Applied Mathematics, Modeling and Computer Simulation
C.-H. Chen et al. (Eds.)

doi:10.3233/ATDE231029

Analysis of Load Current Ripple in a Five Level Buck Converter

Emerson Brilliant Chow, M. K. A. Ahamed Khan[1] and Mastaneh Mokayef
Faculty of Engineering, Technology & Built Environment UCSI University, Kuala Lumpur (56000), Malaysia

Abstract. A buck converter, sometimes known as a step- down converter, is a kind of DC-to-DC converter that belongs to the DC chopper family. Buck converters are a sort of switching power electrical device that is typically used to provide an alternating DC output voltage that is less than the constant DC input voltage source. The primary focus in the field of electronic appliances is on the root cause of harmonic distortion in a Buck converter system, where interference from harmonic signals frequently appears at both the input and output terminals of the load side, affecting the efficiency and performance of the buck converter. This research paper focuses on the load current ripple content and the harmonic problem encountered by a five-level buck converter. The research consists of ten buck converters with varying levels and two different loads, R load and RLC load, and all of these converters were used to compare one to the other as one of the objectives of this research. After repeated calculations, trial and error, and conclusion of the study hypothesis, the research got intriguing findings where the buck converter ripple and harmonic content were minimized by raising the buck converter level.

Keywords. Buck; multilevel; ripple; harmonic; minimalization

1. Introduction

In the rapidly developing field of renewable energy technologies, DC-DC converters or DC choppers are essential components of energy conversion to regulate unregulated DC voltage or current sources. Choppers are direct current transformers with adjustable turn ratios [1,2]. Buck converters, also known as step-down converters, are DC-DC converters that convert an unregulated DC input voltage into a controllable DC output voltage that must be lower. Power electronics demand has grown steadily [3]. This rapid deployment has increased nonlinear currents and voltages in buildings and utility networks. These nonlinear sources were used in arc furnaces and fluorescent light bulbs, and electrical motors and control systems for industries are now common. Nonlinear voltage and current increase harmonic distortion concerns [7].

In this paper, an experimental simulation research was conducted on five level buck converter and buck converters from single to four level converters to show comparison of the output and ripple content behavior. The experiment was conducted by using PWM (Pulse Width Modulation) and a clock voltage source to control the

[1] Corresponding author: M. K. A. Ahamed Khan, UCSI University; Email: mohamedkhan@ ucsiuniversity.edu my

buck converter. The peak current, rise time, settling time, average output current, voltage and current ripple factor, and THD (Total Harmonic Distortion) were analyzed and recorded to compare between the five-level buck converter and single level buck converter. The total harmonic distortion was simulated under a different simulation software with most parameters kept the same.

2. Literature Review

A study was made by (S. Bin Idham Halis et al., 2014) shows by increasing the converter level may increase the overall performance and minimize the ripple occurrence, the study was made in simulation on single-level and multi-level buck converters up to four levels with R load and RL load outputs using MATLAB, the study proves by increasing the buck converter level, shows that the converter output on the four level improves significantly compared to the single level counterpart, the comparison applied to both R load and RL load as it shows the same conclusion [1].

Another study was made by (A. Abdulslam, 2016) shows that multileveled converters are more advantageous when compared to the typical single-level buck converter. The study was made by simulating a single-level, three-level, and five- level buck converter using SPICE, utilizing the same value for each level to maximize performance. The simulation showed that the five-level converter had the highest efficiency, but their research showed that the three-level converter outperformed the five-level due to switching losses [6].

In terms of the effect of harmonics, a study was made by (V. E. Wagner et al. 1993) shows that harmonics have varied effects on electrical equipment. Harmonic levels may be changed by using shunt capacitors to increase voltage and power factor. However, capacitors do not produce harmonics, but the harmonic effect on the capacitor may increase equipment heating and dielectric stress. Another device would be the transformers, system harmonics increase transformer heating, requiring load capacity derating or non-sinusoidal load current transformers to stay under the transformer's temperature rating, this is because overtemperature operation shortens transformer life [7].

A study was also done by (Ortmeyer, T.M., 1985) which shows harmonics can affect insultation, and overvoltage which can induce insulation deterioration, corona, breakdown, and line filter component failure in power line carrier systems. Voltage distortion can cause sparkover and recovery of gapped devices and solid-state electronics heating. Additionally, harmonics can also damage power line carrier system line filters [8].

