Three Phase DC-DC Converter with Six Inverter for EV Application

A.H.M. Zahirul Alam
International Islamic University Malaysia

Zulaikha Bt Che Mat
International Islamic University Malaysia

https://doi.org/10.15017/1906407

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 3, pp.141-144, 2017-10-19. Interdisciplinary Graduate School of Engineering Sciences, Kyushu University

Three Phase DC-DC Converter with Six Inverter for EV Application

A.H.M. Zahirul Alam, Zulaikha Bt Che Mat
International Islamic University Malaysia, Kuala Lumpur, Malaysia.
zahirulalam@iium.edu.my

Abstract: *This paper presents the effect of inductor and switching frequency of a three phase DC-DC converter for possible application in an electrical vehicle. The proposed DC-DC converter consists of the primary and secondary stage. The primary stage of the converter is composed of full bridge converter act as input port which connected in parallel, while at the secondary stage which acts as output port comprised of full bridge rectifier connected in series. At the secondary stage, filter capacitor, an inductor connected in parallel to filter out the ripples from the input voltage and produce a DC output voltage that leads to better performance. Different stages of the DC-DC converter has been simulated through PSpice and performance were evaluated.*

Keywords: DC-DC, converter, three phase, six inverter

1. INTRODUCTION

Three phase converter is suitable for low voltage and high current applications. [1]. A high step up ratio converter is required to enable efficient energy exchanges between DC-DC of different voltages. Higher operating frequency leads to better transformer utilization and increases in power density [2].
High isolated DC-DC converter often used in a high gain application for protecting devices [3]. The converter is commonly used for the conversion of the energy system in high voltage and high power applications. Thus, the converter compatible with high voltage and high power applications [4].
To overcome the problem across the switching, different clamping techniques used such as active clamping and naturally clamping. The proposed converters provide modular power conversion with modular high-frequency transformers and utilize high-frequency low-power transformers. This converter is good for high power and high voltage applications [5].
Three phase converter proposing a high frequency three phase transformer, compared to single phase the losses are well distributed, and it is three times higher in the cutting frequency compared to the switching frequency, and the filter reduced its required size. The output current ripple sufficiently reduced, ripple frequency increases, hence, the output filter can be much smaller [6].
In this paper, three phase DC-DC converter with six inverter performance was evaluated with the variation of the filter capacitor, an inductor with a different load. The effects of switching frequencies were also explored.

2. METHODOLOGY

The DC-DC converter that comprised of three phase converter. This three phase converter consists of three full-bridge converters which connected parallel at the input side and three full-bridge rectifiers connected in series at the output side. The function of the rectifiers is to convert the alternating current (AC) into direct current (DC). The series output connection is suitable to generate a high output voltage with relatively low PWM which results reduced the voltage stress of rectifier diodes, high efficiency and it is suitable for low power applications.
Figure 1 shows a block diagram of the DC-DC converter can be divided into two stages. At the first stage, it is comprised of three full bridge converter and act as an inverter to generate AC output voltage from DC. Meanwhile, at the second stage, a rectifier is used to convert AC voltage into DC output voltage. Therefore, three full bridge diode rectifier is used to generate desired DC output voltage from AC. The advantages of the full bridge rectifier are that it does not need a center tapped transformer thus will reduce the size and its cost. The output voltage of the rectifier at the first stage is acting as an input voltage rectifier for the second stage.

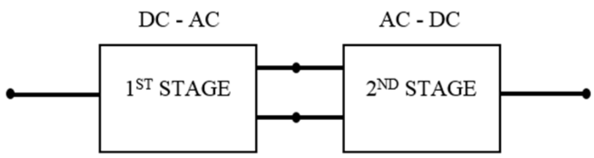

Fig. 1. System block diagram.

