International Journal of Pure and Applied Mathematics
Volume 117 No. 21 2017, 575-589
ISSN: 1311-8080 (printed version); ISSN: 1314-3395 (on-line version)
url: http://www.ijpam.eu
Special Issue
ijpam.eu

The Study on Multi-Function Single Phase Power Converter with Four Operation Modes

[1]Jung-Hwan Lee, [2]Kwang-Suk Song, [3]Seong-Mi Park and [4]Sung –Jun Park

[1]Department of Electrical Engineering,
Chonnam National University,
Korea.
roburst@naver.com

[2]Department of Electrical Engineering,
Chonnam National University.
Korea.
seongmi@klc,ac,kr

[3]Department of Lift Design,
Korea Lift College,
Korea.
kwang1017@nate.com

[4]Department of Electrical Engineering,
Chonnam National University,
Korea.

Abstract

Current industrial sites require diverse power conversion devices. To meet these requirements, a study of the topology that can produce different types of output voltages with a single power converter. System analysis for predicting and evaluating the proposed mutil function single phase power converter performance are conducted by PSIM simulation. A 60Hz 1 kW multi-function single phase converter is designed and realized. The proposed multi-function power converter has AC chopper mode that makes buck or boost output voltage and full-bridge mode that makes AC to DC converter or DC to AC inverter. The multi-function converter is more economical than conventional power converter with only one power conversion mode and can improve the power factor and dynamic characteristics and reduce the size of filter compared with conventional

AVR or slidacs. In addition, it can maintain the function of the conventional full-bridge PWM inverter mode with constant frequency voltage control. The proposed multi-function power converter verifies the increase of efficiency in constant frequency mode compared with DC input voltage method using conventional diode rectifier.

Key Words: Single-phase, power converter, multi-function, AC Chopper, regulator.

1. Introduction

Currently, there is a great demand for automatic voltage regulators and slidacs in the industry. In the case of slidacs, regulations on their use are strict due to their characteristics. As an alternative to this, a single-phase voltage regulator using a general full-bridge PWM inverter method is generally used[1~6].In systems to be required the same input/output frequency and only the magnitude conversion of the output voltage, it is difficult to achieve economical efficiency when a conventional PWM inverter is used. However, if frequency and output voltage conversion are required, slidacscan not be used and power converters that meet the requirements must be applied. Therefore, in this paper, we propose a new multi-function power converter topology that can generate step - up or step - down output voltage with constant frequency and can generate DC/AC conversion (boost) or AC/DC conversion with variable frequency[7]. The validity of the proposed multifunctional power converter topology is verified through simulation and experiments. The proposed multifunctional power converter verifies the increase of efficiency in constant frequency mode compared with DC input voltage method using conventional diode rectifier.

2. The Proposed of Multi-Function Single Phase Power Converter

Typical Single Phase Voltage Regulator

A typical small-sized single-phase voltage converterusing PWM inverter system consists of input filter part,full-bridge diode rectifiers, full-bridge inverter stack and output filter part as shown in Figure 1.If a full-bridge diode rectifier is used to obtain the dc voltage required for the inverter, the harmonic current increases due to the pulsed current of 60 [Hz] and the utilization rate of the transformer decreases. In order to improve, L-C filters are mostly used at the input part. In this case, a large-capacity L-C filter is used for removing lower harmonic components, which is a disadvantage in terms of economy. In addition, an L-C filter is used at the output of the inverter to remove harmonics of the output voltage from the square-wave pulse voltage output of the inverter.

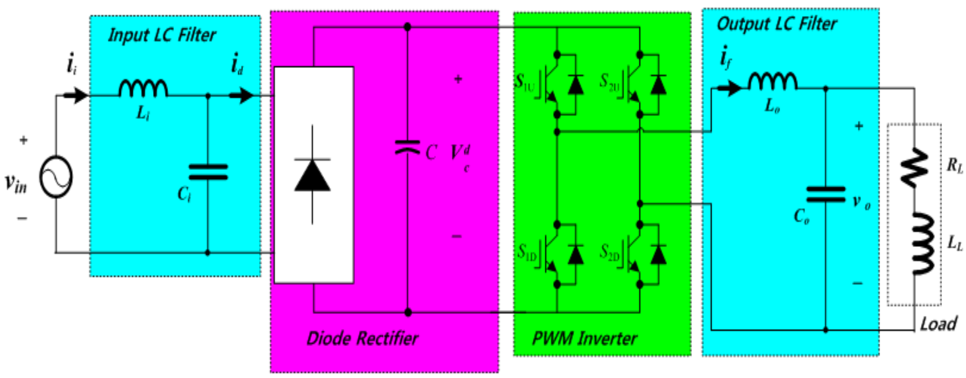


Figure 1: Typical Configuration of the Single Phase Power Converter

If a power converter that can control the frequency as shown in Figure. 1 is used in a system requiring only the magnitude conversion of the output AC power without changing the output frequency, it is difficult to achieve economical efficiency compared with avr or slidacs having the same input and output frequency and the power converter.

The Proposed Multi-Function Single Phase Power Converter

Generally, PWM or PAM control is used to control AC voltage. However, if the frequency of the input voltage and the frequency of the output voltage are the same shape, the output voltage can be controlled by simple duty ratio without PAM control.

