PWM Switching Method for Single Phase Converter and Harmonic Mitigation Technique

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Abstract - ***In this project, the implementation of a single phase AC/AC converter will be discussed. An IGBT single phase converter is built using MATLAB/Simulink. Pulse Width Modulation (PWM) switching is applied to the IGBT gates. A nominal voltage of 240V with 50Hz frequency is applied to run the converter. The simulation results show that PWM switching caused high THD to the circuit. Power Active Filter is used as an attempt to mitigate the harmonic components by compensating the unwanted signal at the resulting waveform. The power active filter is implemented to reduce the THD of the converter. The simulated single-phase AC/AC converter will be beneficial for further studies in improving the performance of electrical mechanism such as the AC machine.***

Keyword – Pulse Width Modulation (PWM), Single-phase AC/AC converter, IGBT, Power Active Filter

1.0 INTRODUCTION

This project presents a single-phase AC/AC converter controlled by PWM switching. Simulations will be done using MATLAB/Simulink software. A power active filter is used to mitigate the harmonics produced at the output waveforms. Results of simulation are evaluated by varying the load and determining the Total Harmonic Distortion (THD). Below are several introductions on the components and applications involved in building the single-phase AC/AC converter and the switching method chosen:

1.1 Insulated Gate Bipolar Transistor (IGBT)

The insulated gate bipolar transistor or IGBT is a three-terminal power semiconductor device, noted for high efficiency and fast switching. It switches electric power in many modern appliances: electric cars, variable speed refrigerators, air-conditioners, and even stereo systems with switching amplifiers. Since it is designed to rapidly turn on and off, amplifiers that use it often synthesize complex waveforms with pulse width modulation and low-pass filters.

The IGBT combines the simple gate-drive characteristics of the MOSFETs with the high-current and low-saturation-voltage capability of bipolar transistors by combining an isolated gate FET for the control input, and a bipolar power transistor as a switch, in a single device. The IGBT is used in medium- to high-power applications such as switched-mode power supply, traction motor control and induction heating. Large IGBT modules typically consist of many devices in parallel and can have very high current handling capabilities in the order of hundreds of amperes with blocking voltages of 6000V. [1]

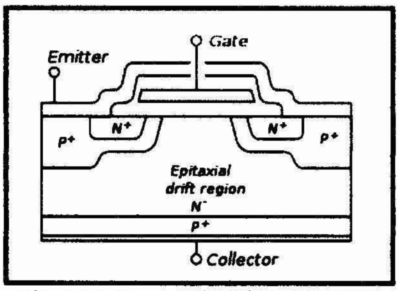


Figure 1.1: Cross section of a typical IGBT

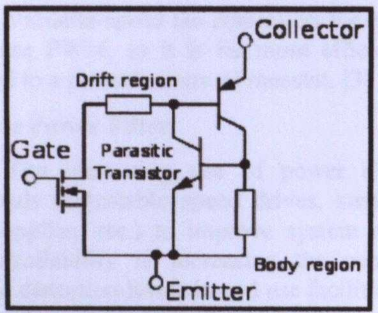


Figure 1.2: Equivalent circuit for IGBT

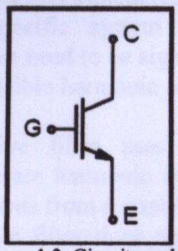


Figure 1.3: Circuit symbol

1.2 IGBT Based Single-phase AC/AC Converter

Figure 1.4 shows a single-phase AC/AC converter circuit whereby the fundamental component used is the IGBT. Since it is an AC to AC converter, current will flow through IGBT labeled S1, S4, S6 and S7 when positive-cycle and negative-cycle source is applied. The output waveform will be in sinusoidal state such as the input.

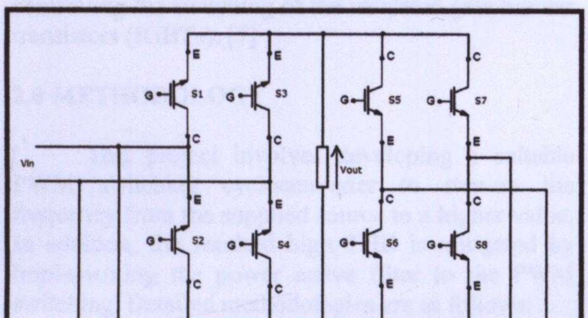


Figure 1.4: IGBT AC/AC Converter

1.3 PWM Switching Method

PWM works well with digital controls, which, because of their on/off nature, can easily set the needed duty cycle.

