



Simulation and Experimental Validation of AC to AC Converter Waveform and Power Consumption using the Integral Cycle PWM Technique

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ABSTRACT: In this paper, integral cycle PWM AC to AC converter waveform and power consumption were successfully simulated and validated by experiment. The simulated waveforms are considerably similar to the experimental waveform. Two types of gate drive were used, which are BJT transistor and Optocoupler. When BJT was used, the experimental waveform was considerably different from the simulated waveform. This problem was overcome by using Optocoupler. 100 Hz switching frequency has the highest power and less error (difference between the simulated and the experimental) among the other switching frequency. The integral cycle PWM generated by using Tiva C Launchpad and Code Composer Studio (CCS) software were used to write program. This topology has the lowest THD and the high power factor among the other topologies.

KEYWORDS: AC to AC converter, Integral cycle, PWM, Optocoupler, Experimental validation, Integral cycle PWM

I. INTRODUCTION

Improving the efficiency, producing specific power consumption, and implementing conservation can be done by using power controllers which are devices used to control the power to the load. In the past, engineers used to control the power by resorting to transformer tap changing or resistive control. However power electronic technologies can control the power flow by amendment of the AC waveform which is considered as a great advantage of the power controllers. There are four types of power controllers, which are also known as power converters, which are DC to DC converters, DC to AC converters, AC to DC converters and AC to AC converters. AC to AC converter is the lowest cost among the power converters. It used to produce variable output voltage when the input is AC supply by using either of two techniques which are integral cycle or phase angle. It is only applicable for lighting control (dimming), industrial heating (heaters and furnaces) and low range speed control of induction motor, because of the waveform distortion at low cyclic pulsation or large delay angles [1].

Chopping (switching) elements, which can afford high power, are needed in AC to AC converters, high power flexible alternate current transmission systems (FACTSs), motor drives and huge UPS systems. Multiple rectifiers for unity power factor correction, multiple switching elements in one leg of an inverter and optimization of motor performance indices are developed to overbear limits of semiconductor choppers [2].

Phase angle AC to AC converter technique, which can be called an integral cycle control with thyristor, has been widely used. However, this technique has many obstacles, such as abundant low order harmonics in both of supply voltages/currents, a severance of power flow to the load arise and lagging power factor at the input side due to the tardiness of the firing angle [2].

Integral cycle AC to AC converter technique, which is also known as PWM AC controller, is used to overcome the Phase angle AC to AC converter technique obstacles using forced commutated apparatus, which have best synoptic

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performed. If the load is inductive, a freewheeling diode across it can be used to make it behave as a resistive load. This technique has important advantages as compared to the phase angle technique, which are an input power factor is improved, better transient response, does not require enormous and expensive LC input/ output filter components, and considerable lessening in the harmonic contents [2].

Lessening in the number of switching instants is fundamental for efficiency because chopping control is usually escorted by extra losses due to the switching losses. Thus, eclectic harmonic abstraction/ control has been a vastly studied ersatz to traditional PWM techniques [2].

This topology has the highest power factor and the lowest total harmonic distortion among other topologies that listed in the references [1-12].

II. METHODOLOGY

The schematic diagram shown in figure 1 has been simulated and built to compare between the simulation and experimental results. The schematic diagram and simulation were done using MATLAB/Simscape. The schematic consists of two sources, two main components, and one load. Firstly, the two sources are a 12 V AC source and the Pulse Width Modulation (PWM) generator. A 12 Vrms source was used as input to the converter. The PWM generator amplitude is 5 V, the switching frequency has been varied between 10 Hz and 1 kHz, and the duty cycle also has been varied between 10% and 90%. Secondly, the two main components are two bi-directional MOSFET switches. A MOSFET switch works only with DC power; therefore, two MOSFET were used as back to back. Thus; each MOSFET can control one cycle. MOSFET switch is a type of power transistor. MOSFET has three terminals, which are gate, drain and source. PWM is applied through the gate of it to control the power. Thirdly, the load is a resistive load, which is a 10 k resistor.