The switching harmonics are generated in the output voltage controlled by the simple duty ratio, and an L-C filter is necessary at the output terminal in order to eliminate the switching harmonic component.

The concept of a singlephase voltage regulator is shown in Figure2. As shown in the figure 2, the input voltage (v_{in}) and zero voltage are generated by using the bidirectional switch (Q_{SW}, Q_{bar}) having the interlocked four operation mode. The rmsof the output voltage atvoltage regulator can be controlled by duty rate (*d*).

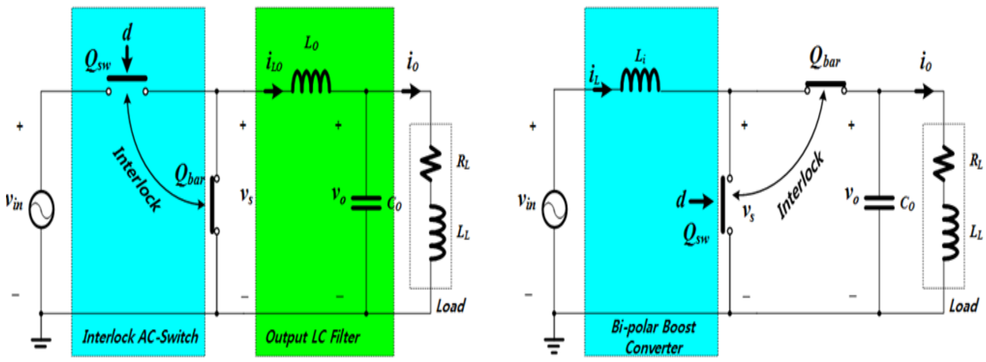


Figure 2: Single Phase Regulator Concept

Figure 3 shows the power circuit diagram of the single-phase voltage regulator to implement the concept of single-phase voltage regulator ofFigure 2 with high-speed switching. The bidirectional switch can be configured in various ways, but a bi-directional switch that consists of two switch elements in series is used as shown in Figure 2.

Compared with the conventional power circuit shown in Figure 1, the power converter in Figure 3 has a structure to remove the full-bridge rectifier and the DC smoothing capacitor.

Generally, the lifetime of the power converter depends on the lifetime of the electrolytic capacitor, thereby eliminating the DC smoothing capacitor, which plays a large role in increasing the lifetime of the power converter.

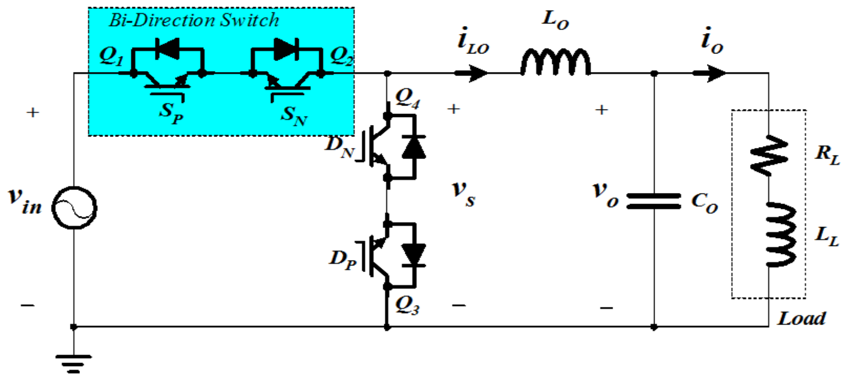


Figure 3: Single Phase Voltage Regulator with High-Speed Switching

Figure 4 shows the power circuit diagram of the single-phase voltage regulator proposed in this study. This power circuit is characterized by a bi-directional switch that can be used for four-phase operation with two P-channel FETs and two N-channel FETs. The advantages of this power circuit will be discussed in the next section.