PWM of a signal or power source involves the modulation of its duty cycle, to either convey information over a communications channel or control the amount of power sent to a load.

Pulse-width modulation uses a rectangular pulse wave whose pulse width is modulated resulting in the variation of the average value of the waveform.

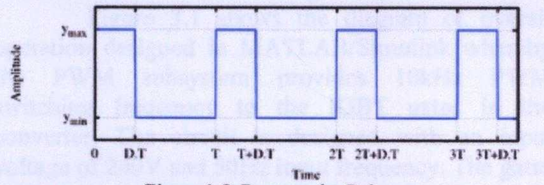


Figure 1.5: Rectangular Pulse

Referring to Figure 1.6, a simple method to generate the PWM pulse train corresponding to a given signal is the intersective PWM: the signal (sinewave) is compared with a saw tooth waveform (triangular waveform). When the latter is less than the former, the PWM signal (rectangular wave) is in high state (1). Otherwise it is in the low state (0).

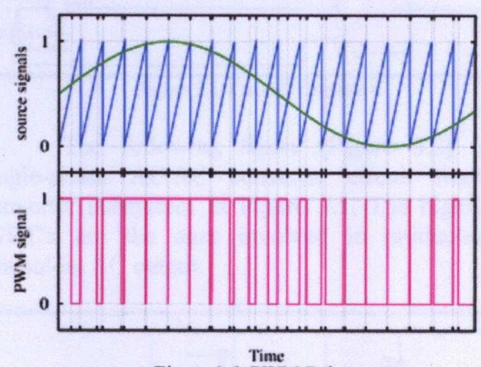


Figure 1.6: PWM Pulse

Many digital circuits can generate PWM signals (e.g. many microcontrollers have PWM outputs). They normally use a counter that increments periodically (it is connected directly or indirectly to the clock of the circuit) and is reset at the end of every period of the PWM. When the counter value is more than the reference value, the PWM output changes state from high to low (or low to high).

PWM is also used in efficient voltage regulators. By switching voltage to the load with the appropriate duty cycle, the output will approximate a voltage at the desired level. The switching noise is usually filtered with an inductor and a capacitor.

One method measures the output voltage. When it is lower than the desired voltage, it turns on the switch. When the output voltage is above the desired voltage, it turns off the switch.

Variable-speed fan controllers for computers usually use PWM, as it is far more efficient when compared to a potentiometer or rheostat. [3]

1.4 Active Power Filter

The increasing use of power electronics based loads (adjustable speed drives, switch mode power supplies, etc.) to improve system efficiency and controllability is increasing the concern for harmonic distortion levels in end use facilities and on the overall power system. The application of passive tuned filters creates new system resonances which are dependent on specific system conditions. Also, passive filters often need to be significantly overrated to account for possible harmonic absorption from the power system.

The active filter uses power electronic switching to generate harmonic currents that cancel the harmonic currents from a nonlinear load.

The active filter does not need to provide any real power to cancel harmonic currents from the load. The harmonic currents which will be canceled show up as reactive power. Reduction in the harmonic voltage distortion occurs because the harmonic currents flowing through the source impedance are reduced. Therefore, the dc capacitors and the filter components must be rated based on the reactive power associated with the harmonics to be canceled and on the actual current waveform that must be generated to achieve the cancellation. The desired current waveform is obtained by accurately controlling the switching of the insulated gate bipolar transistors (IGBTs). [7]

2.0 METHODOLOGY

This project involves developing a suitable PWM switching cycloconverter to step-up the frequency from the supplied source to a higher value. In addition, the resulted high THD is mitigated by implementing the power active filter to the PWM switching. Detailed methodologies are as follows:

a) Understanding the operation and characteristics of an IGBT in which it is the component involved in the AC/AC converter.
b) Designing an IGBT based single-phase AC/AC Converter.
c) Designing a PWM switching for the single-phase Converter.
d) Reducing or eliminating ripple and total harmonic distortion (THD) by applying power active filter to the designed converter circuit.
e) Running a simulation on the single-phase AC/AC Converter using MATLAB/Simulink.
f) Varying load to evaluate the performance of the designed converter.