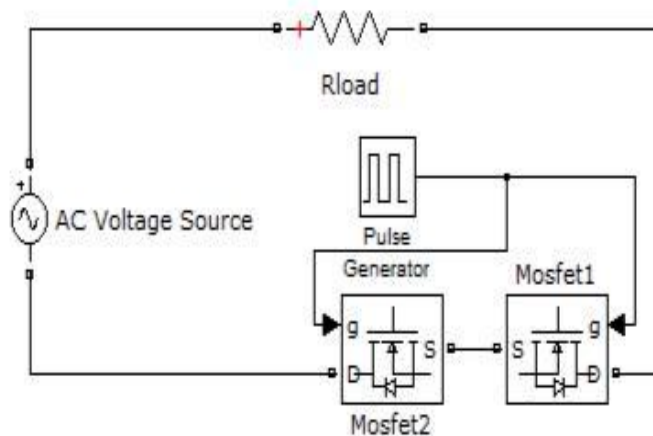


Figure 1: Schematic diagram of the AC-AC converter.

The duty cycle of the PWM generator has been varied and the output power has been recorded and plotted. Figure 2 shows the flow chart process for fixed switching frequency with different duty cycle.

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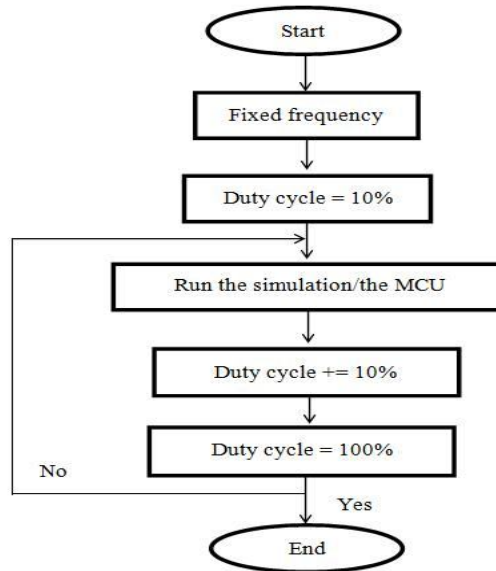


Figure 2: Flow chart of fixed switching frequency among different duty cycle

IV. SIMULATION DEVELOPMENT

The AC-AC converter was simulated using MATLAB software. The schematic diagram shown in Figure 1 has been simulated to obtain the output voltage waveform. The simulation was done for fixed switching frequency among different duty cycle. Figures 3, 4, 5 and 6 show the simulated output voltage waveforms when $f_{sw} = 50$ Hz and $k = 90\%$, $f_{sw} = 100$ Hz and $k = 50\%$, $f_{sw} = 200$ Hz and $k = 10\%$, and $f_{sw} = 1$ kHz and $k = 90\%$, respectively.

The output power (P_o) was calculated by multiplying the rms output voltage (V_{rms}) times the rms output current (I_{rms}) using equation (1).

$$P = V_{rms} \times I_{rms} \quad (1)$$

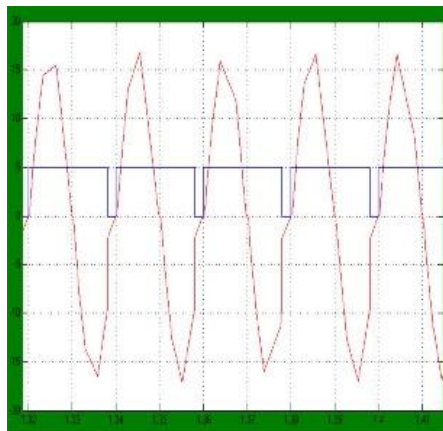


Figure 3: The simulated output voltage waveform when $f_{sw}=50$ Hz and $k= 90\%$

