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Efficient Performance Technical Selection of Positive Buck-Boost Converter

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ABSTRACT

The necessity for stable DC voltage in both removable and non-removable systems has been considerably desired recently. These systems have to be implemented efficiently in order to be responding rapidly based voltage variations. Under this act, the efficient power can extend the lifetime of the employed batteries in such systems. The presented efficiency can be realized with respect to buck and boost components that were implemented to generate what is called positive Buck-Boost converter circuits. The main functions of the positive Buck-Boost converter are identified by announcing the unchanged situation of output voltage polarity and indicating the level of the voltage rationally between the input and the output. It is worth mention, the positive Buck-Boost converter circuit was simulated based *Proteus* software, and the hardware components were connected in reality. Finally, the microcontroller type that employed in the proposed system is PIC_16F877A, which realizes the input voltage sensitively to generate Pulse Width Modulation (PWM) signals in order to feed the employed MOSFET element.

Keywords: Converter Circuits, Inverting and Non inverting Converters, Positive Buck and Boost Converters.

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تقنيات ألاداء الفائق لإختيار العاكس (الخافض – الرافع) إلأيجابي

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الملخص

الحاجة إلى الجهد المستمر(DC) الثابت في كثير من الأنظمة التي يتغير فيها الجهد المستمر عندما يكون مصدرا للتغذيه او لايكون مصدرا في الآونة الأخيرة أصبحت مطلوبة بشكل كبير. لذلك تتطلب الحاجة الى مثل هكذا دائره الكترونيه لمثل هذه الأنظمة للعمل بكفاءة من أجل الاستجابة لتغيرات الجهد على أساس سريع. وبموجب هذا المتطلب ، يمكن للطاقة الفعالة أن تطيل عمر البطاريات المستخدمة في هذه الأنظمة مثلا ام المحافظه على أداءبكفائه عاليه. وكذلك يمكن أن تتحقق الكفاءة المتقدمة فيما يتعلق بالعواكس Back و Boost التي تم تنفيذها لتوليد ما يسمى تحويل دفعة Back و Boost إيجابية. الوظائف الرئيسية لمحول Back و Boost الإيجابي هي في حالة عدم تغيير قطبية الجهد الناتج ، والإشارة إلى مستوى الجهد بشكل رشيد بين المدخلات والمخرجات. ومن الجدير بالذكر ، تم محاكاة دائرة محسنة دفعة إيجابية على أساس برنامجProteus للتمثيل الرياضي ، وكذلك تم توصيل مكونات الأجهزة في الواقع الحقيق. وأخيرًا ، يكون نوع المتحكم الدقيق المستخدم في النظام المقترح هو PIC_16F877A ، الذي يحقق جهد الإدخال بحساسية لتوليد إشارات تعديل العرض النبضي (PWM) من أجل تغذية عنصر MOSFET المستخدم.

الكلمات الدالة: دائرة التحويل، المحول العاكس وغير العاكس، محول الخافض والرافع بالاتجاه الموجب

1. Introduction

The modern technologies have fascinated the universe by developing and enhancing the devices especially the portable devices that are massively needed nowadays. These portable devices need to be under the domination of great power providers. Lithium-ion batteries are considered the most applicable item in these devices. Hereby, the question is: how to design a power system capable of providing these devices by the required power in an efficient way without wasting. That would be one of the applications of positive Buck-Boost converter that magnifies – reduce the input voltage based DC-DC conversion principle. There are many typologies were used for converting of DC-DC voltage. They have been commonly used in power supply applications for the majority of electronic systems. The most popular kind of converters are identified by [1, 2]:

1. Individual Buck converter.
2. Individual Boost converter.
3. Buck-Boost converter.

The basic principle of DC to DC positive Buck-Boost converter converts DC output voltages. The output voltage can be less than input, which is during Buck converter (step down), higher than the input during Boost converter (step-up) converter. It also could be same as the input. Recently, DC to DC converters is developed to be a popular subject matter, which has many requirements for best specification such as less costly, smaller size, lighter in weight and fewer power losses towards a highly efficient power conversion. Moreover, pulse width modulation (PWM) has been grown of DC electronic devices. Buck-Boost converter adapts an unstable input voltage into a fixed output voltage. The output voltage of the circuit can be dominated by utilizing a duty cycle.

