IES
International Journal of Energy and Power Systems (IJEPS), ISSN: 2789-3766

Research Article

Variable Frequency Control in High Switching Frequencies DC-DC Converters

Syahir Syafiq[1], Tze-Zhang Ang[1,*] and Mohamed Salem[1]

[1]Affiliation 1; School of Electrical and Electronic Engineering, Universiti Sains Malaysia (USM), Nibong Tebal, 14300, Penang, Malaysia.

syahirsyafiq1797@student.usm.my, salemm@usm.my

*Correspondence: angtzezhang@student.usm.my;

Citation: Syafiq, S. Ang T.Z. Salem, M., "Variable Frequency Control in High Switching Frequencies DC-DC Converters," *International Journal of Energy and Power Systems*, vol. 2, pp. 12-15, 2022. https://doi.org/10.54616/ijeps/20220303

Academic Editor: Firstname Lastname
Received: date
Accepted: date
Published: date

Abstract: The switching mode DC- DC was extensively researched and developed to meet most industrial power electronics requirements. Using the switch mode has the advantage of reducing conductive and switching losses by increasing the switching frequency. In addition, the power converters structure includes energy storage components, and power switches that reduce their performance. The development of new typologies for the power converters was undertaken in parallel with the advancement of instruments, materials, and control systems technology. By minimizing the switching losses and the overall converter size, these typologies may provide high performance. This study will therefore reflect on the classifications of DC- DC converters, and their ability to operate at high switching frequencies. Also, the control methods of the DC- DC converters will be discussed and compared. This project includes an intensive comparison between different typologies of DC-DC converters by using Matlab/ Simulink software to implement the frequency control for the most two effective typologies.

Keywords: Switching Mode; MATLAB; DC-DC Converter

1. Introduction

Low-power portable battery-operated devices, such as cell phones, laptops, PDAs, etc., have become increasingly popular [1]. Growing system requires multiple digital processors in which the power management unit plays a key role in efficient DC power processing to extend the battery life. It consists primarily of one or more DC- DC converters with the objective to control output voltage under varying input voltage and load current conditions, and to achieve high efficiency with rapid transient results. The relentlessness of high power density motivates efforts to increase the switching frequency to multi-megahertz in order to significantly reduce passive elements such as magnetics and capacitors [2]. Resonant converters have been thoroughly researched in order to minimize switching losses at such a high switching frequency, among which the Class E DC–DC converter, featuring simple topology and fast zero-voltage switching (ZVS) for the power switch, has attracted considerable attention in recent year [3-5].

Figure 1 shows a Class E DC- DC converter main circuit consist of a Class E inverter and a network rectifier. The inverter of Class E converts the DC input voltage to the AC voltage, while the rectifier transmits the AC voltage to the desired DC voltage.

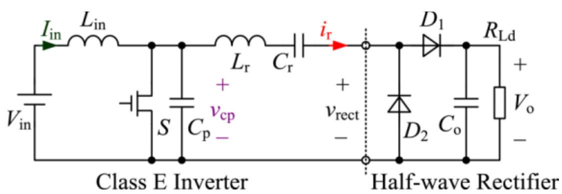

Figure 1. Class E DC-DC converter circuit schematic diagram

Pulse frequency modulations are often used for the control of the output voltage and soft power switching simultaneously. Nevertheless, the switching frequency has a wide range of variations, making optimizing the inductors and capacitors difficult. The Class E DC- DC converter is therefore preferred to run at a constant switching frequency (CSF).

2. Literature Review

I. Voltage-boosting Techniques, Topologies and Applications

These techniques include switched capacitor (charged pump), voltage multiplier, switched inductor / voltage lift, multi-stage/ level and magnet coupling, each one of which has a unique performance in terms of cost, complexity, density of power, reliability and efficiency, and, depending on its application [6]. In addition, new power converter topologies are continuously being proposed to meet the growing demand for such applications using the above-mentioned voltage boosting techniques and certain active and passive components. Lastly, large applications of DC- DC converters were presented, together with a comparative study of different techniques for voltage boosting. A large number of power conversion applications include DC- DC converters that boost the voltage from fraction-of-volt to ten thousand volts, from milli watts to megawatts at power levels. This report aims to review and classify different DC- DC converters based on their characteristics as well as voltage-boosting techniques, in order to present a clear picture of the general legislation and framework for the development of DC- DC converters for the next generation stage. The permutations and combinations of different voltage boost techniques with additional components in a system enable many new topologies, often confusing and difficult to follow. Various voltage boosting techniques were reported in this literature, using basic energy storage elements (inductor and capacitor) and / or transformers with switches and diodes [7].