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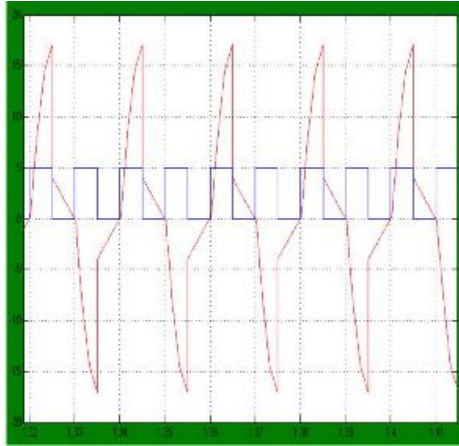


Figure 4: The simulated output voltage waveform when $f_{sw}=100$ Hz and $k= 50\%$

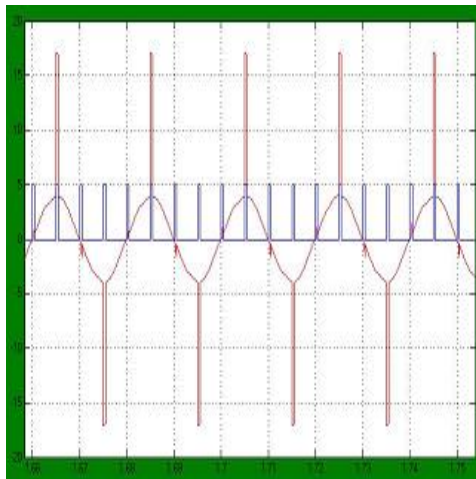


Figure 5: The simulated output voltage waveform when $f_{sw}=200$ Hz and $k= 10\%$

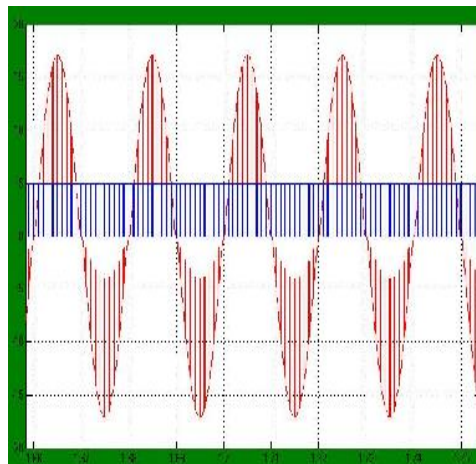


Figure 6: The simulated output voltage waveform when $f_{sw}=1$ kHz and $k= 90\%$

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V. EPERIMENTAL DEVELOPMENT

The schematic shown in Figure 1 was built for experimental test. Then a PCB was fabricated. Two IRFP 460 power MOSFET were used. The type of the MCU used in this experiment was Tiva C Launchpad and Code Composer Studio (CCS) software were used to program it. The output PWM from the Launchpad's voltage is only 3.3 Vpp. However the minimum voltage to fire the MOSFET is 5 V. Therefore, an Optocoupler was used between the MCU and the gate of the two MOSFET to boost the amplitude of the PWM up to 10 Vpp. A step down transformer was used to step down the voltage from 240 Vrms to 12 Vrms. Then, the 12 Vrms was connected to the converter as the input voltage. (Figure 7) shows the experimental setup.