1.1. DC-DC Converters

The basic typologies widely employed in DC-DC conversions are Buck converter, the Boost converter, and Buck-Boost converters. The Buck converter that is known as step-down the output voltage, regulates the output voltage to be less than the input. Besides, the Boost converter or what is called the step-up converter is utilized to regulate the output voltage, which could be higher - equal to the input voltage. Additionally, the Buck-Boost converter is used for both conversion issues, which could operate as a step-down and step up. There are a couple of different typologies of Buck-Boost converter in same circuit topology.

I. Buck-Boost inverting converter: The output voltage is reverse polarity.
II. Buck-Boost non-inverting converter: The output voltage is a similar polarity as the input voltage.

There are many different types of a single step up or step down DC-DC switching converters. For example of these converters topologies as Buck-Boost inverting converter, SEPIC- Single Ended Primary Inductance Converter, and Cuk converter that match the similar functionality. Nonetheless, some types of converters include drawback in terms as Buck-Boost inverting converter and Cuk converter where the output voltage is reversed in polarity [3].

On the other hands, the combination of positive Buck and Boost converter by a single circuit, which is by combining Buck and Boost converter circuits with independently controllable switches, which are a common choice for these types of applications requiring conversion capability. In this review paper, several different types of Buck-Boost with positive output voltage will be discussed. There are numerous approaches to provide a controlled the output voltage (without change polarity of the output voltage). The basic Buck-Boost inverting converter and Cuk converter are excluded, due to the output voltages that are reversed in polarity to the input.

In this review paper, the kind of Buck-Boost converter with a positive output voltage reviewed and analyzed by other researchers. In these days, the applications of DC-DC converters have been improved and expanded drastically since they commonly utilized as a part of sustainable power source frameworks, for example, fuel cells, hybrid electric vehicles, battery chargers, and solar systems [4, 5]. The hybrid energy such as solar energy and wind energy are categorized as varied voltage due to the fact that solar power is dependent on sunlight and the wind energy depends on the wind. For that reason, DC-DC converter is used to regulate the output voltage to step-up or step-down the output voltage to supplied steady levels, the range of the input voltage is a between (6-18) V and need to get 12V output at steady.

1.2. Single Ended Primary Inductor Converter (SEPIC)

SEPIC is certainly the simplest circuit is a kind of DC-DC converter, the electrical power potential voltage at the output could be higher, lower or same as the input voltage. The SEPIC is regulated by the duty cycle [6]. A SEPIC converter generally is the same as a classic of Buck-Boost inverting converter. However, SEPIC has an advantage of getting Non-inverted output voltage, which can be identified as the output voltage that is similar to polarity voltage [7]. The conventional SEPIC converter has two inductors, two capacitances, one switching and one diode as shown in Fig. 1.

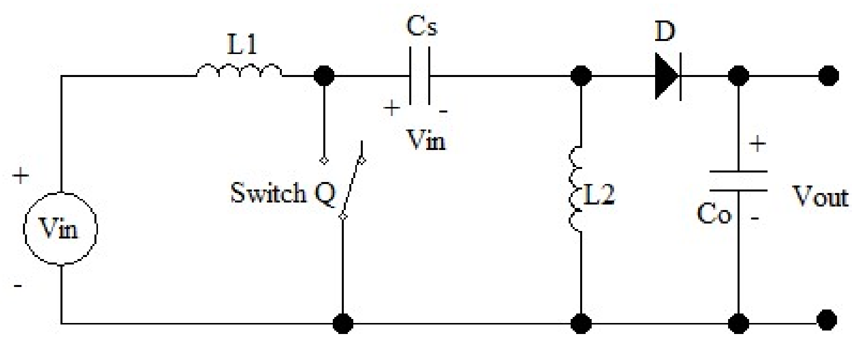

Fig. 1 SEPIC circuit diagram

It is clearly understood that the (switch Q) is connected parallel with the input voltage, and $L2$ is joined together in parallel to the load. Capacitance Co is connected in parallel with switch Q and the resonant inductor $L1$ is connected

