
0.1	78.26V
0.3	79.45V
0.5	79.89V
0.7	80.22V
1	80.46V

Matlab simulation with switching frequency of 9kHz

The data shown in the table above are the data for the RMS output voltage when the modulation index is being varied. The data consists of all the switching frequency involve in this propose paper which are 5kHz, 7kHz and 9kHz. The modulation indexes being varied from 0.1 to 1 respectively. To further compare the findings, all the data are put into the chart as shown in Figure 11.

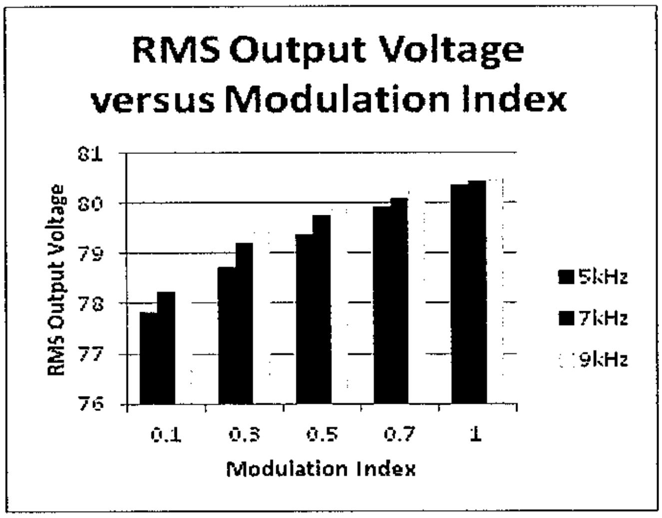


Fig 11. Variation of RMS Output Voltage versus Modulation index

The total harmonic distortion (THD) also is being investigated in this proposed study. The observation is being made to see the effect of varying the switching frequency and also the modulation index towards THD. The results are presented in the Table 3 below:

TABLE 3: RESULT OF TOTAL HARMONIC DISTORTION

Modulating index, mi	THD
0.3	2.87%
0.5	2.63%
0.7	2.24%
1	1.81%

Matlab simulation with switching frequency of 5kHz

Modulating index, mi	THD
0.3	2.50%
0.5	2.14%
0.7	1.76%
1	1.45%

Matlab simulation with switching frequency of 7kHz

Modulating index, mi	THD
0.3	2.33%
0.5	1.59%
0.7	1.46%
1	1.22%

Matlab simulation with switching frequency of 9kHz

The data shown in the above table is the result of total harmonic distortion when the modulation index and the switching frequencies are being varied. To further compare the findings, all the data are plotted into the chart as shown in Figure 12.

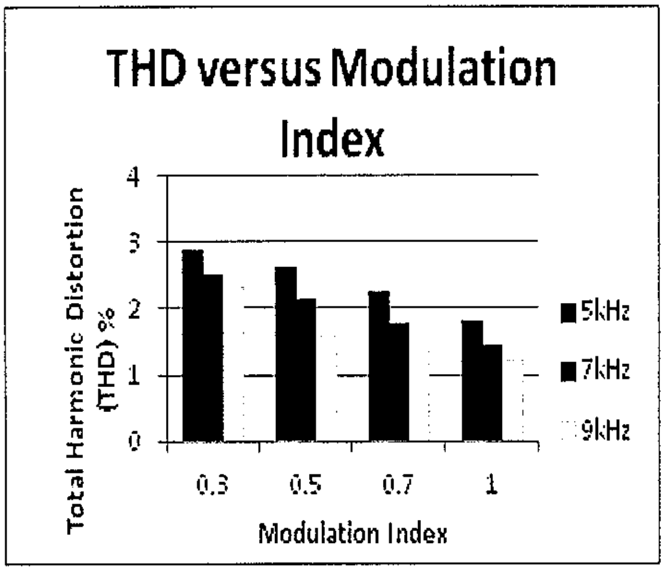


Fig 12. Total Harmonic Distortion versus Modulation Index

Based on the findings above, it can be seen that as the switching frequency being varied from 5kHz, 7kHz and 9kHz and the modulation index being varied from 0.1 to 1, the output RMS voltage is increasing. The total harmonic distortion (THD) of the converter is decreasing as the modulation index and switching frequencies being varied.