II. Power Balancing Control of a Multi-Terminal DC Constructed by Multiport Front-to-front DC-DC Converters

This study by examines the power balance control of an HVDC system built from a DC– DC converter type (MF2F) in front of a multi-port system. Dynamics of the MF2F inner AC circuit, which shows natural MF2F instability in unbalanced power orders, are analyzed. The solution to the problem of instability is to have an internal power balance and an external power balance loop on each MF2F port. The inner balance loop guarantees the power of the MF2F and the external balance loop provides the balance of power between a port and its external DC system. Even for external converters under constant power control, power balance control is developed. In order to enable the balance controllers automatically in normal operation, integrator limit and total output of the balance loops are specifically set. The controllers are automatically enable during power imbalances. The self-blocking modular multi-level converters on each port of the MF2F are used to isolate the DC faults in external DC systems. Extensive simulations of AC failures and DC failures that cause unbalanced power orders verify the efficiency of the proposed power balance control. The controllers proposed may be used as MF2F generic controllers [8].

3. Methodology

Figure 2 shows the Class E DC- DC converter circuit, consisting of an inverter of Class E and a network rectifier. The inverter of the class E turns the DC input voltage into AC voltage/ current, and the rectifier converts the AC voltage/ current into a suitable DC voltage. Pulse frequency modulation is also used in order to control output voltage and at the same time to achieve soft switching for the power switch. However, the switching frequency varies widely making the optimization of capacitors and inductors difficult. The Class E DC- DC converter should therefore be used with a constant switching frequency (CSF). In [9], a modulated phase control is proposed for the modified Class E DC-DC converter with parallel connection for many Class E inverter modules and sharing a single network downstream. By changing the phase angle of each AC current given by Class E inverter modules, the output voltage of the modified Class E DC-DC converter is controlled by CSF. In [10], the resonant branch of the Class E DC- DC converter adds a serial switch-controlled capacitor, and regulates the output voltage while maintaining a fixed switching frequency, by adjusting the resonant frequency. The additional switch controlled capacitor however makes topology and control more complicated. In the rectifier network of [11], the synchronous rectifier is used and the output voltage is controlled by the CSF conductive angle of the rectifier switch. However, because of increased loss of circulation, the efficiency of the light charge is very low.

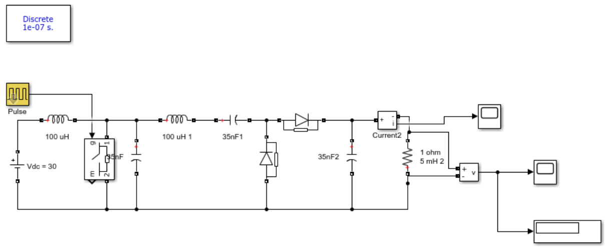

Figure 2. Class E DC-DC converter circuit in Simulink

Figure 3 shows the controller circuit in Simulink. A simple integral control is implemented in Simulink in the controller block and the switch is an ideal switch. The output scope shows the load variation of output current and output voltage. Note that the maximum voltage stress is higher than would be expected if output capacity were constant due to the nonlinear output capacitance of the transistor. Furthermore, the scope also displays the frequency control signal, the output voltage and the output voltage reference value. In this model, the power output information from circuit components can be calculated.

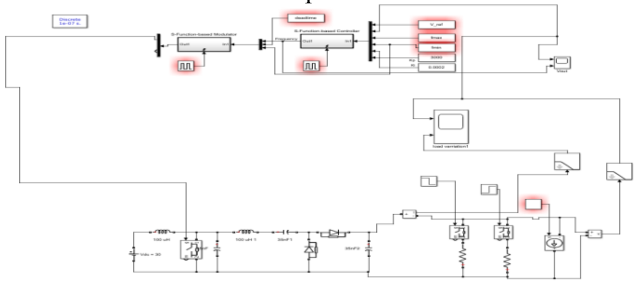

Figure 3. Controller circuit

4. Results and Discussion

I. Converter

To verify the effectiveness of the converter circuit, a 120V of class E DC- DC converter is used with the different parameters given in Table I and Table II.