3. Methodology

The design of single and multilevel buck converters are utilizing equal parameters to one and another to ease the experiment progress and comparison. The input and output voltage were set to 24 V and 11 V respectively to set the duty cycle of the buck converter.

$$d = \frac{V\ Output}{V\ Input} \tag{1}$$

Based on equation (1) the duty cycle was found which equals to 0.46 or 46%. Other parameters would need to be considered such as the resistive load, inductive load, the output voltage ripple, and inductor current ripple. The output voltage ripple and inductor current ripple can be described in (2) and (3).

$$\Delta V = (\leq 2\%)V_{Out(Max)} \tag{2}$$

$$\Delta I = (Around\ 20 - 40\%)I_{Out(Max)} \tag{3}$$

In this experiment, the output current was estimated to be 3 A, the voltage ripple was chosen to be 2% of the maximum output voltage, and the current ripple was chosen to be 30% of the maximum output current. By using (2) and (3), the output voltage ripple obtained is 0.22 V and the current output voltage obtained is 0.9 A, with this, the inductor and capacitance of the buck converter can be found.

$$L = \frac{V_{Out}(V_{In} - V_{Out})}{\Delta I f V_{In}} \tag{4}$$

$$C = \frac{V_{in} d(1-d)}{8Lf^2 \Delta V} \tag{5}$$

The switching frequency of the buck converter was set to 20 kHz, with this, by using (4) and (5), the inductor obtained is 331.02 µH and the capacitor obtained is 25.582 µF, both values were adjusted to 330 µH and 26 µF respectively.

$$R_{Load} = \frac{V_{Out(\mathrm{Max})}}{I_{Out(\mathrm{Max})}} \tag{6}$$

And lastly, the resistance load of the buck converter can be found using (6), since the estimated output current is 3 A and output voltage is 11 V, the resistance load obtained is 3.67 Ω. Meanwhile, the inductance and capacitance load for the RLC load buck converter experiment, were utilizing the same value as the inductor and capacitor of the buck converter.

3.1. Conventional Buck Converter

Figure 1 shows the conventional single level buck converter with R load configured output modelled in MATLAB Simulink. R load configured design helps this experiment grasp the foundations of buck converter operation, while next converters utilise RLC configurated load, this is because it is the most common load configuration used by many applications. This load arrangement is considered as a passive harmonic compensator positive power filter [3].

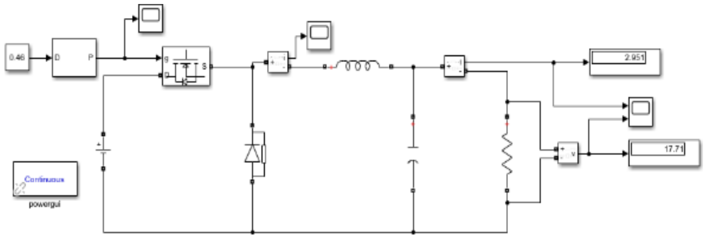

Figure 1. Conventional Buck Converter with R Load.

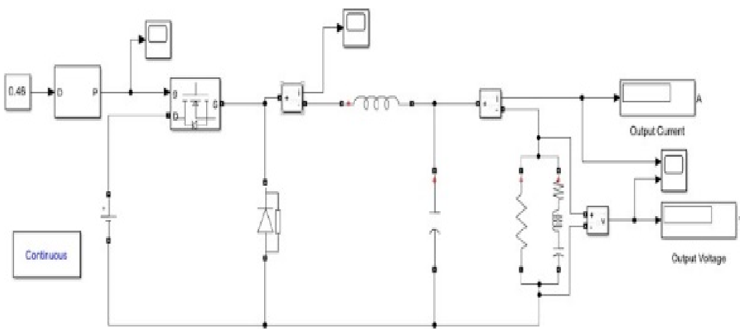

Figure 2. Conventional Buck Converter with RLC Load.

Figure 2 shows a single-level buck converter with RLC configured load in Simulink. This load configuration is considered as a positive power filter which is a passive harmonic compensator [4]. The circuit design is similar to Figure 1 with the addition of inductive and capacitive load, a resistor is added in parallel to differentiate the capacitor filter from the capacitance load in the RLC, and the resistor is doubled on both paralleled resistors, resulting 7.34, to keep the load resistance the same in the output.

3.2. Multilevel Buck Converter with R Load

Based on the single-level buck converter, two-level, three- level, four-level, and five-level converters add one MOSFET and an ON-delay module to change switching period. Each converter level boosts One inductor, and one diode must be connected in parallel, and phase shifted to get the same output voltage value.

Multilevel Buck Converter with R Load

Based on the single-level buck converter, two-level, threelevel, four-level, and five-level converters add one MOSFET and an ON-delay module to change switching period. Each converter level boosts One inductor, and one diode must be connected in parallel, and phase shifted to get the same output voltage value.

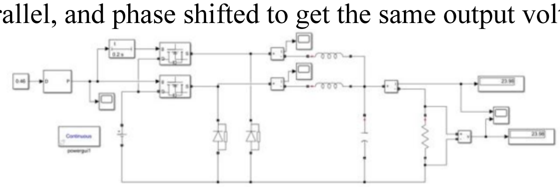

Figure 3. Two Level Buck Converter with R Load

The two-level buck converter design in Figure 3 adds a MOSFET, diode, inductor, and ON delay. This converter works like a conventional buck converter, but it is connected in parallel with another MOSFET attached with a delay and inductor to the MOSFET stacks above it and a different diode parallel and reverse biased to the switch output. For switching period difference, the ON delay is adjusted to 0.2 seconds and the inductor is doubled to 660 µH each due to its parallel design.