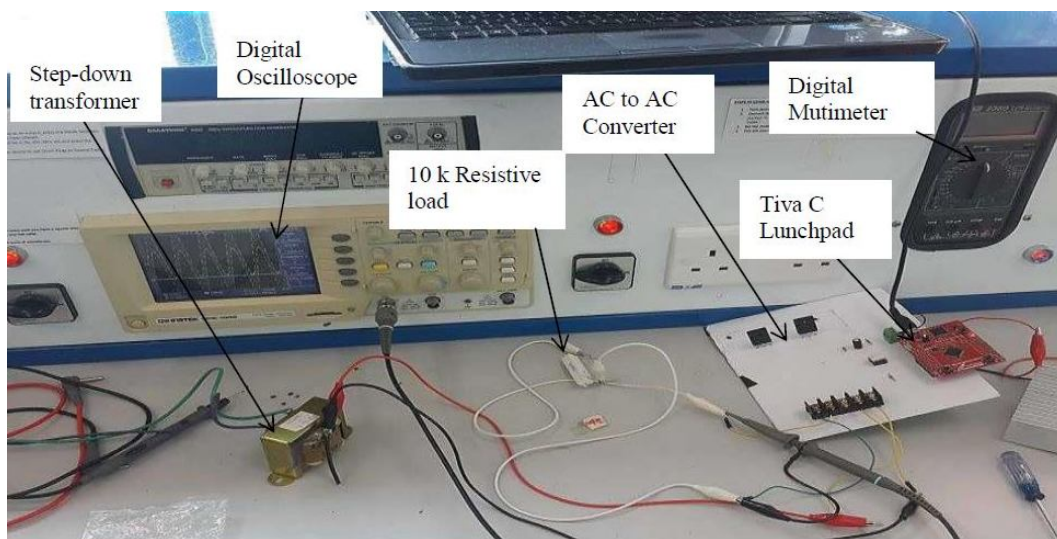


Figure 7: Experimental setup

(Figure 7) shows the oscilloscope used to measure and observes the waveform of the output voltage. Figures 8, 9, 10 and 11 shows the experimental output voltage waveforms when $f_{sw} = 50$ Hz and $k = 90\%$, $f_{sw} = 100$ Hz and $k = 50\%$, $f_{sw} = 200$ Hz and $k = 10\%$, and $f_{sw} = 1$ kHz and $k = 90\%$, respectively.

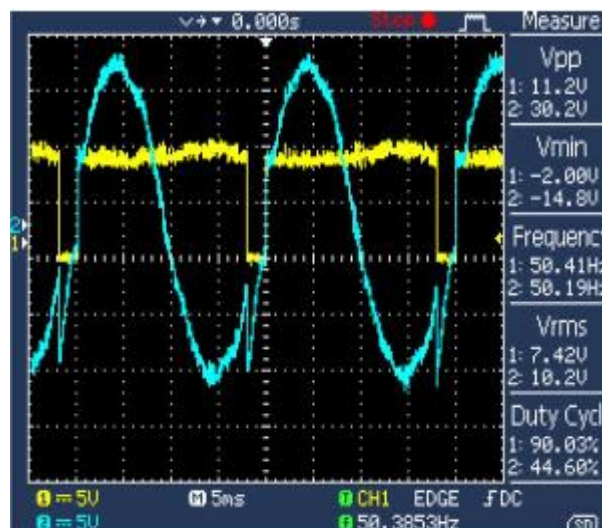


Figure 8: The experimental output voltage waveform when $f_{sw}=50$ Hz and $k=90\%$

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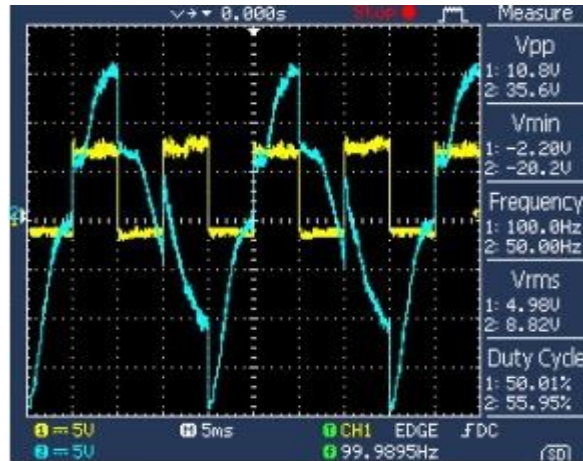


Figure 9: The experimental output voltage waveform when $f_{sw} = 100$ Hz and $k = 50\%$