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in series with Cs [8]. The operation of SEPIC has happened during two states. When switch Q is closed, the current of I_{L1} is increased in a positive direction and the I_{L2} is increasing in the negative direction. The energy power required to raise I_{L2}, which is come from the input supply. When the switch is closed the voltage of V_{CS} is roughly equal to V_{IN}, the voltage V_{L2} is also roughly to V_{IN}. Thus, the capacitor V_{CS} provides the power to improve the magnitude field of the current in I_{L2} for growing the energy stored in I_{L2}. Additionally, the diode works as a reverse as open circuit [9]. When (switch Q) is open, the current I_{CS} becomes equal to I_{L1} because the inductors do not enable on immediate changes in the current. I_{L2} keeps in the negative path, in reality, it certainly not reverses path. $I_{L2}$and I_{L1} leads to increase the current delivered to the load [10]. There are some researchers were discussed about the model of SEPIC converters [11, 12, 13], which was the extremely popular Buck-Boost converter. However, it needs additional components. SEPIC, used a couple of inductors and capacitors. Thus, including occupy extra space lead to be increasing the size and the price. Extra components lead to increase the losses, and the efficacy of converter will be lower. However, the SEPIC include some advantages which the output voltage is actually having a similar polarity of the input voltage. Additionally, it could be regulated fixed output voltage regardless of the input voltage is lower or higher than the required.

1.3. Combination Circuit Converters

There are two types of the most popular combination converters, which is Boost-Buck converter and Buck-Boost converter. The characteristics of the proposed converters are obtained by connection a couple of general converters with positive output voltage [5]. At the first type of converter, which is Boost-Buck converter, the Boost converter stage could be located at the first then Buck converter is connected by series with it. At second the type of Buck-Boost converter, the Buck converter could be located at the first stage and followed by the Boost converter. Both of converters will be explained, discussed and compared.

1.4. Positive Boost-Buck Converter

The topology that achieved by separated devices includes two DC-DC converters. In these types of converter, the output voltage could be greater or smaller than the input voltage. The output voltage of Boost-Buck converter is a positive. During a Buck or a Boost converter, 2 switches are turned on and off per every period [14, 15]. This type of circuit is required two inductors, a couple of MOSFETs, two diodes and two capacitors as shown in Fig. 2.

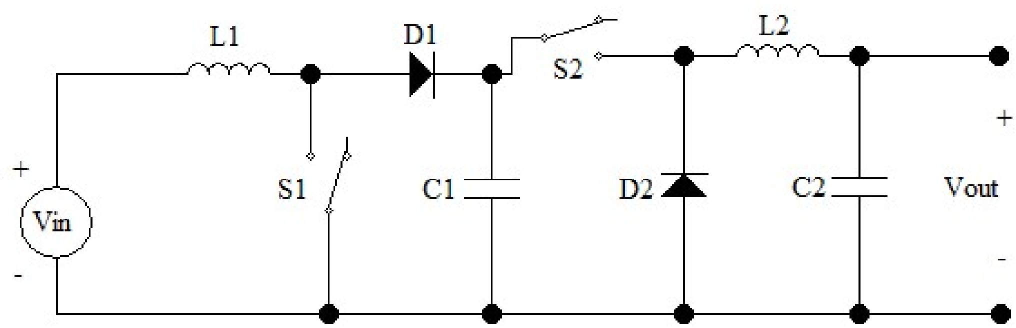

Fig. 2 Circuit of positive Boost-Buck converter

In spite of the fact that the circuit works with respect to drive the two switches concurrently, as well as Pulse Width Modulation (PWM) control is used to drive S1 and S2. When the Boost function is needed, the S1 is driven by PWM and S2 is adjusted through the output voltage as shown in Figure 2. Besides that when the Buck function is required as a (Vin>Vout) MOSFET S2 will be operated by controlled PWM while S1 hold off [8].