2.1 DC-DC Converter

Single phase converter topology employs parallel one phase input and series output structure. Figure 2 shows the schematic diagram of a single phase DC-DC converter. In this schematic, at the first stage of the converter which is the primary side has one part of the full - bridge converter consists of IRF150 rectifier connected to a voltage source. The second stage of the converter has a series output connection of full-bridge diode rectifier. There have four diodes that arranged in series labeled D_1, D_2, D_3 and D_4. During half cycle only two diodes conducting current. During the positive half cycle, D1 and D_3 conduct in a series while D_2 and D_4 conduct in reverse biased. The second stage converter also comprised of the filter capacitor, filter inductor and load resistance. This single phase converter works really well, but for high power, the converter could suffer from current stresses.
Adding one more part to the single phase to obtain two phase DC-DC converter. The two phase converter have better improvement of the output voltage performances

compared to the single phase converter. Meanwhile, three phase converter is comprised of single phase and two phase converter. Three phase converter has low input/output ripple and low output voltage compared to single phase and two phase. Therefore, three phases have better performance. The result of the various operating operations is illustrated in the simulation result.

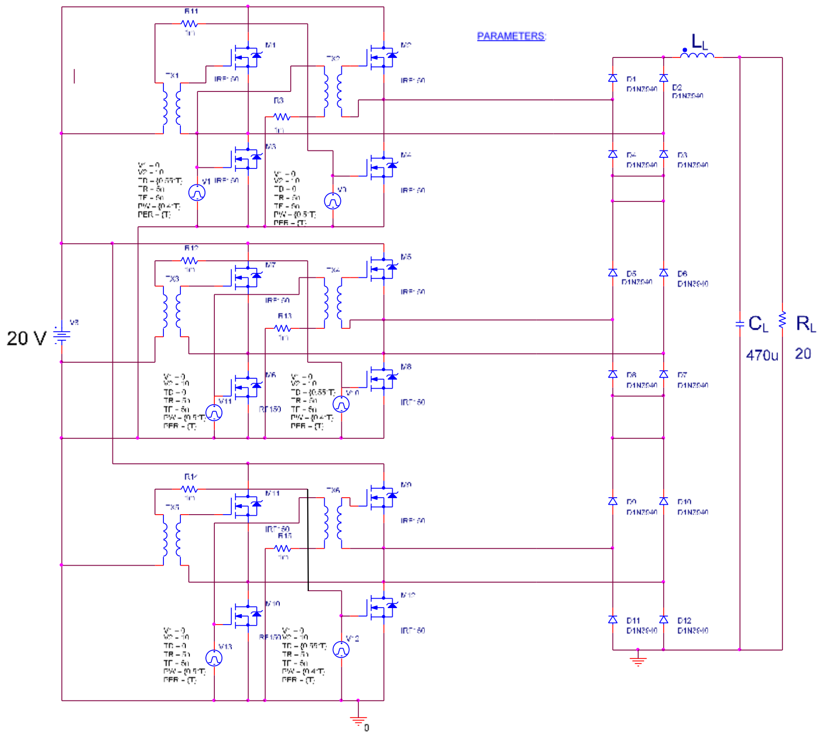

Fig. 2. Three phase DC-DC converter.

3. RESULTS AND DISCUSSION

3.1 Effect of the Inductor to the converter

The analysis has been carried out to evaluate the converter operation. Simulations have been executed to see the effect of the inductor to the simulation result of single phase, two phase and three phase DC-DC converter. The frequency varies in range, from 100 kHz, 10 kHz and 1 kHz. Different frequencies result in the different output waveform of the simulations. On the other hand, a different value of the inductor that varies from 100μH, 200μH, 400μH and 640μH also gives significant impact on the results. The input and output voltage is constant. Results are shown respectively in Figure 3.

From the simulation results, when inductor at 100 μH with frequency 10 kHz and 100 kHz it shows the output voltage ripples are fairly constant. The overshoot value is significantly lower with higher switching frequency at 100 kHz. For single phase as can be seen in Figure 3(a), based on the observation the converter has a peak voltage around 21V and short settling time with ripple at frequency 1 kHz. The circuit settled around 2.4ms at the output voltage.

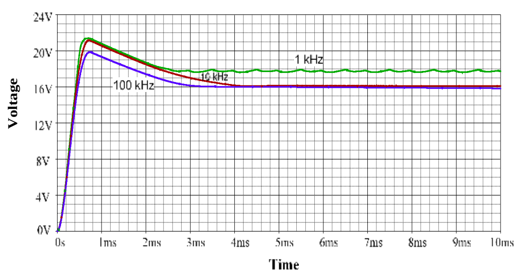

Fig. 3(a). Variation of the output voltage with frequency for single phase converter with inductor L_f =100 μH.