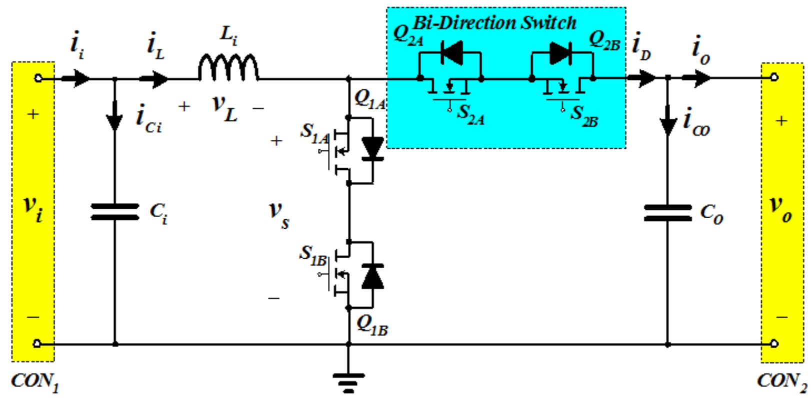
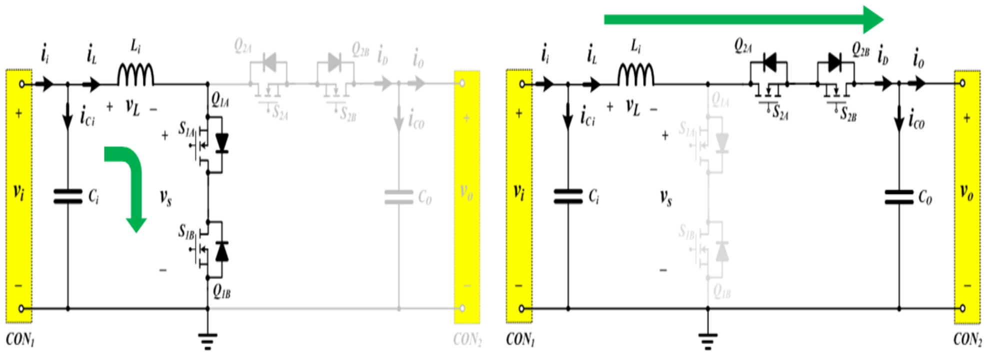
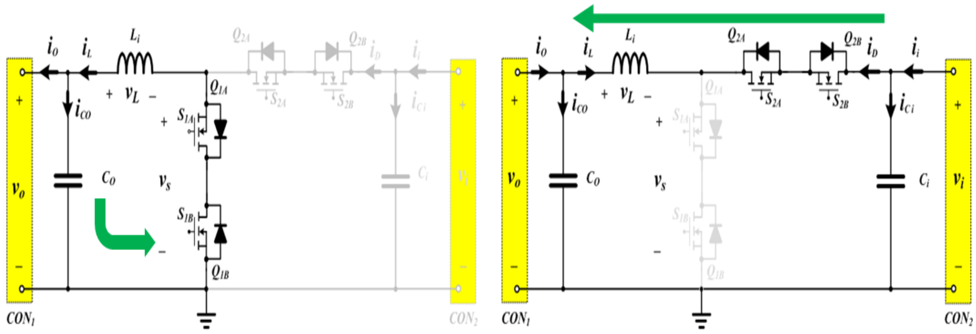


Figure 4: Circuit Topology of the Proposed Single Phase Regulator

Figure 5 shows the operating mode of the single-phase voltage regulator offigure 4.Figure 5 (a) and 5 (b) show the operating mode when the input AC voltage is postive and Figure 5 (c) and figure 5 (d) show the operating mode when the input AC voltage is negative. The inductor current(i_i) of figure 5 (a) flows through the diode of Q_{1A} and the switch of Q_{1B}. The switch-stage output voltage is zero voltage. In figure 5 (b),the inductor current(i_i) flows through the switch of Q_{2A} and the diode of Q_{2B}. The output AC voltage issum of input AC voltage and inductor voltage(v_L).In negative AC voltage range, the inductor current (i_i) of figure 5 (c) flows through the switch of Q_{1A} and the diode of Q_{1B}. The switch-stage output voltage is zero voltage. In figure 5 (d),the inductor current (ii) flows through the diode of Q_{2A} and the switch of Q_{2B}. The output AC voltage is sum of input AC voltage and inductor voltage (v_L). In all operating modes, If bi-directional switch is used by MOSFET turning on the MOSFET instead of conducting the diode can reduce the switching loss.



(a) positive current and input voltage (b) positive current and zero voltage



(c) negative current and input voltage (b) negative current and zero voltage

Figure 5: Operation Mode of Proposed Single Phase Regulator

Fig 6 shows the operating signals of the singlephase voltage regulator.In order to simplify the operation analysis, the gate signal for bidirectional switch turns on and off equally.

Therefore, the bi-directional switch operates regardless of the direction of the current. When bidirectional switches Q_{1A} and Q_{1B} are turn on and Q_{2A} and Q_{2B} are turn off, the switch output voltage is equal to the input voltage as shown in the following equation.

$$V_S = V_{in}$$

When the bidirectional switches Q_{1A} and Q_{1B} are turned off and Q_{2A} and Q_{2B} are turned on, the switch output voltage becomes zero voltage

$$\mathrm{Vs} = 0$$

Therefore, when the bidirectional switches Q_1 and Q_2 are controlled to the duty ratio d, the rms of the switch output voltage is given by the following equation