The researchers were combined a circuit of positive Boost-Buck converter by used two switches to regulate the output voltage. This work was applied by using two DC-DC converters that are combined Boost converter and followed by Buck converter [16, 17]. The advantage of this converter was the output voltage always-positive direction. Whereas the limitations of this converter are, the losses are high, which leads to lowers on efficiency

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because the amount of the components as twice of capacitors, inductors, and compensation network required for both of controllers is more. More equipment, additional space is engaged, which leads to increase [18, 19] the cost. Furthermore, the control system of the two PWM loop is difficulty according to [20].

1.5. Positive Buck-Boost Converter

This converter circuit has similar functions previous circuit of positive Boost-Buck converter, which is explained before and shown in Figure 2. In this case, of positive Buck-Boost converter is basically a combination of a Buck section converter concatenated by the Boost section. This topology has two MOSFETs switches, two diodes one output capacitor and one inductor [21] as shown in Fig. 3.

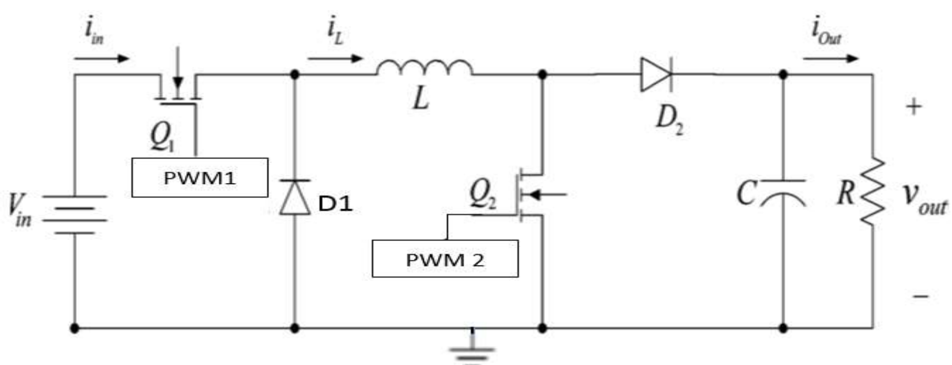

Fig. 3 A circuit of positive Buck-Boost converter [19]

In addition this circuit of positive Buck-Boost converter or what is called Buck-Boost Non-inverting converter could be used as step-up or step-down DC-DC converters [22], it is permitted to connect a Buck with Boost converter in one topology to lead a single inductor in order to be employed with high fulfillment in Buck-Boost converter [23, 24]. This type of converter could be used as a Buck converter only by controlling switch Q1, diode D1, Q2 will be turned OFF and D2 will be conducted. Besides, it could work like a Boost converter by dominating switch Q2 and diode D2, during the Q1 conducts, While D1 not conducts.

The operation of Buck converter occurs in two cases, the first case when MOSFET of Buck converter S1 is closed and the second case when S1 is opened. In the first case, the current flow through the source Vin from the inductor to the load that charges the inductor by rising the magnetic field, when the Diode of Buck converter D1 is reverse bias. Simultaneously, the current flow from the inductor, causes energy amplification. When V_{out} reached to the required value, switch S1 opens and diode D1 turns ON in the second case of the operation in Buck converter. When the MOSFET1 (S1) is open, the inductor works as the main source to preserve the current over the load resistor. The current goes on streaming over the inductor from the diode D1 and waits for magnetic field break down operation and the inductor discharges. Before discharge operation, D1 is opened, S1 is closed, and the period is repeated.

The operation of the Boost converter also occurs in two cases. As well as, in Buck converter. During the first case, the MOSFET2 S2 is closed. The current through the switch MOSFET2 S2 conducts, therefore current flows between the positive and negative source terminals throughout the inductor, which can store electrical energy by generating a magnetic field. There is certainly no current streaming in the other parts of the circuit as diode D2 or capacitor C. The MOSFET is quickly turned OFF (during S2 open). It causes a drop in current and eventually derives the inductor to generate a back electromagnetic field (e.m.f), in a reversed polarity with respect the voltage across the inductor. While on period, to continue current streaming which leads to a couple of voltages, the given supply voltage V_{in} and the generated back (e.m.f). The higher voltage comes from voltage supply and inductor. There is absolutely no current through the MOSFET 2. Lastly, the current through D2 charges up the capacitor to V supply +VL with a small forward voltage drop across D2, then supplied to the load.