3.0 TOPOLOGY

3.1 Simulation Circuit Configuration

Figure 3.1 shows the diagram of overall operation designed in MATLAB/Simulink whereby the PWM subsystem provides 10kHz PWM switching frequency to the IGBT gates in the converter. The circuit is designed with an input voltage of 240V and 50Hz input frequency. The gates at IGBT involved are fed with PWM. The PWM will appear at the output voltage following the switching sequence.

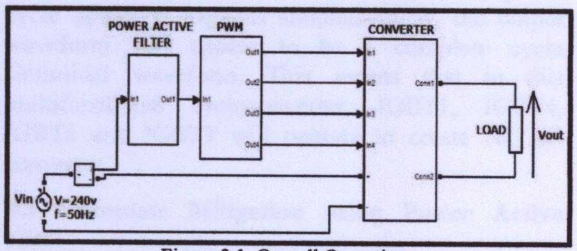


Figure 3.1: Overall Operation

The following figure (Figure 3.2) is the single-phase AC/AC converter circuit from the converter subsystem in Figure 3.1. The highlighted IGBT's are the ones involved in producing the sinusoidal AC output.

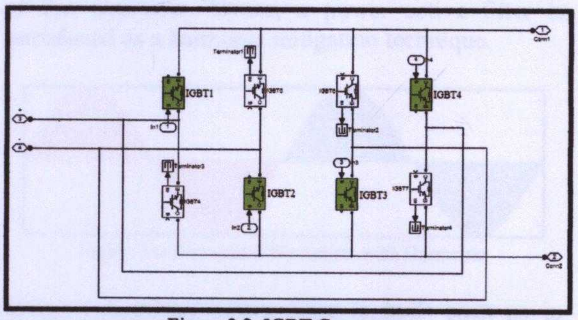


Figure 3.2: IGBT Converter

Figure 3.3 shows the PWM control signal constructed in MATLAB/Simulink. The carrier signal configured in this control circuit is 10kHz and the amplitude is 1V. The modulation index is set to 0.5 and as for the sine wave setting; the signal amplitude is set to 1V and 100π rad/sec frequency. The sine wave is transformed to positive and negative cycle PWM by multiplying the sinusoidal signal with the configured repeating sequence.

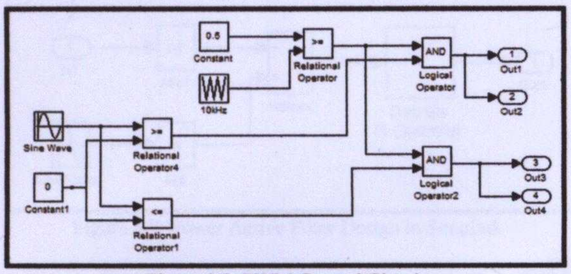


Figure 3.3: PWM Control Circuit

3.2 Single-phase AC/AC Converter Operation

The operation of an IGBT based converter is simple and easy to be understood. During positive cycle showed in Figure 3.4, the current flow through IGBT1, making IGBT1 in an ON state. Then the current flows through load and turning IGBT4 into ON state when it flows through the component. IGBT2, IGBT3, IGBT5, IGBT6, IGBT7 and IGBT8 are in the OFF state. This operation will result a positive sinusoidal half cycle at the output.

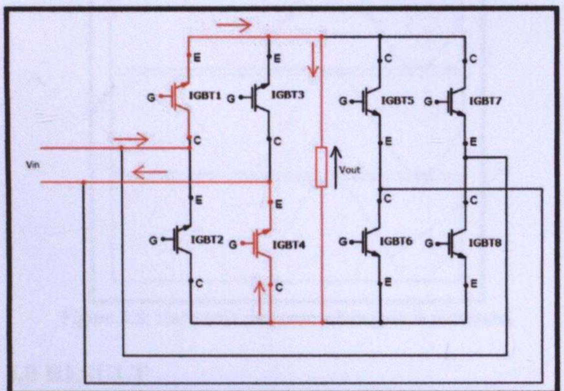


Figure 3.4: During Positive Cycle

It goes similarly the other way around. During the current flow in a negative cycle direction as shown in Figure 3.5, current flows straight through IGBT6 thus turning it into ON state. After passing through load, the current then flows through IGBT7 and therefore switching it ON. IGBT1, IGBT2, IGBT3, IGBT4, IGBT5 and IGBT8 are switched OFF. A negative sinusoidal half cycle will then appear at the output.