$$\mathrm{Vs} = \mathrm{d\ Vin}$$

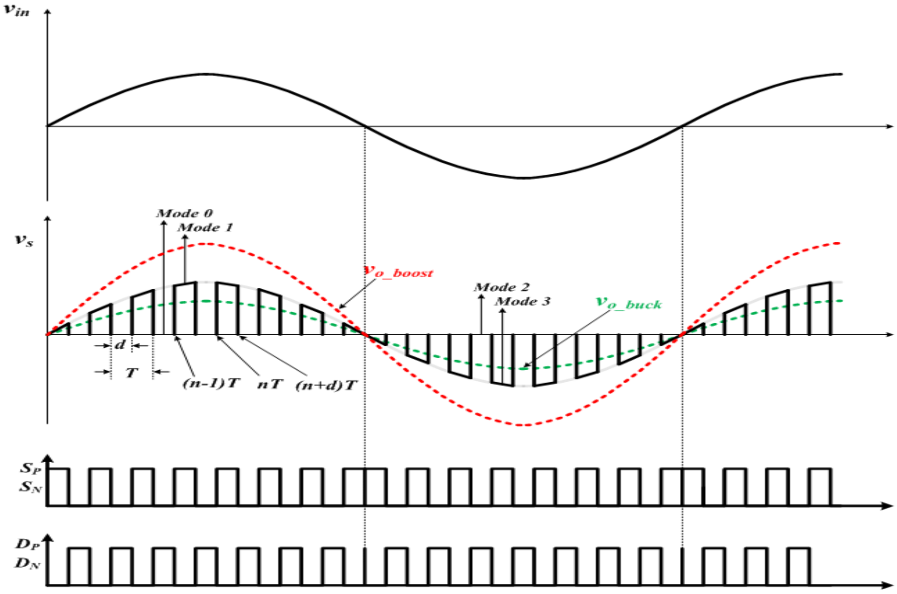


Figure 6: Switching Patterns of the PWM Signal in Single Phase Regulator

Figure 7 shows the circuit configuration of the multi-function power converter proposed in this paper. The input / output terminal is consisted of three sets of two AC input / output terminals and one DC input / output terminal. The conversion modes of the power converter are divided into two modes that are AC chopper mode and PWM converter mode.

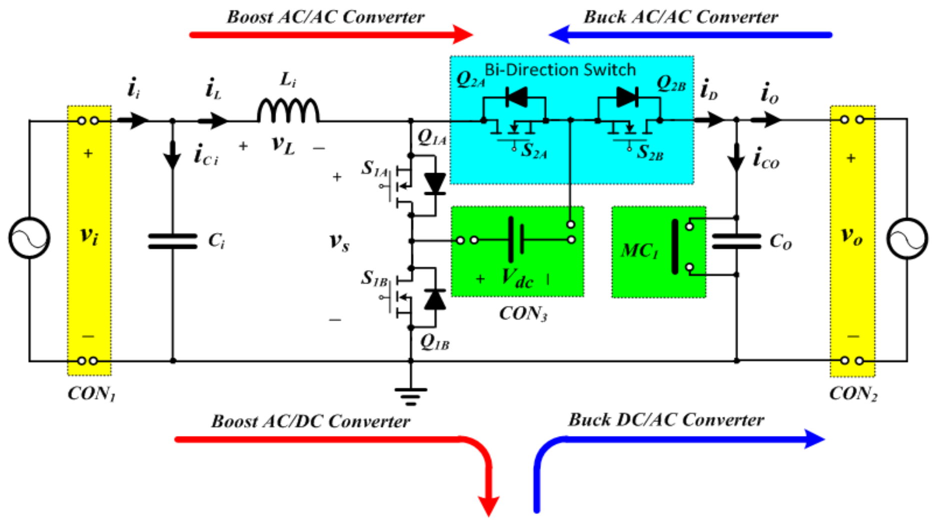


Figure 7: Circuit Topology of the Proposed Multi-Function Single Phase Converter

The AC chopper mode are divided into two types, one for type is a step-up type AC chopper mode with CON1 as AC input and CON2 as AC output and the other for type is a step-down AC chopper mode with CON2 as AC input and

CON2 as AC output as shown in Figure8. The PWM converter mode is devided into two types, one for type is a boost converter mode (AC to DC) in which CON1 is an AC input and CON3 is a DC output, and the other for type is inverter mode (DC to AC) in which CON3 is a DC input and CON1 is an AC output.In the AC chopper, the power circuit is constituted by the MC1 being turned off. In the PWM converter mode, the power circuit is constituted by the MC1 being turned on. The configuration of this mode is made possible by using twothe bidirectional switches with two P-channel FETs and two N-channel FETs. [8~10]