A. Result of Matlab simulation

The SPWM is generated by multiplying the modulation index which in this case is 0.5 with the sine wave. Then the product is being compared to the triangular wave. The result of the SPWM generated by the controller circuit is show in the Figure 13 below.

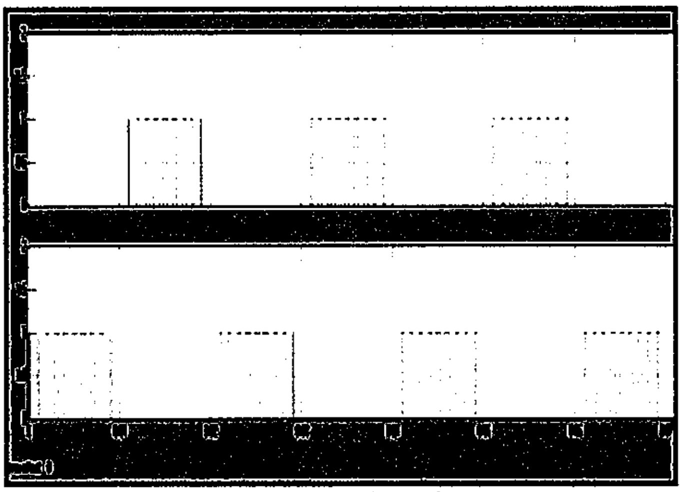


Fig 13. SPWM Waveform Generated

For the waveform of the output voltage with switching frequency 5kHz and 9kHz based on the modulation index that has been varies is shown in Figure 14.1, Figure 14.2 and Figure 14.3 below:

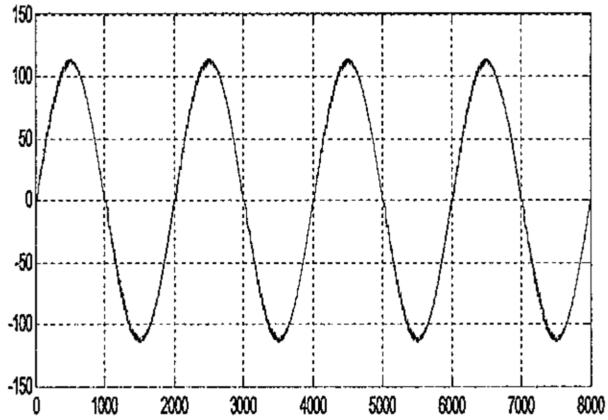


Fig 14.1 Matlab simulation RMS output voltage Vout=79.36 for modulation index, mi=0.5 with switching frequency of 5kH

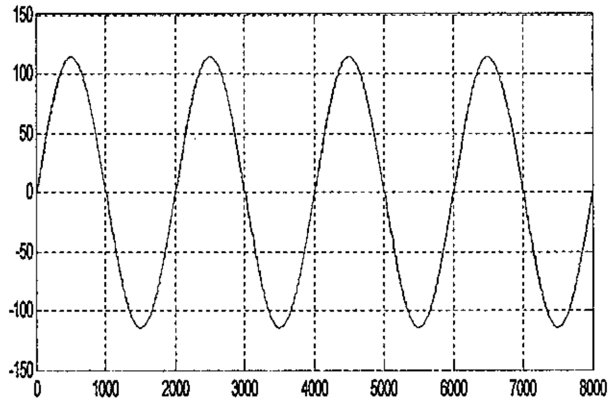


Fig 14.2 Matlab simulation RMS output voltage Vout=80.37V for modulation index, mi=1 with switching frequency of 5kH

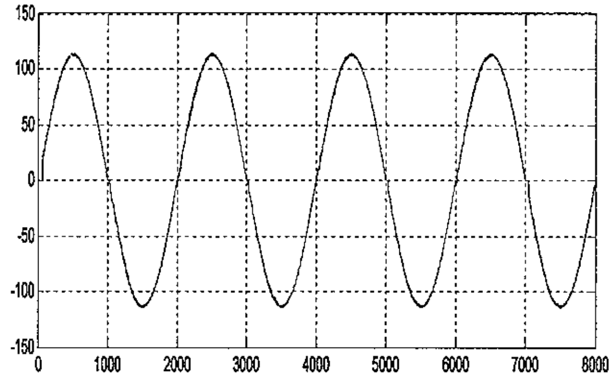


Fig 14.3 Matlab simulation RMS output voltage Vout=79.89 for modulation index, mi=0.5 with switching frequency of 9kH

The Figure 15.1 and Figure 15.2 shown below is the result of the total harmonic distortion (THD) of the proposed circuit.