Table I
Data of frequency and output voltage

Frequency (Hz)	Output Voltage (V)
10k	281.3
20k	216.3
30k	216.6
40k	121.7
50k	111.8

Input voltage= 120V, Duty cycle= 50 %

Table II
Data of duty circle and output voltage

Duty Cycle	Output Voltage (V)
10	52.78
20	108.9
30	167.5
40	223.3
50	281.3

Input voltage= 120V, period= 1/10000

Figure 4 shows the results waveforms of the converter under same value of input voltage and duty cycle but different value of frequency. As already seen, the amplitude of the voltage is always achieved in different values, indicating that the adjustment of the frequency will affect the output voltage. In general, the inductor ripple current and the output voltage ripple decreases when a fixed inductance increases the switching frequency. It increases the switching losses and reduces efficiency. It can lead to a smaller entire structure, but with potentially even more losses due to the core loss of the inductor. Based on the frequency and characteristics of the output capacitors, the output ripple may or may not decrease.

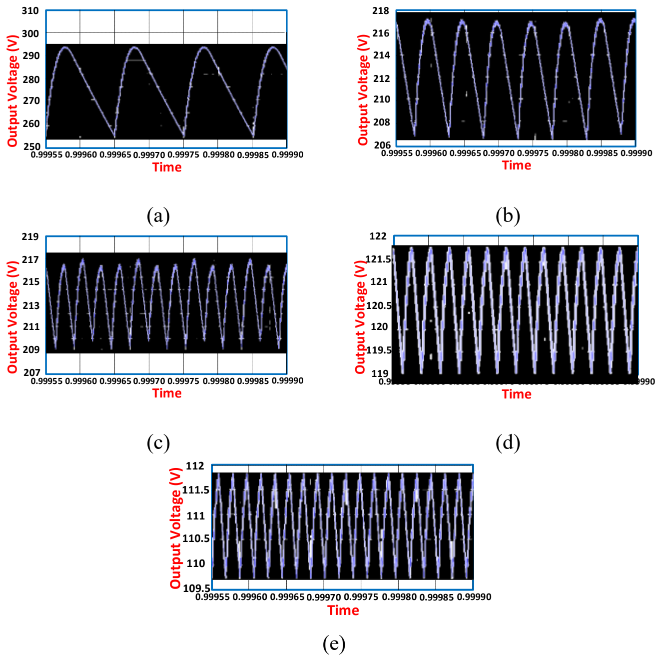

Figure 4. Waveform of converter at different frequency: (a) 10kHz; (b) 20kHz; (c) 30kHz; (d) 40kHz; (e) 50kHz

Figure 5 shows the experimental waveforms of the converter with same value of input voltage and period but different value of duty cycle. Compared with figure 4.1.1 to figure 4.1.5, the output voltage is greatly increased as the duty cycle increased indicating that the adjustment of the duty cycle with lowest value of frequency is feasible. Dynamic losses are seen to grow very slowly as the duty cycle increases. However the load resistor fixed will also increase the output current as the duty cycle increases. The conduction losses are affected by increasing current values. This is the result of the relationship between dynamic and conduction losses.

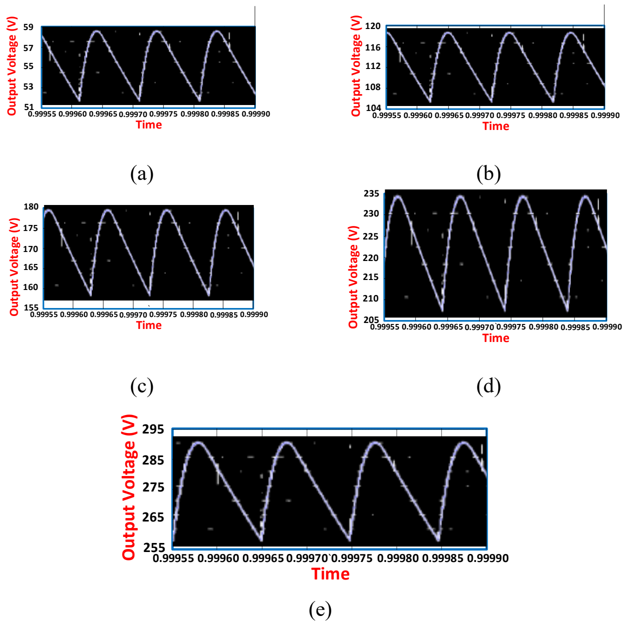

Figure 5. Waveform of converter at different duty circle: (a) 10%; (b) 20%; (c) 30%; (d) 40%; (e) 50%

Figure 6 shows the experimental waveforms of the output voltage as compared to the reference voltage. It also shows how the control system tries to keep track of the reference voltage of the switching frequency.