For two phase converter shown in Figure 3(b), the peak voltage of the converter has slightly increased to 26V and have longer settling time around 3ms.

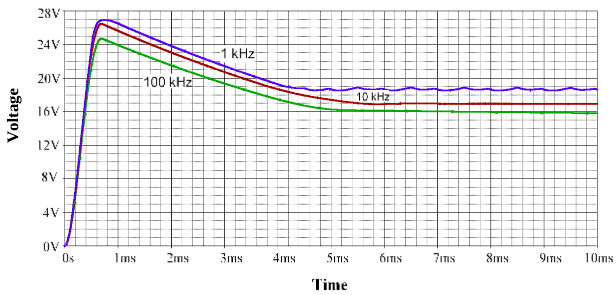

Figure 3(b): Variation of the output voltage with frequency for two phase converter with inductor L_f = 100 μH.

Meanwhile, in Figure 3(c), three phase converter shows peak voltage is sufficiently reduced compared with that in single phase and two phase converter which is 12V.

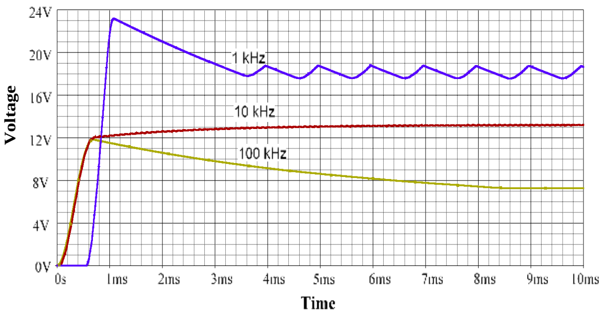

Fig. 3(c). Variation of the output voltage with frequency for three phase converter with inductor L_f =100 μH.

3.2 Effect of the Frequency to the converter

Simulations are carried out to see the effect of frequency as shown in Fig. 4. The overshoot value is significantly lower with higher switching frequency at 100 kHz and inductor value at 100μH. The simulations result in single phase represented in figure 3.2 (a) shows the output voltage ripples are low and the settling time settled around 4ms. Meanwhile, the value of voltage peak overshoot at 20V.

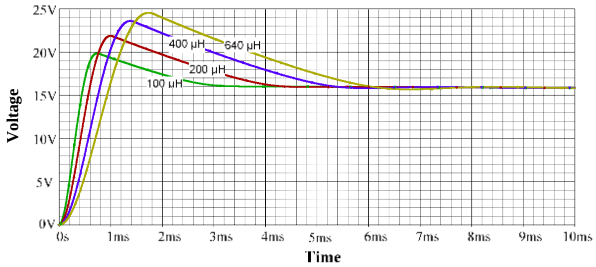

Fig. 4(a). Variation of the output voltage with an indicator for single phase converter with switching frequency fs=100 kHz.

Two phase converter simulation result is illustrated in Fig. 4(b), the overshoot point is slightly increased the output voltage shows at 25V and have longer settling time around 5ms.

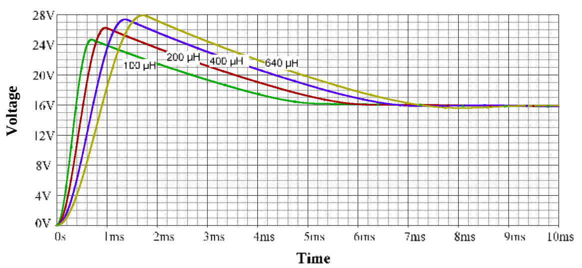

Fig. 4(b). Variation of the output voltage with an indicator for two phase converter with switching frequency fs=100 kHz.

Three phase converter is shown in Fig. 4(c) as a most efficient because it lowers the output voltage. In conclusion, the higher the value of the switching frequency, the better performance of the simulation waveform will be achieved. On the other hand, it leads to better performance and increases the power density of the converter.