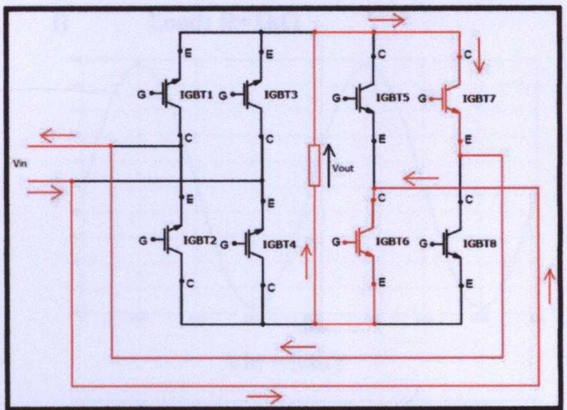


Figure 3.5: During Negative Cycle

However, since the positive and negative cycle operation happens simultaneously, the output waveform will appear to be a complete cycle sinusoidal waveform. This means that in this multifunctional cycloconverter, IGBT1, IGBT4, IGBT6 and IGBT7 will operate to create AC/AC converter.

3.3 Harmonic Mitigation using Power Active Filter

When the IGBT gates are induced with PWM switching signal, there will bound to be harmonics in the current and voltage of the AC/AC converter. This is due to the natural characteristic of PWM switching. Figure 3.6 shows the signal with harmonic distortion that can affect the performance of the converter. Hence, a power active filter is introduced as a harmonic mitigation technique.

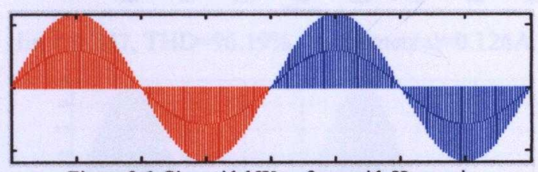


Figure 3.6: Sinusoidal Waveform with Harmonic

A power active filter is built such as in Figure 3.7. Since harmonic affects the current, the harmonic signal will be detected by current sensor whereby unwanted signals are reduced and the original signal will be smoothen by varying the proportional and the integral gain in the Discrete PI Controller.

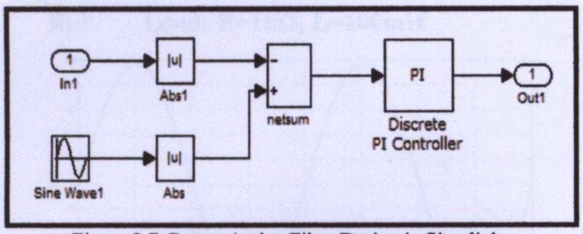


Figure 3.7: Power Active Filter Design in Simulink

By varying the gain in PI controller, total harmonic distortion such as in Figure 3.6 can be reduced. Figure 3.8 shows a sequence on how increment of gain corrected the waveform:

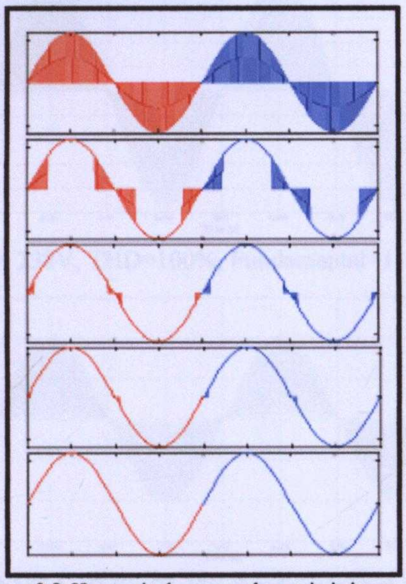


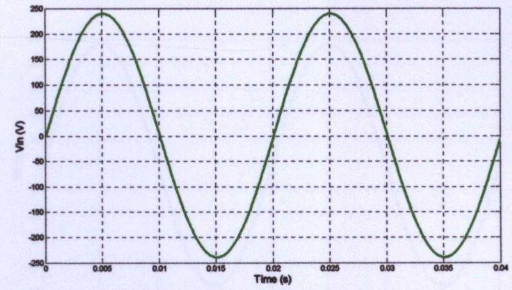
Figure 3.8: Harmonic decrease when gain is increased