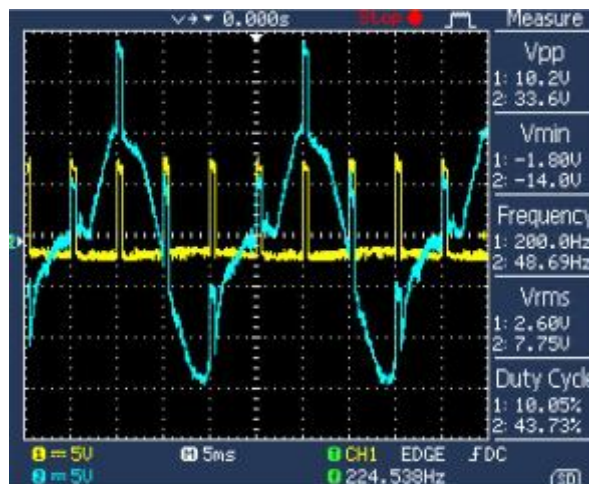


Figure 10: The experimental output voltage waveform when $f_{sw} = 200$ Hz and $k = 10\%$

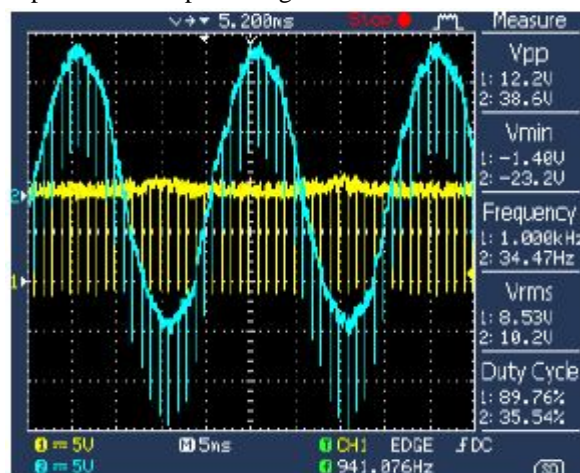


Figure 11: The experimental output voltage waveform when $f_{sw} = 1$ kHz and $k = 90\%$

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VI. RESULT AND DISCUSSION

One of the problems that have been faced in doing the experimental results was driving the gate of the MOSFET. NPN BJT was used as a gate drive; however, the experimental waveform was considerably different from the simulation as shown in Figure 12. The problem was in the positive cycle because the gate signal is not fully ground. The problem was fixed by using an opto-coupler, also it can be named as opto-isolator (part no: TLP250). The correct waveform after using the TLP250 was shown in (Figure 11). Thus, the opto-coupler can fully ground the PWM signal as well as boost up the amplitude of the signal.

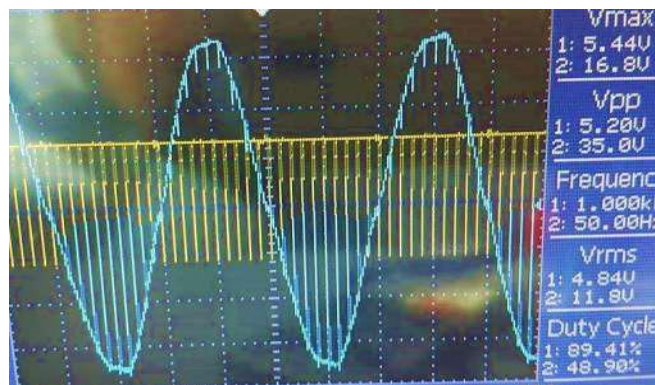


Figure 12: The experimental output voltage waveform when $f_{sw}=1$ kHz and $k=90\%$ using NPN BJT as a gate drive

The output power (P_o) was simulated and measured using fixed switching frequency and varied duty cycle (k) as shown in Figure 12. Graphs were plotted after collecting the results from the MATLAB software (simulation) and digital multi-meter, recording, and inserted into Microsoft Excel and plotted on it. Figure 13 shows the simulated total output load power comparison among different duty cycle and fixed switching frequency. Figure 14 experimental total output load power comparison among different duty cycle and fixed switching frequency.