In the work of researchers [3, 24, 25] an identification technique was presented for soft transitions in positive Buck-Boost converter. The circuit is chosen because it has an individual inductor, which is used for both of converters, Buck and Boost. It is a well-known decision for applications requiring bidirectional conversion capability, high efficiency and less component stressed. The researchers found reduced conduction losses and decreased inductor stress as compared to the Boost converter. In Addition, the characteristic of this arrangement includes the capacity to select the output DC voltage. Moreover, the researchers in [19, 26] stated the perfect techniques requires an exchange among the costs, lesser output noise and lesser ripple factor. This type of converter techniques could regulate the output voltage into lower, higher or equivalent voltage. The extra benefit of the converter circuit is the output voltage of the converter in a positive direction.

2. Positive Buck-Boost Technique Implementation

The models of different converter topologies are discussed in this review paper. The operation of different circuits of Buck-Boot converters, which were supplied positive output voltage, were explained in details. The advantages and disadvantages in the converters, was addressed. The techniques theory of combination of DC-DC converters was presented. The SEPTIC is a simple circuit, however not considered functional. A converter topology named positive Buck-Boost converters, which can work with both converter (step-down), and (step-up) was chosen, because it has, many advantages compared with another type of Buck-Boost converter. The main difference between configurations converters that have explained the positive Buck-Boost converter was utilized less number of components electrical devices compared with other converters. The circuit of positive Buck-Boost converter has been simulated by Proteus simulation software and fabrication in hardware to get the result as shown in Fig. 4, 5.

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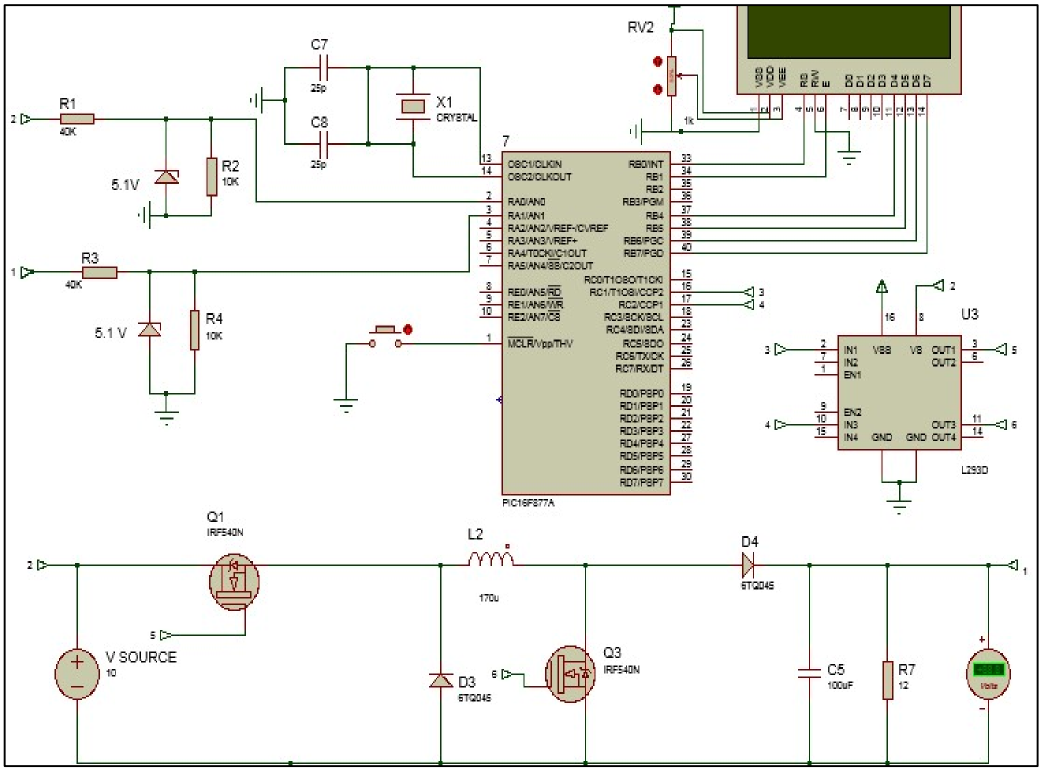