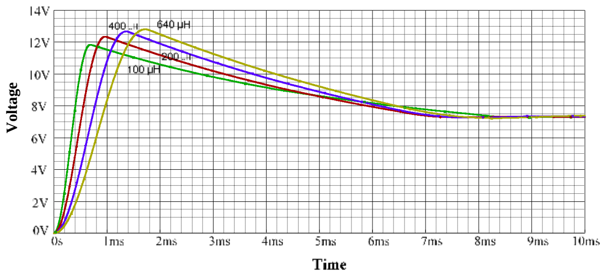

Fig. 4(c). Variation of the output voltage with an inductor for three phase converter with switching frequency fs=100 kHz.

3.3 Effect of the Load Resistance the converter

Figure 5 shows the effect of the load resistance to the simulation. We also need to consider the effect of load resistance. The load resistance varies from 20, 40, 60 and 100 Ωs, the value of inductor of 640μH and frequency is at 100 kHz. From the observation, the converter needs to have minimal load resistance to handle the DC output voltage.

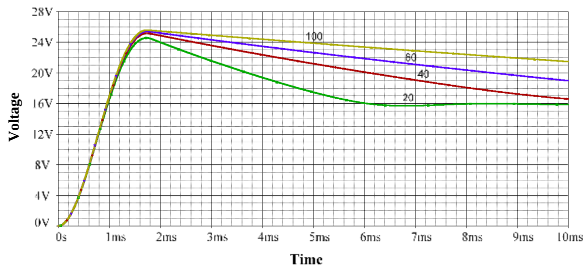

Fig. 5. Effect of the load resistance of the output stage.

3.4 Effect of the Capacitor to the converter

Figure 6 shows the output capacitance affect the stability of the converter. The capacitance can significantly influence the converter which defines the stability of the converter operation. The filter capacitor is to convert the rippled output of the rectifiers into a smooth DC output voltage. The parameter has to be in a certain range to assure the stability of the system. As the capacitance value of 100uH, the voltage peak is at 26V and settled at 2ms with small oscillation. Increase the value of the capacitor to 470μF we can clearly see the peak value is around 24V and have the smooth output waveform. Hence, it is important to consider the value of the capacitance which will determine the number of ripples at the output waveform. If the capacitance value is too low it will have a little effect on the output waveform.

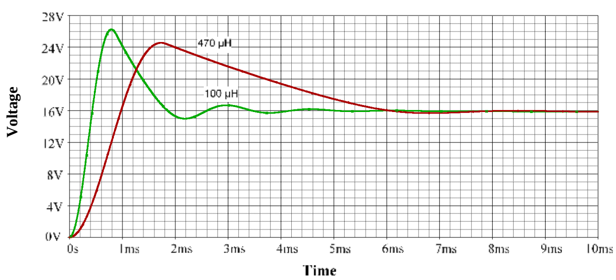

Fig. 6. Effect of the filter capacitor in the output stage.

3.5 Output voltage after rectification

Figure 7 shows the output voltage after rectification and before filter and after the filter. The output voltage after rectification is displayed in figure 3.5(a) shows the simulation result before filter when current is not passing through the inductor.

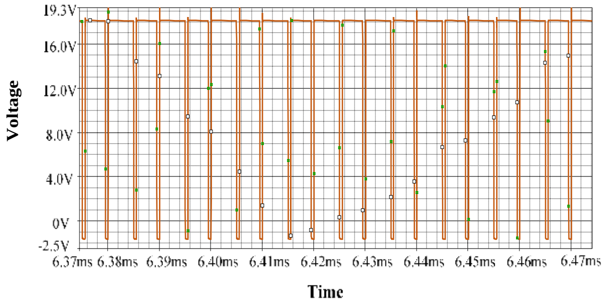

Fig. 7. Output voltage without a filter.

Meanwhile, as can be seen in Fig. 8, it shows the simulation result after filter when the current passing through the inductor. The output of the after rectification has less ripple and produced a smooth output waveform.