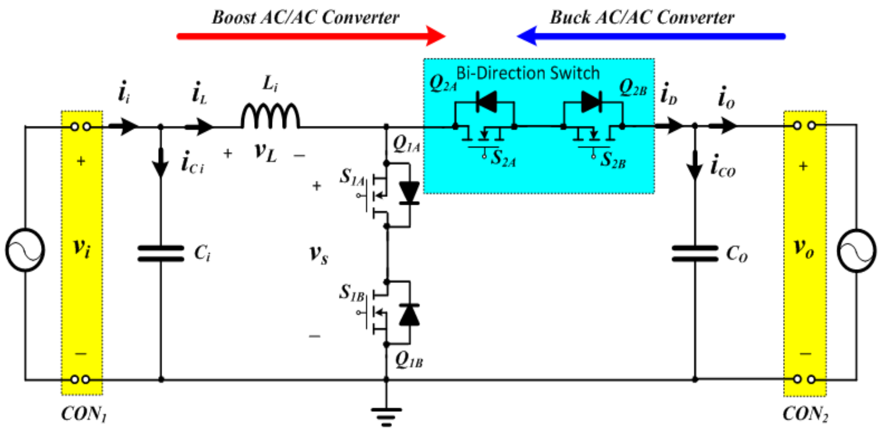


Figure 8: AC Chopper Operation Mode

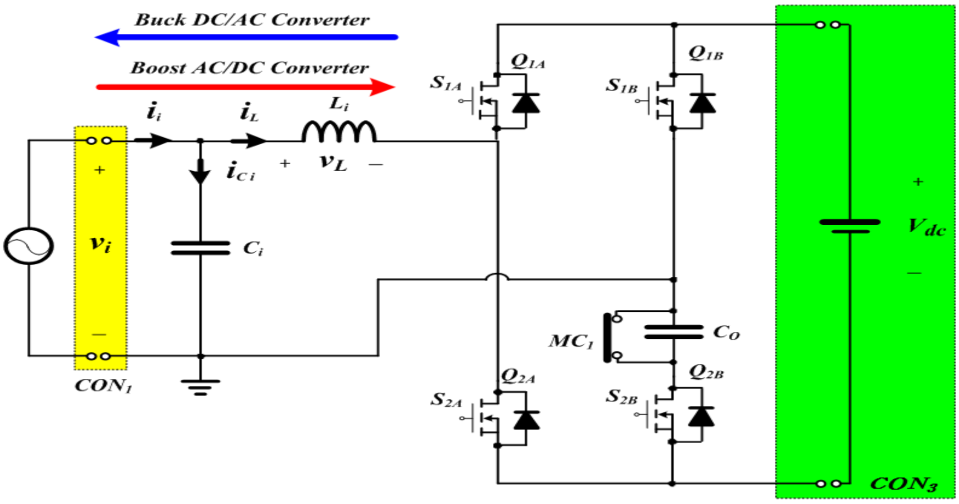


Figure 9: Full Bridge Configuration

3. Simulation and Experimental Results

Simulation Results and Analysis

The simulation circuit for verifying the validity of the proposed single-phase power converter is shown in Figure10. The simulation conditions are shown in Table 1.

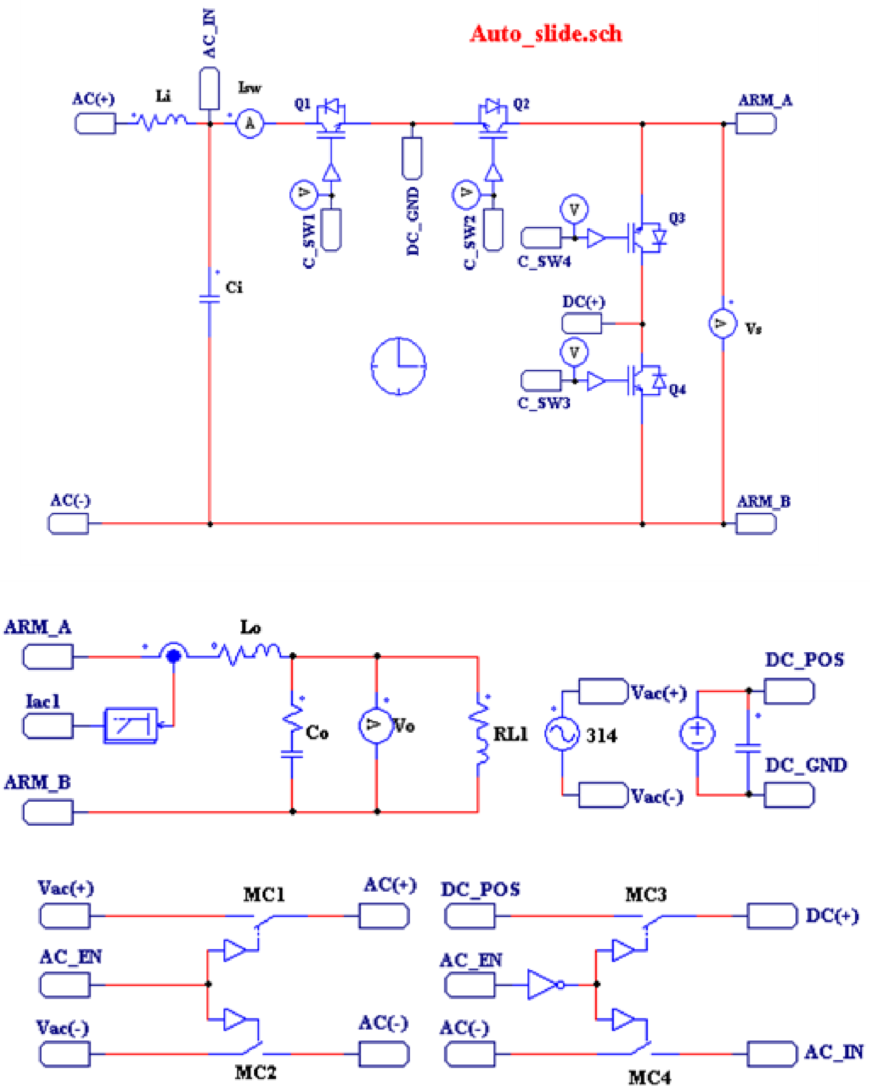
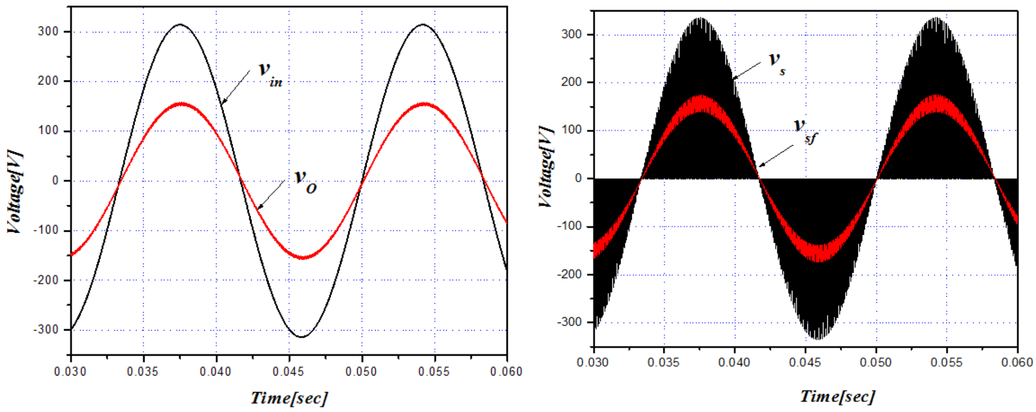