Fig. 4 Design circuit connection of positive Buck-Boost Converter

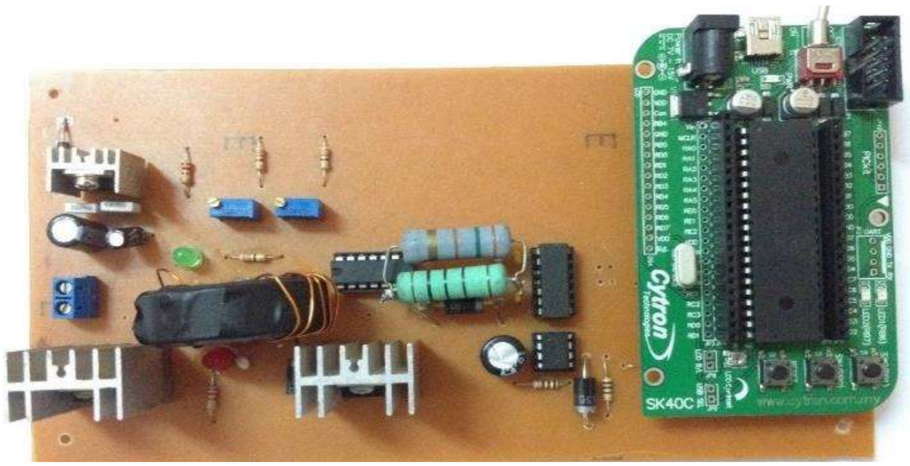

Fig. 5 Hardware implementation of positive Buck-Boost converter.

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3. Results And Discussions

3.1. PWM Waveform Result

PIC Microcontroller (16F877A) generates PWM waveform, which is the frequency that has been used is 50 KHz. The duty cycles of PWM are not constant. It is dependent on the input voltage supply. Fig. 6 shows the PWM waveform in software simulation during different duty cycle value.

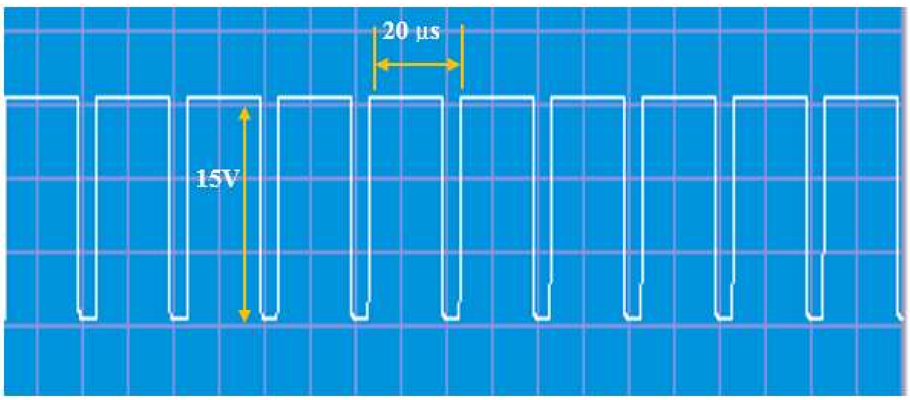

Fig.6 PWM on simulation software at 80% of the duty cycle.

3.2. The result of Buck Converter Simulation

Consequently, the following results were obtained from the simulation. The outcomes were found in accordance with the result than expected. The output voltage is the main part of this project. The output of Buck circuit is always lower than the input. The input voltage is not constant which is a variable. The range of input voltage for Buck converter is from 13-18 and the output is 12VDC. Table 1 shows a several different input value through Buck converter. Despite the input voltage is varied, the output voltage still virtually regulated at approximately 12VDC. The difference of the duty cycle as the assignment of the output voltage is shown in Table 1, which exposes a linear relationship between the duty cycle and the Vout/Vin ratio for a larger scope of output voltages.