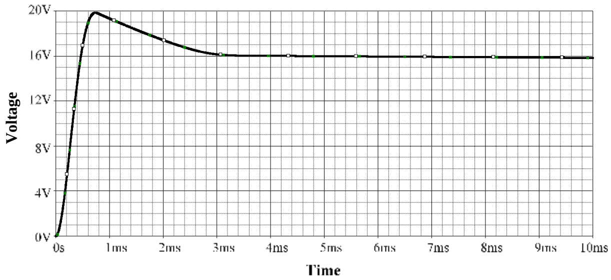

Fig. 8. Output voltage after the filter.

3.6 Load current

Figure 9 shows the load current in the inductor. The ripples are not only determined by the smoothing capacitor but load current is also important to determine the ripples of the output waveform. We have to consider the parameter of the load current to obtain smooth output waveform of the simulation. Figure 9 shows the inductor current peak value is at 11.2A.

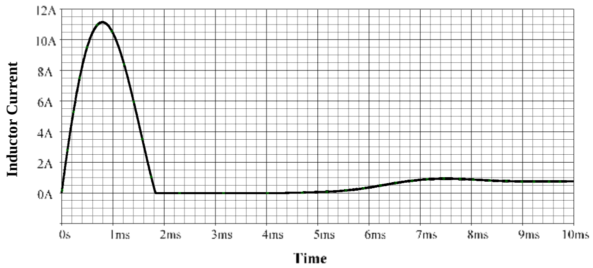

Fig. 9. Load current before inductor

The inductor current is pulled down as shown in Fig. 10 after the load current passing the inductor. It shows that the load current reaches the minimum value and after a short period of time inductor current becomes zero.

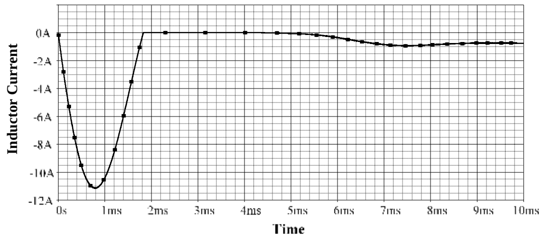

Fig. 10. Load current after inductor

4. CONCLUSION

The simulation of the DC-DC converter has been done for designing various phases. The DC-DC converter can be operated at different phases, first is a single phase, then two phases and lastly three phases. The performance of the converter is simulated using PSPICE simulation software and the performance are evaluated accordingly based on the switching frequency (f_s) which varies from 1 kHz, 10 kHz and 100 kHz, inductor (L_f) which varies from 100uH, 200uH, 400uH and 640uH, filter capacitor (C_f) selected as 470uH, load resistance and load current. The input voltage (U_{in}) used for this converter is 20V and output voltage varies from 20V up to 100V. This converter simulation result shows better performance compared to the proposed converter from the previous study. Features such as high switching frequency and high capacitance value make this converter better in performance.

REFERENCES

[1] R. S. K. Moorthy and A. K. Rathore, Analysis and design of impulse commutated ZCS three-phase current-fed push-pull DC/DC converter, 2016 IEEE Applied Power Electronics Conference and Exposition (APEC), Long Beach, CA (2016) 794-801.

[2] L. Sobrayen and A. K. Rathore, Three-phase soft-switching bi-directional DC-DC converter for low voltage high power applications, 2016 IEEE 8th International Power Electronics and Motion Control Conference (IPEMC-ECCE Asia), Hefei (2016) 90-97.

[3] Z. Yao and J. Xu, A three-phase DC-DC converter for low and wide input-voltage range application, 2016 IEEE Transportation Electrification Conference and Expo, Asia-Pacific (ITEC Asia-Pacific), Busan (2016) 208-213.

[4] A. Mohammadpour, T. Li and L. Parsa, Three-phase current-fed zero current switching phase-shift PWM DC-DC converter, 2014 IEEE Energy Conversion Congress and Exposition (ECCE), Pittsburgh, PA (2014) 5079-5084.

[5] K. Modepalli, A. Mohammadpour, T. Li and L. Parsa, "Three-Phase Current-Fed Isolated DC–DC Converter With Zero-Current Switching," in IEEE Transactions on Industry Applications, vol. 53, no. 1 (2017) 242-250.

[6] J. Zhang, Z. Wang and S. Shao, A Three-Phase Modular Multilevel DC–DC Converter for Power Electronic Transformer Applications, IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 5, no. 1 (2017) 140-150.