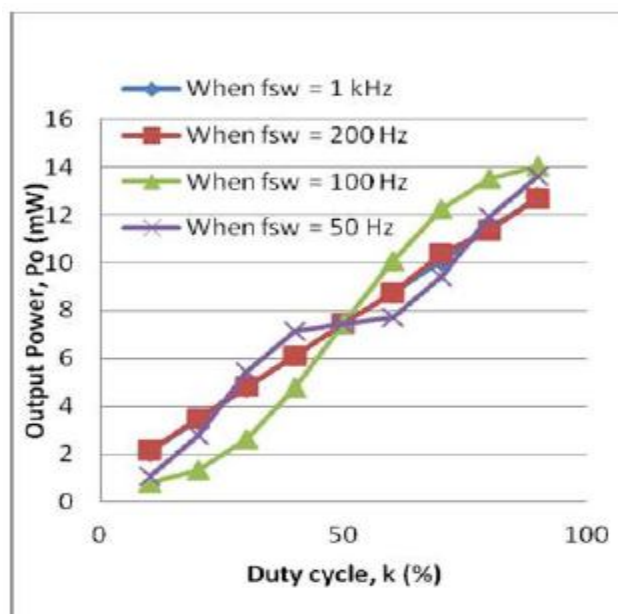


Figure 13:The simulated total output load power comparison among different duty cycle and fixed switching frequency

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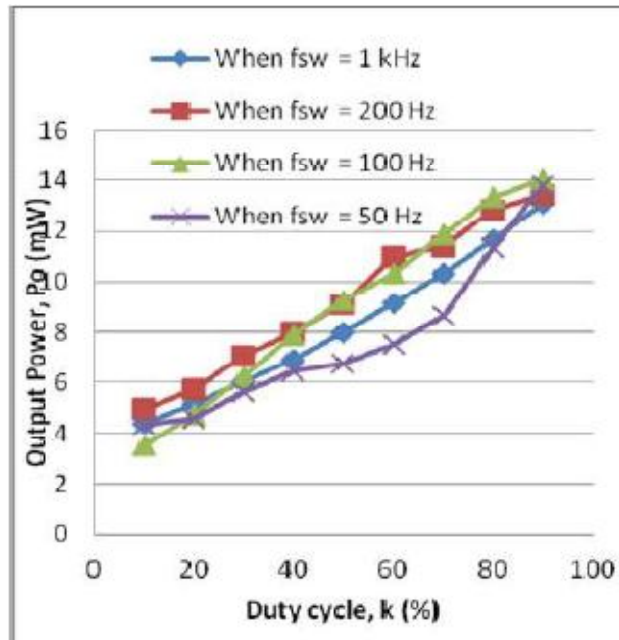


Figure 14: the experimental total output load power comparison among different duty cycle and fixed switching frequency

From the simulation results, the output power is linear when the switching frequency is 1 kHz and 200 Hz as well as they have the same output power. When the switching frequency is 50 Hz, the output power is higher at a lower duty cycle and lower at higher duty cycle. When the switching frequency is 100 Hz, the output power is lower at a lower duty cycle and higher at higher duty cycle.

From the experimental results, the output power is linear when the switching frequency is 1 kHz, however, when the fsw is 200 Hz, the P_o goes linear starting from lower duty cycle but it becomes non-linear at 60% duty cycle and above. When the switching frequency is 100 Hz, output power is lower at a lower duty cycle and higher at higher duty cycle. However, the output power is lowest when the switching frequency is 50 Hz.

The observation that can be taken from these two figures is that there is slightly difference between the simulated and experimental results. Therefore, the difference (error) between the simulated and practical results was calculated and plotted as shown in (Figure 15).