Table 1 Output voltage during Buck converter on simulation.

V_{in}	V_{out}	Duty Cycle (%)
13	11.97	93.2
14	12.08	85.7
15	12.02	80
16	12.04	75
17	12.05	70.5
18	12.05	66

3.3. The result of Boost Converter Simulation

Table 2 shows the output voltage through the Boost converter, which indicates that the output voltage is greater than the input. Table 2 shows the indicates a fairly constant output of approximately 12 VDC. Even the input voltage for Boost converter is varied from 6V to 11V, the output voltage remained virtually at 12VDC.

Table 2 Output voltage during Boost converter on simulation.

V_{in}	V_{out}	Duty Cycle (%)
6	12.16	50
7	11.99	41.6
8	12.07	33.3
9	11.96	25
10	11.98	16.6
11	11.98	8.3

4. Hardware Implementation Result

4.1. The result of Buck Converter on Experimental

The results of Buck converter were presented in Table 3. The input voltage of this project was a variable with a range from 13V to 18V. The output voltages of Buck converter was roughly constant at 12V. The correlation between the output voltage and the duty cycle is a positive relationship, which that means; when the duty cycle increased the output will be increased.

Table 3 Output voltage during Buck converter on hardware.

V_{in}	V_{out}	Duty Cycle (%)
13	11.85	92.3
14	11.83	85.7
15	11.90	80
16	11.88	75
17	11.86	70.5
18	11.92	66

4.2. The result of Boost Converter on Experimental

The results from the Boost converter were presented in Table 4. The Boost converter is an operation with a different input voltage also and the output voltage was kept at around 12V. The relationship between the output voltage and the duty cycle is a positive relationship also, which that means; when the duty cycle increased the output will be increased.

Table 4 Output voltages during Boost converter on hardware.

V_{in}	V_{out}	*Duty Cycle (%)*
6	11.87	50
7	11.93	41.6
8	12	33.3
9	11.93	25
10	11.95	16.6
11	11.9	8.3

From the results, there are two sections; simulation software results and hardware implementation. The values of Buck converter and Boost converter from the simulation software were almost the same as the value of the experimental fabrication result. The result values from the simulation were quite high compared with the values from hardware fabrication. The hardware implementation has higher losses because of the electrical power losses such as conduction losses and switching losses. Conduction losses were those voltage drops and currents of the elements that happen when the MOSFET is conducting. Switching losses were included in both of equipment as MOSFETs and diodes. The frequency of switching was high, the switching operations change quickly. This includes rise time and fall time for each switching change. Besides what was mentioned, the components sometimes, do not give the exact value that required because of other effects as temperature. The accuracy voltage for experimental are not very different and still under the limit.

5. Conclusions

The analysis has been done for the control signals. PWM waveform generated by using PIC Microcontroller 16F877A to drive the MOSFETs. PWM waveform connected to the gate driver provides a greater amplitude of the waveform. The converter was checked and tested with variable input voltages. The circuit has achieved output voltage at 12VDC that means the Buck-Boost DC-DC converter circuit was able to step-up or step-down the output voltage. The output voltage could be controlled by fixing at 12V even though the input voltage keeps changing from 6V to 18V. The important part for this circuit was achieved by working without changing the polarity of the output voltage. This kind of converter has found more compact, with high efficiency. Analog - Digital Converter ADC on the PIC16F877A was used to sense the input voltage to generate the PWM as required. From the data collected of the input and output power, it has been found the overall efficiency of positive Buck-Boost converter is 82%.

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References

[1]. Chakraborty, A., Khaligh, A., Emadi, A., & Pfaelzer, A. (2006, June). ***Digital combination of buck and boost converters to control a positive buck-boost converter.*** In Power Electronics Specialists Conference, 2006. PESC'06. 37th IEEE (pp. 1-6). IEEE.