In DC– DC converters operated with switching frequency up to multi-megahertz, variable frequency control has been commonly used. From this experiment, as shown for the variable frequency control class E DC– DC, the values of the output voltage, output current, diode rectifier and resonant current decrease as the frequency increases during ON mode, leading to significant efficiency deterioration. It is found that the input power during ON mode increases with the constant of input voltage but decreases with the increase of the switching frequency. Based on this, a VSF ON–OFF control is proposed, with which, the switching frequency is slightly increased when the input voltage is constant. Thus, the input power during ON mode is maintained greatly higher than the rated output power over the entire input voltage range, leading to improved conversion efficiency at high input voltage. The duty cycle remains constant with the switching frequency variation in order to achieve ZVS of the power switch.

The variable frequency control provides several benefits over a fixed frequency control. The choice of sampling frequency in a variable frequency digital modulator also remains a problem due to the inadequacy of the sampling points and the switches.

By increasing the proportional gain, the performance can be improved. However, this would increase the maximum inductor current. If the inductor current is kept within its current limit, this would also improve the on- time duration of the high-side MOSFET for a faster down-time and thus increase the sample interval using this event-based sampling approach. Due to the unavailability of the output voltage samples during this slew-up process, the voltage controller is not updated, which may result in the complete collapse of the closed-loop system.

An external sample clock that needs to be time-multiplexed with the event-based sampling clock, in which the latter is used all the time and the latter is used only if inter-sample length reaches a threshold value, can be avoided. For this configuration, a variable frequency digital/ mixed signal current mode controller can be configured to satisfy the high demand for bandwidth over a large operating range. In this regard, a ramp compensation for the current lap stability is not needed while the operation of a wide duty- ratio is performed, unlike in the CMC technique, thus retaining the advantages of current-mode control without affecting current bandwidth.