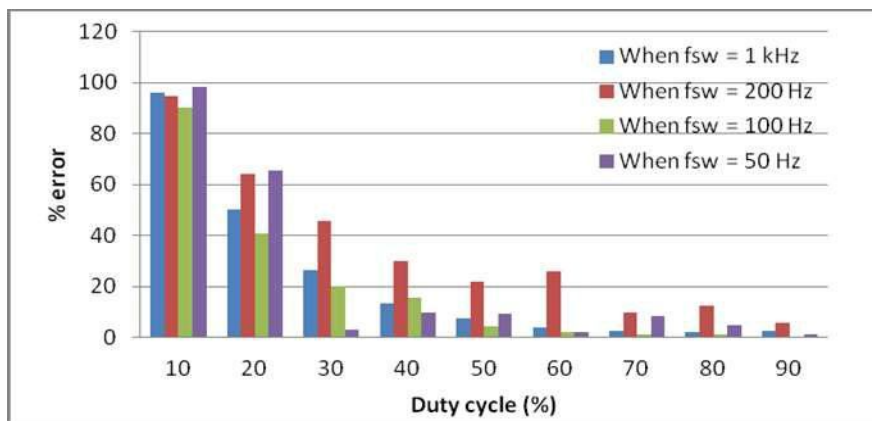


Figure 15: The difference between the simulated and experimental results.



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Figure 15 shows when the switching frequency is 50 Hz, the difference is very high at 10% and 20% and it is very low at a higher duty cycle. When the switching frequency is 200 Hz, the difference keeps decreasing from 10% to 50 % and increased by 60% then keeps decreasing again. The difference keeps decreasing with the increasing of the duty cycle when the switching frequency is 1 kHz as well as for the 100 Hz switching frequency, which has the lowest difference.

VII. CONCLUSION

This AC to AC converter topology was successfully validated by using simulation MATLAB/SimPowerSystems and with experimental development. This topology has the lowest total harmonic distortion and the high power factor among other topologies. After analysing the simulated and experimental results, 100 Hz switching frequency has the highest output power, which is dissipated by the load and the less error among the other switching frequencies.

The power quality, especially the total harmonic distortion and eliminated it, i.e. using filters for eliminating it. Furthermore, a comparison between this topology and other topologies is recommended to be analysed by validating method for all the topologies, i.e. simulation and experimental developments.

REFERENCES

1. Nigim KA, HeydtGT, "Power quality improvement using integral-PWM control in an AC/AC voltage converter", Electric Power Systems Research, 65-71, 2002.
2. Al-OthmanAK, Nabil A, Ahmed, AlSharidahME, Hanan A, AlMekhaizim, "A hybrid real coded genetic algorithm-Pattern search approach for selective harmonic elimination of PWM AC/AC voltage controller", Electrical Power and Energy Systems, 44: 123–133, 2013.
3. Ahmed NA, Faisal Q, EneziEI, Al-OthmanAK, "Comprehensive analysis and transient modelling of symmetrical single phase PWM AC–AC voltage converters", Electric Power Systems Research, 81: 57–65, 2011.
4. Samo AL, Sattar AL, Ahmed MM, "SIMULATION AND EXPERIMENTAL HARMONIC ANALYSIS OF AC VOLTAGE CONVERTER TOPOLOGIES", Sci.Int,Lahore,25(2): 327-331,2013.
5. KwonBH, MinBD, KimJH, "Novel commutation technique of AC–AC converters", IEE Proc.Electr. Power Appl., 145: 4, July 1998.
6. Ahmed NA, Amei K, Sakui M, "AC chopper voltage controller-fed single-phase induction motor employing symmetrical PWM control technique", Electric Power Systems Research 55: 15–25, 2000.
7. Basavaraj N, Choukimath, "Harmonic Analysis of Output Voltage of Single phase AC Voltage Controllers", 2014 International Journal of Modern Trends in Engineering and Research, 02: 1, January 2015.
8. Agarwal A, Agarwal V, "FPGA based variable frequency AC to AC power conversion", Electric Power Systems Research, 90: 67– 78, 2012.
9. CovicGA, BoysJT, "Noise quieting with random PWM AC drives", IEE Proc.Electr. Power Appl., 145:1, January 1998.
10. Mansoor MK, Rana A, Dong F, "Improved ac/ac choppers-based voltage regulator Designs", IET Power Electron., 7(8): 1989–2000, 2014.
11. Aditya T, "Research to study Variable Frequency Drive and its Energy Savings", 2(6), June 2013.
12. Lazzarin TB, Mocolini MP, Barbi I, "Split-phase switched-capacitor ac–ac converter", IET Power Electron., pp. 1–11, 2015.