Figure 10: Simulation Circuit

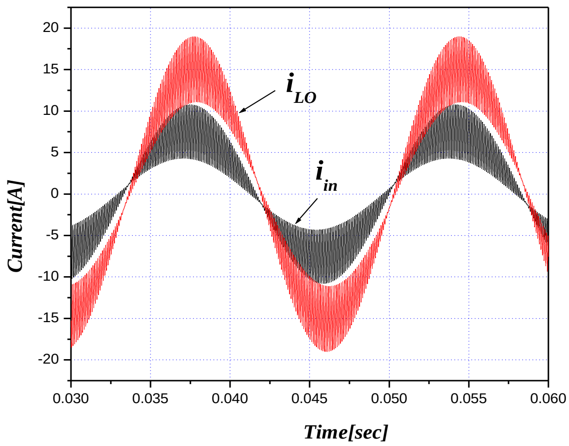
Table 1: Simulation Conditions

Input voltage (V_i)	110 V (boost), 220 V(buck)
Input filter inductor (L_i)	0.1 mH
Input filter capacitor (C_i)	10 uF
Output filter inductor (L_o)	1 mH
Output filter capacitor (C_o)	20 uF
Switching frequency	20 kHz
Duty ratio	0.5
Load R-L	10 Ohm – 4 mH

Figure 10 is a simulation circuit diagram modeled for AC chopper mode. Fig 11 (a) shows the output voltage waveform at a modulation ratio of 0.5 when an input voltage is 220 [V] and the output voltage is formed at a ratio of 0.5 to the input voltage. Fig 11 (b) shows the waveform that is the switch output voltage in the cutoff frequency of 3 kHz. The output voltage of the switch shows a PAM type waveform with the same input voltage as the input voltage. The filter output voltage is a sinusoidal wave form.Fig 11 (c) shows the inductor current on the input side and the inductor current on the output side. It can be seen that the input current is 0.5 of the output current because the modulation ratio is 0.5.



(a) Input and output voltage (b) switching voltage and switching filter voltage



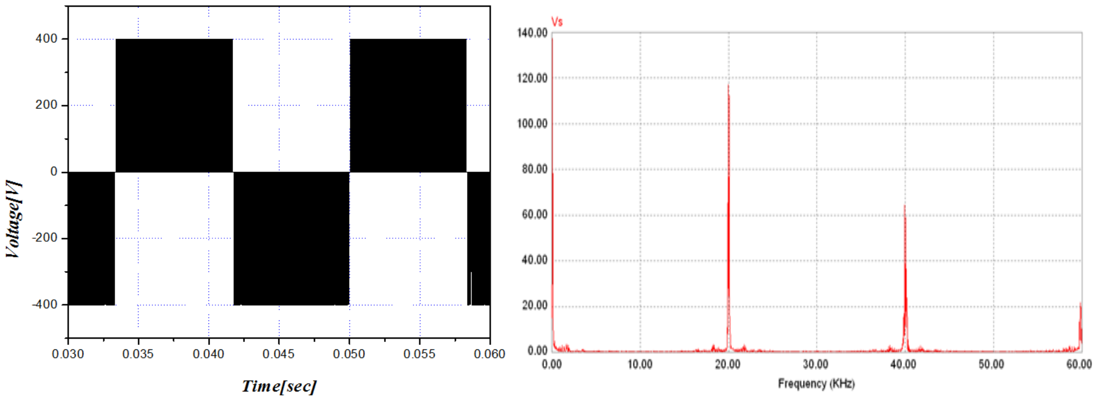
(c) Input inductor current and output inductor current