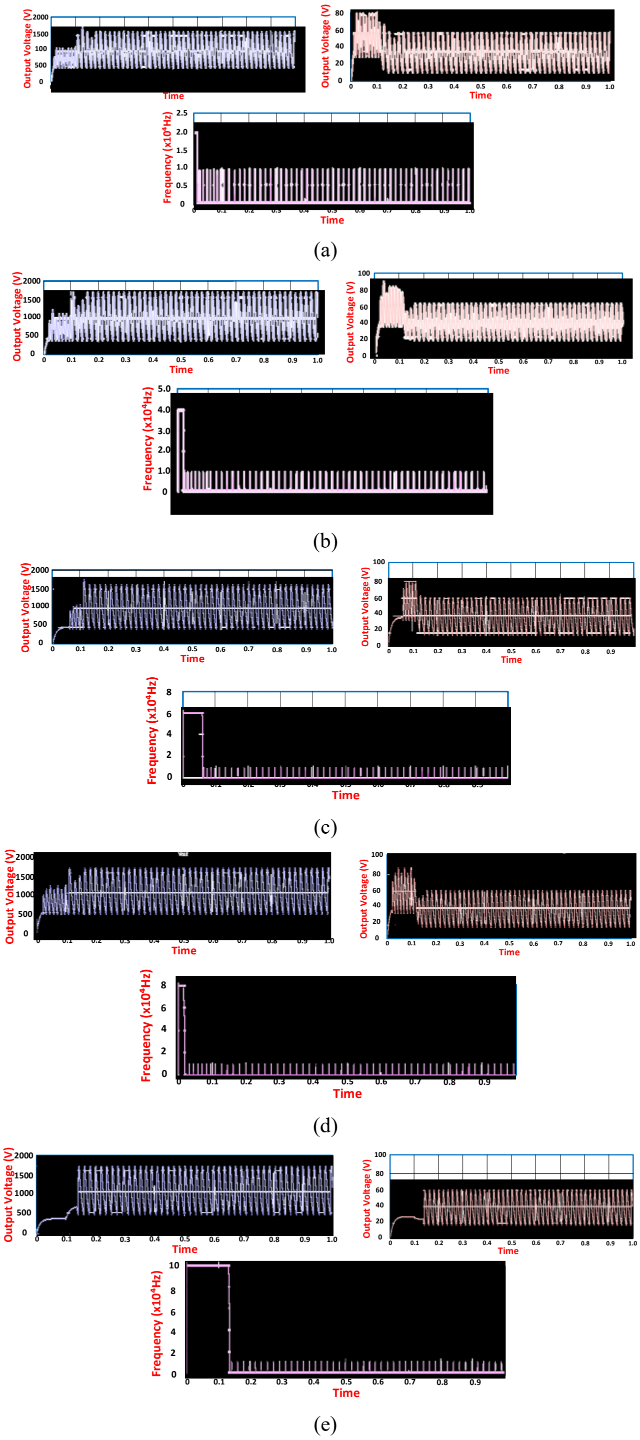

Figure 6. Waveform of output voltage at frequency: (a) 10kHz; (b) 20kHz; (c) 30kHz; (d) 40kHz; (e) 50kHz

5. Conclusion

The advantages and disadvantages of both fixed-frequency and variable-frequency control techniques for DC-DC converters have been highlighted. It was observed, without an additional compensating ramp, that variable frequency control would achieve inherent current- loop stability over a wide range of duty- ratio. A fully digital phase- locked loop enables precise control of the steady-state switching frequency. A digital controller is also available to further improve performance. To overcome multi- limit cycles, an event-driven samples mechanism would be very useful. Thus, this technology emerges for future power control applications as an attractive digital control solution.

Acknowledgments

The authors would like to pay gratitude to Research Creativity and Management Office (RCMO) of the Universiti Sains Malaysia for supporting with funding, and library facilities. Lastly thanks to those colleagues who have either directly or indirectly contributed to the completion of this work.

References

[1] Salem, M., et al. *Phase-shifted series resonant DC-DC converter for wide load variations using variable frequency control*. in *2017 IEEE Conference on Energy Conversion (CENCON)*. 2017. IEEE.

[2] Salem, M., et al., *Three-phase series resonant DC-DC boost converter with double LLC resonant tanks and variable frequency control.* IEEE Access, 2020. **8**: p. 22386-22399.

[3] Salem, M. and K. Yahya, *Resonant power converters*, in *Electric Power Conversion*. 2019, IntechOpen London, UK.

[4] Grebennikov, A. *Early history of switching-mode Class-E techniques for high-efficiency power amplification*. in *2017 IEEE MTT-S International Microwave Symposium (IMS)*. 2017. IEEE.

[5] Salem, M., et al., *Phase-shifted series resonant converter with zero voltage switching turn-on and variable frequency control.* International Journal of Power Electronics and Drive Systems (IJPEDS), 2017. **8**(3): p. 1184-1192.

[6] Alhamrouni, I., et al., *Design and development of SEPIC DC-DC boost converter for photovoltaic application.* International Journal of Power Electronics and Drive Systems, 2019. **10**(1): p. 406.

[7] Forouzesh, M., et al., *Step-up DC–DC converters: a comprehensive review of voltage-boosting techniques, topologies, and applications.* IEEE transactions on power electronics, 2017. **32**(12): p. 9143-9178.

[8] Xiang, W., et al., *Power balancing control of a multi-terminal DC constructed by multiport front-to-front DC–DC converters.* IET Generation, Transmission & Distribution, 2017. **11**(2): p. 363-371.

[9] Li, Y., et al., *Variable switching frequency ON–OFF control for class E DC–DC converter.* IEEE Transactions on Power Electronics, 2018. **34**(9): p. 8859-8870.

[10] Ye, L., et al., *Resonant converters with an improved voltage regulation range*. 2017, Google Patents.

[11] Nair, S.D., G. Nadh, and S.A. Rahul. *Constant switching frequency virtual vector based predictive control of a three-level flying capacitor active front end converter*. in *TENCON 2019-2019 IEEE Region 10 Conference (TENCON)*. 2019. IEEE.

https://doi.org/10.54616/ijeps/20220303