4.0 RESULT

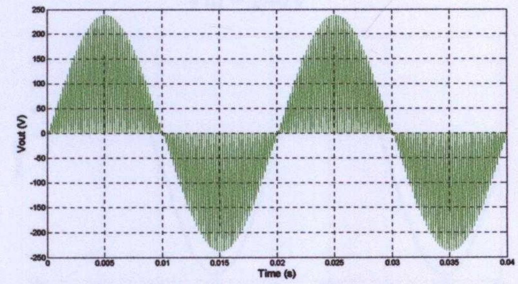
4.1 Simulation Result of Single-phase AC/AC Converter without Power Active Filter

Referring to the waveforms obtained, PWM switching has caused the sinusoidal output signal to have multiple pulses per cycle in both R-load and RL-load AC/AC converter. This shows increment in frequency but the THD also increases.

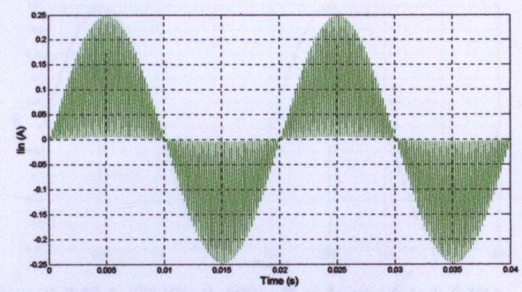
i) Load: R=1kΩ



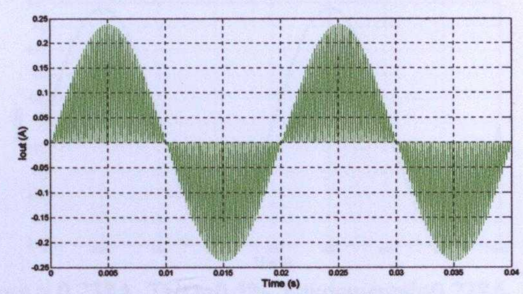
Vin = 240V



Vout = 238V, THD=100%, Fundamental=118.7V

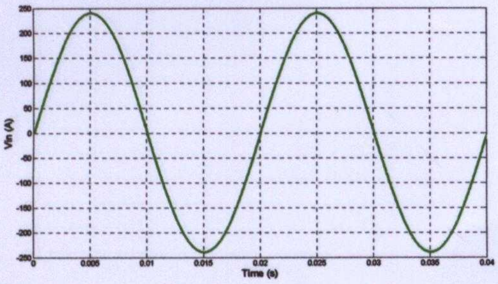


Iin = 0.247, THD=96.19%, Fundamental=0.126A

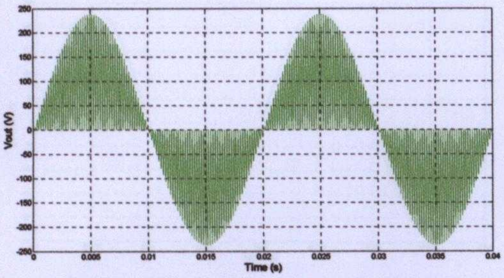


Iout = 0.238, THD=100%, Fundamental=0.119A

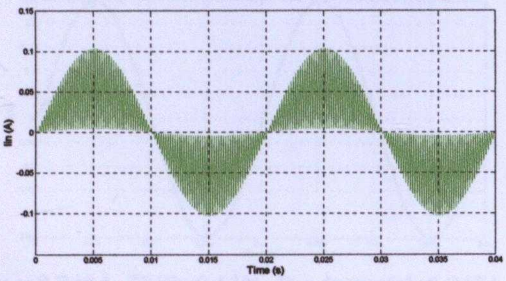
ii) **Load: R=1kΩ, L=100mH**



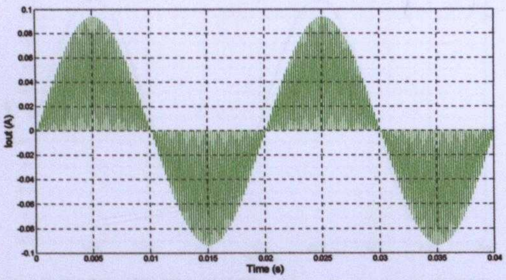
Vin = 240V



Vout = 238V, THD=100%, Fundamental=118.7V



Iin = 0.103A, THD=91.1%, Fundamental=0.054A

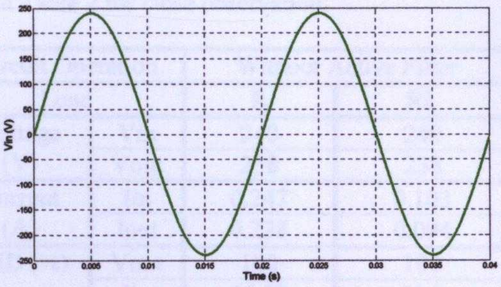


Iout = 0.094A, THD=100%, Fundamental=0.047A