Figure 11: The Simulation Results for AC Chopper Mode

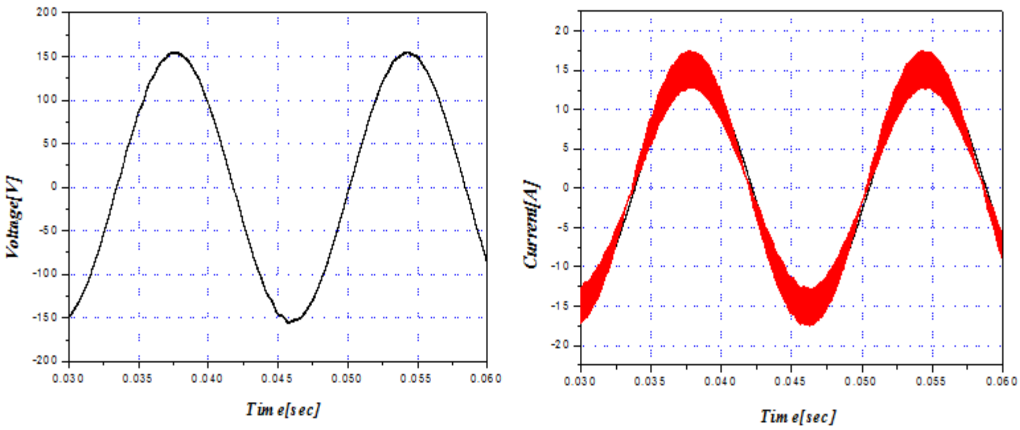
Figure 12 shows the simulation results for inverter mode. Figure 12 (a) shows inverter output voltage waveform when the modulation ratio is 0.4 at 400[V] inputvoltage.

When the harmonic waveform is analyzed, the frequency of 60[Hz] component and the switching frequency of 20[KHz] (Figure 12 (b)). As can be seen from the output voltage waveform shown in Figure 12 (c).

It can be seen that the multiples of the switching frequency are removed by the filter. Figure 12 (d) shows the inductor current and load current for the filter.



(a) Output voltage of Inverter (b) THD analysis of output voltage



(c) Output voltage of Inverter (d) Output reactor current of Inverter

Figure 12: The Simulation Results for the PWM Converter

Experimental Results

Figure 13 shows the prototype actually produced to verify the validity of the proposed topology. The system consists of a relay part for determining the operation mode, a sensing part for measuring LC-filter secondary voltage current, a gate amplifier part and a DSP for controlling TMS320f28027 board.

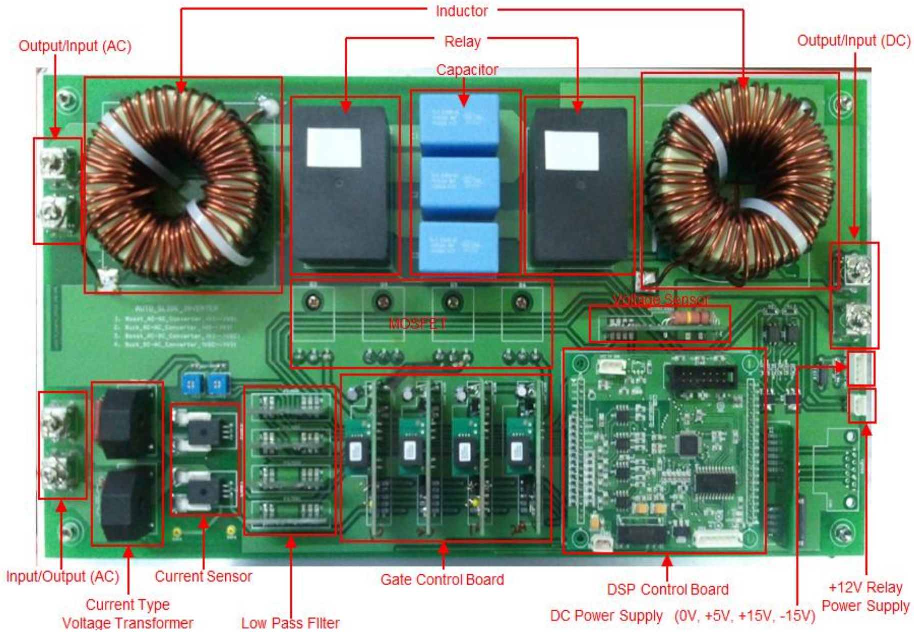
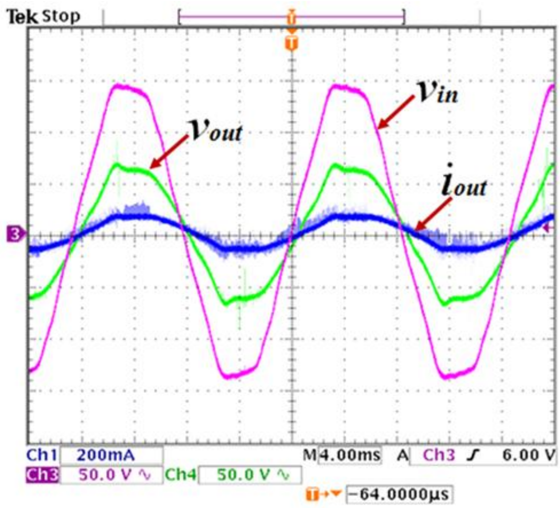