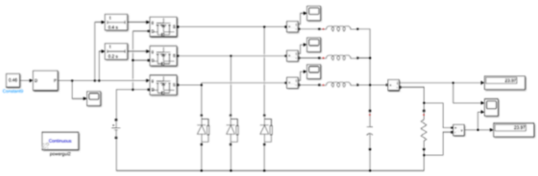

Figure 4. Three Level Buck Converter with R Load

The three-level buck converter model in Figure 4 adds two MOSFET, two diode, two inductor, and two ON delay. The second ON delay is set to 0.4 seconds, up 0.2 seconds from the two-level, and the parallel inductor is tripled to 990 µH apiece.

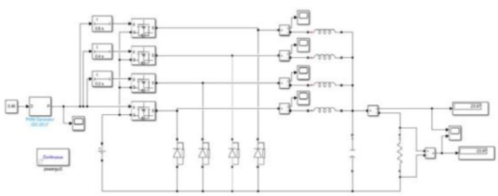

Figure 5. Four Level Buck Converter with R Load

The four-level buck converter model in Figure 5 adds three MOSFET, three diode, three inductor, and two ON delay. The third ON delay is 0.6 seconds, up 0.2 seconds from the threelevel, and the inductance is quadrupled to 1320 µH (1.32mH) due to its parallel design.

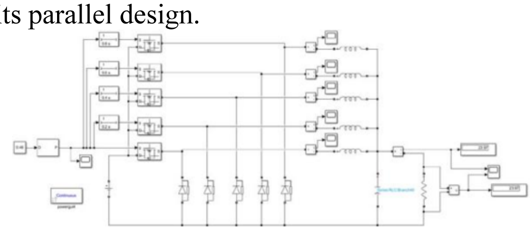

Figure 6. Five Level Buck Converter with R Load

The five-level buck converter model in Figure 6 adds four MOSFET, four diode, four inductor, and three ON delay. The fourth ON delay is 0.8 seconds, up 0.2 seconds from the fourlevel, and the inductance is quintupled to 1650 µH (1.65 mH) due to its parallel design. Research will focus on the five-level buck converter.

4. Conclusion

As technology advances, there is a growing demand for the safety of electrical and electronic devices. The buck converter is one of many DC chopper converters that could be beneficial in the future, but voltage and current ripple and harmonics became the main worry in the electrical and electronic arena. In this paper, a multilevel buck converter simulation project was developed, analyzed, and recorded. During the conversion simulation, ripples and harmonics occurred in the output waveform. Based on the results taken from both Simulink and Multisim, improving the output performance and harmonic minimization is undoubtedly possible by increasing the buck converter level number, the higher the better the outcome it gets.

References

[1] S. Bin Idham Halis, M. K. A. A. Khan, S. N. B. b. Zawawi, R. Bt Mohd Ghazali and I. Elamvazuthi, "Analysis of load current ripples in a four level Buck Converter," 2014 IEEE International Symposium on Robotics and Manufacturing Automation (ROMA), Kuala Lumpur, Malaysia, 2014, pp. 22-26, doi: 10.1109/ROMA.2014.7295856.
[2] Rashid, M.H., 2014. Power Electronics: Devices, circuits, and applications. Noida, India: Pearson India Education Services Pvt. Ltd.
[3] Papppala, R. and Naredla, R.R., 2010. Input filter design to prevent line oscillations in buck converter. Master's thesis. Blekinge Institute of Technology.
[4] Z. Gao, Y. Qiu, X. Zhou and Y. Ma, "An overview on harmonic elimination," 2015 IEEE International Conference on Mechatronics and Automation (ICMA), Beijing, China, 2015, pp. 11-16, doi: 10.1109/ICMA.2015.7237448.
[5] "IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems," in IEEE Std 519-2014 (Revision of IEEE Std 519-1992) , vol., no., pp.1-29, 11 June 2014, doi: 10.1109/IEEESTD.2014.6826459.
[6] A. Abdulslam, S. H. Amer, A. S. Emara and Y. Ismail, "Evaluation of multi-level buck converters for low-power applications," 2016 IEEE International Symposium on Circuits and Systems (ISCAS), Montreal, QC, Canada, 2016, pp. 794-797, doi: 10.1109/ISCAS.2016.7527360.
[7] V. E. Wagner et al., "Effects of harmonics on equipment," in IEEE Transactions on Power Delivery, vol. 8, no. 2, pp. 672-680, April 1993, doi: 10.1109/61.216874.
[8] Ortmeyer, T.M. and Chakravarthi, K.R., 1985. The effects of power system harmonics on power system equipment and loads. IEEE Trans.
[9] Power Appar. Syst.;(United States).