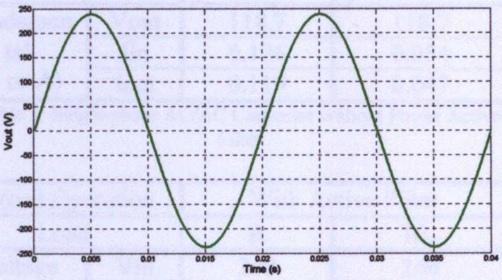
4.2 Simulation Result of Single-phase AC/AC Converter with Power Active Filter

Implementing power active filter causes the output signal in R-load and RL-load AC/AC converter to reduce the THD. The output sinusoidal signals appear to be smoothened.

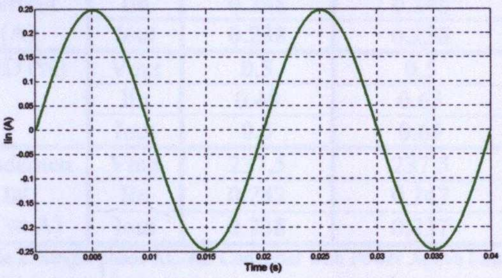
i) **Load: R=1kΩ**



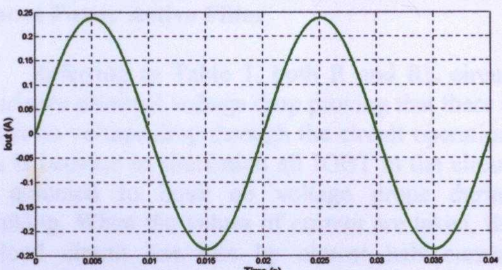
Vin = 240V



Vout = 238V, THD=0.5%, Fundamental=237.5V

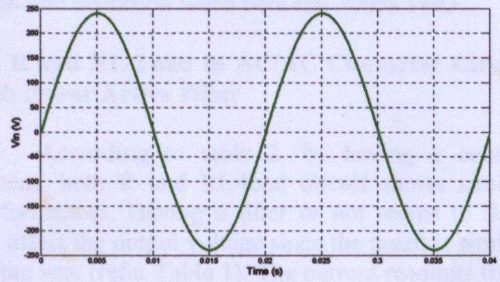


Iin = 0.248A, THD=0.49%, Fundamental=0.247A

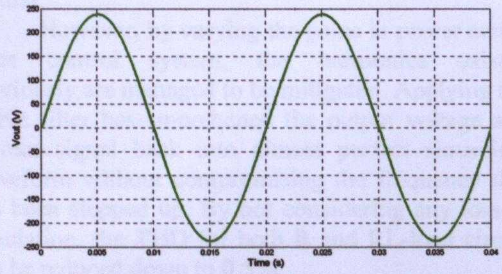


Iout = 0.238A, THD=0.5%, Fundamental=0.238A

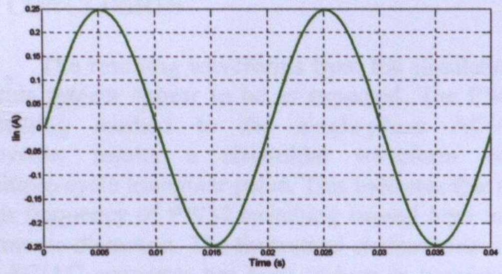
ii) Load: R=1kΩ, L=100mH



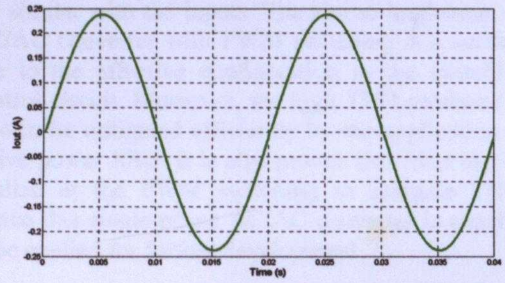
Vin = 240V



Vout = 238V, THD=0.5%, Fundamental=237.5V



Iin = 0.248A, THD=0.63%, Fundamental=0.247A



Iout = 0.238A, THD=0.65%, Fundamental=0.237A

5.0 DISCUSSION

The results obtained are tabulated in Table 1and Table 2 for close observation.