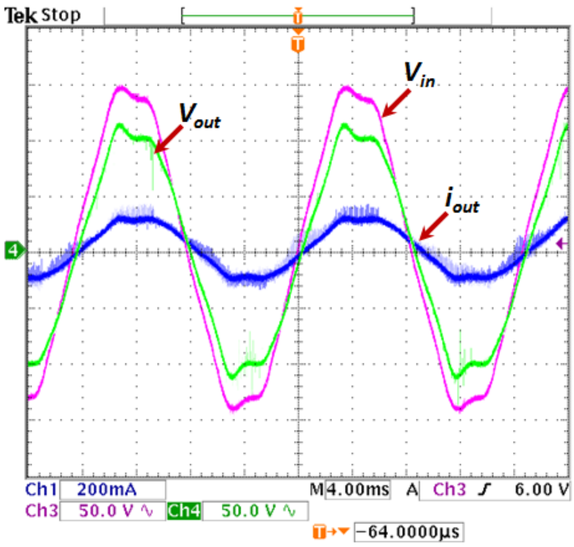
Figure 13: 1[kW] Prototype Main Control Hardware

Figure 14 (a) shows buck AC chopper mode where the duty rate is 0.5 and Fig 14 (b) shows buck AC chopper modewhere the duty rate is 0.8. As can be seen from the experiment, it is found that the rms voltage of the output voltage is satisfactory while the output voltage to be form the input voltage.

When the input voltage is applied at 50 [V] and the output voltage is 110 [V] Figure 15 shows the waveform to analyze the boost ac chopper mode characteristics. It can be seen that the output voltage is well generated by the gate signals of PWM1 (Q_{1A}) and PWM2 (Q_{1B}).



(a) Waveform at duty ratio 0.5



(b) Waveform at duty ratio 0.8

Figure 14: Experimental Results in Buck AC Chopper Mode

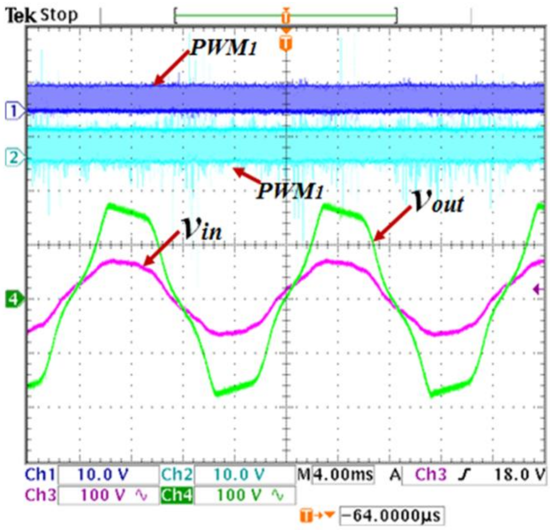


Figure 15: Experimental Results in boost AC Chopper Mode

4. Conclusion

This study proposes a new structure of a multi-function power converter and concludes the following conclusions as a result of simulation and experiment to verify the validity of the proposed topology.

1. The proposed power converter is able to generate step-up and step-down AC in the AC chopper mode, and it is possible to operate DC to AC inverter and DC to AC converter in the PWM converter mode.
2. In the constant frequency control, the AC chopper mode has a maximum efficiency increase of 2.3 [%] compared with the inverter mode.

3. This power converter is expected to be very useful in industry if it is commercialized as a multipurpose universal power converter.

References

[1] Kei Eguchi, Design of a Simple Inductor-less AC-AC Converter Realizing High Input Power Factor, Indian Journal of Science and technology 10(4) (2017), 1-6.

[2] Mohan Raj K., Single Stage Multi Input DC-DC/AC Boost Converter with Sliding Mode Control, Indian Journal of Science and technology 9(38) (2016), 1-12.

[3] Balci M.E., Hocaoglu M.H., Effect of Source Voltage Harmonics Distortion on Power Factor Compensation in Triac Controlled AC Chopper Circuits, International Conference on PEDS (2005), 1199-1024.

[4] Veszpremi K., Hunyar M., New Application fields of the PWM IGBT AC Chopper, Eighth International Conference of Power Electronics and Variable Speed Drives (2000), 46-51.

[5] Kwon B.H., Youm J.H., Choi J.H., Automatic Voltage Regulator with Fast Dynamic Speed, IEEE Proceeding of Electrical Power Application 146 (2) (1999), 201-207.

[6] Wang C.M., Jiang M.C., Lin C.H., Liu C.H., Yang D.J., A series-resonant single-phase step up/down AC chopper, IEEE International Conference on Power Electronics and Drive Systems (2009), 603-608.

[7] Taylor C.W., Scott G., Hammad A., Static var compensator models for power flow and dynamic performance simulation, IEEE Transactions on Power Systems (Institute of Electrical and Electronics Engineers);(United States) 9(1) (1994) 229-240.

[8] Babu A.R., Comparative analysis of cascadeded multilevel inverter for phase disposition and phase shift carrier PWM for different load, Indian Journal of Science and Technology 8(S7) (2015), 251-262.

[9] Rashid M.H., Power electronics: circuits, devices, and applications, Pearson Education India, (2009).

[10] Nagisetty S., Modeling and Simulation of Controller for Single Phase and Three Phase PWM Rectifiers, Indian Journal of Science and Technology 8(32) (2015), 1-8.