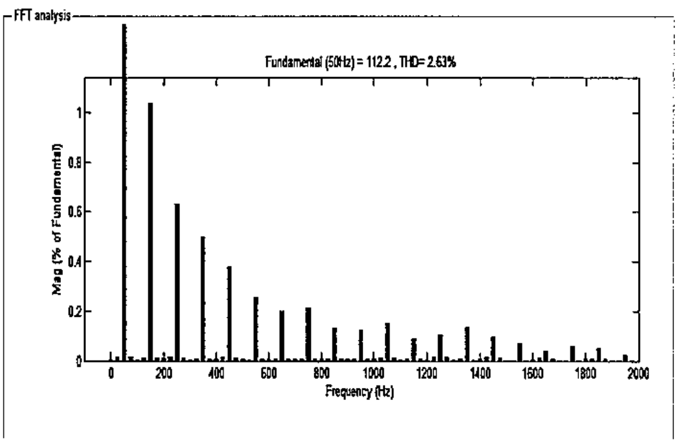


Fig 15.1 Matlab simulation Total Harmonic Distortion (THD) = 2.63% for modulation index, mi=0.5 with switching frequency of 5kH

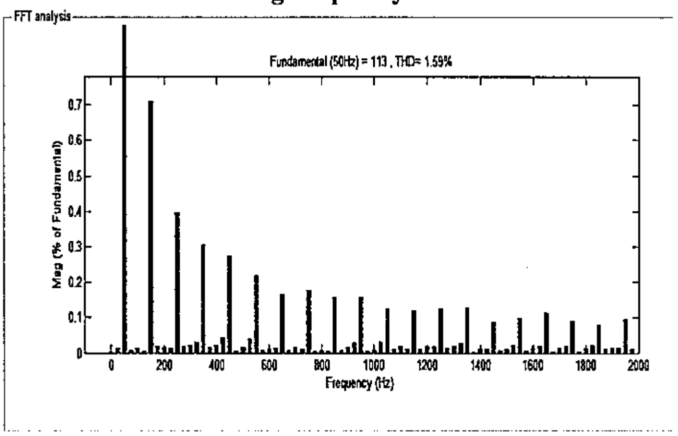


Fig 15.2 Matlab simulation Total Harmonic Distortion (THD) = 1.59% for modulation index, mi=0.5 with switching frequency of 9kH

From the results obtained above, it can be seen that as the modulation index and also the switching frequencies are increase, the output voltage waveform become much smoother with fewer ripple. The value of the total harmonic distortion (THD) also becomes decreasing as the modulation index and switching frequencies are increase.

VIII. CONCLUSION

An AC chopper using SPWM is studied in this project. In AC Choppper, the input signal that is being provided is AC signal and the output signal that supposed to being produced is also AC signal. A traditional ac chopper using thyristor produced some disadvantages such as high voltage peak and power losses. An intelligent gate-switching patterns using information from input and output voltage can overcome the high voltage peak that is resulted by the commutation problem. SPWM that is used in this project can eliminate the harmonic distortions that occur in the system. As we all known harmonic will cause the system disturbance and also increase the heating losses in the system. So by using the SPWM can improved power factor, elimination of low-order harmonics and wide voltage control range. By improving the AC Chopper, all the customer demand can be fulfill and will contribute to the growth in electrical industry

IX. RECOMMENDATIONS

This project can be improved for the future work as listed below:

1. Implementation of the AC Chopper hardware to investigate the actual operation and also the actual characteristic of the proposed study.
2. Using digital electronics control to control the switching technique of the circuit by using Xilinx FPGA, PIC and also DSP.
3. Use the suitable value of capacitor in filter part to produce a much smooth waveform with fewer ripples.

ACKNOWLEDGMENT

Thank you to Madam Siti Zaliha bt Mohammad Noor for all the guidance and support in helping to finish this project. Also thank you to all the other lecturers and friend who are involve in giving ideas and motivation until this research is completed. Their contribution is really appreciated.

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