Circuit Operation		Without Active Filter	
Load		R	RL
Voltage (V)	Vin	240	240
	Vout	238	238
Current (A)	Iin	0.247	0.103
	Iout	0.238	0.094
THD (%)	Vout	100	100
	Iin	96.19	91.1
	Iout	100	100
Fundamental (V or A)	Vout	118.7	118.7
	Iin	0.126	0.054
	Iout	0.119	0.047

Table 1: Single-phase AC/AC Converter without Power Active Filter

Circuit Operation		With Active Filter	
Load		R	RL
Voltage (V)	Vin	240	240
	Vout	238	238
Current (A)	Iin	0.248	0.248
	Iout	0.238	0.238
THD (%)	Vout	0.5	0.5
	Iin	0.49	0.63
	Iout	0.5	0.65
Fundamental (V or A)	Vout	237.5	237.5
	Iin	0.247	0.247
	Iout	0.238	0.237

Table 2: Single-phase AC/AC Converter with Power Active Filter

5.1 R and RL Load in AC/AC Converter Circuit without Power Active Filter

Referring to Table 1, both R and RL circuit experience minimal voltage drop proving that there is almost no voltage drop through the circuit operation. This is because in simulation all IGBT in the circuit are assumed to have no voltage drops during switching. When the values of current are taken, the RL-load circuit has less by almost half current reading comparing to the R-load circuit. The existence of induction in RL-load circuit has caused the current to reduce.

It is highly noticeable when the circuit runs without applying power active filter, the THD for both Vout and Iout appear to be high where both obtained 100% THD respectively. This is due to a very large amount of multiple cycle pulse produced by the PWM switching. The input current from both circuits also yield high THD with 96.19% and 91.1% in R-load and RL-load circuit respectively. The output current from both circuit also has high harmonic distortion when both has 100% THD.

5.2 R and RL Load in AC/AC Converter Circuit with Power Active Filter

According to table 2, by having a control system, both R and RL-load circuit shows similar performances. Having a filter or not seems to does not affect the output voltage since the result is similar all the way (refer Table 1). The current readings from both R-load and RL-load circuit also appear to be similar.

However, by varying the gains in power active filter control system, the harmonics existed previously are managed to be mitigated. Applying the active filter has smoothened the output voltage and current signal back into almost perfect sinusoidal waveform without compromising the frequency that has been stepped up. By not considering any loss in simulation, the THD for both R and RL-load circuit can be reduced down to 0.5%.

6.0 CONCLUSION

The resulting waveforms from the simulations in this project appear to be as expected. The PWM switching method to the single-phase AC/AC converter results a sinusoidal waveform with multiple-cycle triangular pulse. This indicates that the high frequency of PWM switching caused high total harmonic distortion. The theoretical characteristics of an AC/AC converter has been proven in simulation whereby the sinusoidal output waveforms obtained are similar with the inputs. The aim to implement an AC/AC converter with PWM switching is a success due to the effective configuration in the switching control circuit. Moreover, the high THD produced is able to be mitigated efficiently by the application of active power filter. It is also proven that filter can be applied at the PWM switching to mitigate THD. Hence this single-phase AC/AC converter is capable to be applied for further development.

7.0 FUTURE DEVELOPMENT

This project can be applied to improve the performance of related electrical mechanism such as the single phase AC induction machine. A frequency step-up cycloconverter can be built by implementing the proposed methods. The increment of frequency will compliment the induction machine speed formula which is (120f)/p, saying that frequency increase will increase the rotor speed of machine. The simulation and PWM switching method from this paper can be referred to develop a more effective and efficient cycloconverter thus can improve a higher powered induction machine.

8.0 ACKNOWLEDGEMET

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