[2]. Yao, K., & Lee, F. C. (2002). ***A novel resonant gate driver for high-frequency synchronous buck converters***. Power Electronics, IEEE Transactions on, 17(2), 180-186.

[3]. Chen, J., Maksimovi C, D., & Erickson, R. (2001). ***Buck-boost PWM converters having two independently controlled switches***. In Power Electronics Specialists Conference, 2001. PESC. 2001 IEEE 32nd Annual (Vol. 2, pp. 736-741). IEEE.

[4]. Restrepo, C., Calvente, J., Cid-Pastor, A., Aroudi, A. E., &Giral, R. (2011). ***A noninverting buck-boost DC-DC switching converter with high efficiency and wide bandwidth***. Power Electronics, IEEE Transactions on, 26(9), 2490-2503.

[5]. Erickson, R. W. (1997, May). ***Some topologies of high-quality rectifiers***. In the Proc. of the First International Conference on Energy, Power, and Motion Control.

[6]. Chiang, S. J., Shieh, H. J., & Chen, M. C. (2009). ***Modeling and control of PV charger system with SEPIC converter***. Industrial Electronics, IEEE Transactions on, 56(11), 4344-4353.

[7]. Dongbing Zhang. (2013). ***Designing A SEPIC Converter*** This page was last modified on 21 November 2014, at 16:41. https://en.wiki2.org/wiki/Single-ended_primary-inductor_converter.

[8]. Mullett, C (2013). ***DC-DC Converter for Driving High-Intensity Light-Emitting Diodes with the SEPIC Circuit***. Application Note AND8138/D, available from ON Semiconductor (www. onsemi. com).

[9]. Venkatanarayanan, S., & Saravanan, M. (2014). ***Design and Implementation Of Low-Cost Sepic Photovoltaic System For Constant Voltage***. Journal of Theoretical & Applied Information Technology, 63(3).

[10]. Chiang, S. J., Shieh, H. J., & Chen, M. C. (2009). ***Modeling and control of PV charger system with SEPIC converter. Industrial Electronics***, IEEE Transactions on, 56(11), 4344-4353.

[11]. Wei, C. L., Chen, C. H., Wu, K. C., &Ko, I. T. (2012). ***Design of an average-current-mode noninverting buck-boost DC-DC converter with reduced switching and conduction losses***. Power Electronics, IEEE Transactions on, 27(12), 4934-4943.

[12]. Adar, D., Rahav, G., & Ben-Yaakov, S. (1997, June). ***A unified behavioral average model of SEPIC converters with coupled inductors.*** In Power Electronics Specialists Conference, 1997. PESC'97 Record. 28th Annual IEEE (Vol. 1, pp. 441-446). IEEE.

[13]. Moussa, W. M. (1995, March). ***Modeling and performance evaluation of a DC/DC SEPIC converter***. In Applied Power Electronics Conference and Exposition, 1995. APEC'95. Conference Proceedings 1995. Tenth Annual (pp. 702-706). IEEE.

[14]. Xiong, Y., Sun, S., Jia, H., Shea, P., &Shen, Z. J. (2009). ***New physical insights into power MOSFET switching losses***. Power Electronics, IEEE Transactions on, 24(2), 525-531.

[15]. Eberle, W., Zhang, Z., Liu, Y. F., &Sen, P. C. (2009). ***A practical switching loss model for buck voltage regulators. Power Electronics***, IEEE Transactions on, 24(3), 700-713.

[16]. Wai, R. J., & Shih, L. C. (2011). ***Design of voltage tracking control for a DC-DC boost converter via a total sliding-mode technique***. Industrial Electronics, IEEE Transactions on, 58(6), 2502-2511.

[17]. Lee, Y. J., Khaligh, A., Chakraborty, A., & Emadi, A. (2009). ***Digital combination of buck and boost converters to control a positive buck-boost converter and improve the output transients***. Power Electronics, IEEE Transactions on, 24(5), 1267-1279.

[18]. Mao, H., & Thottuvelil, V. J. (2000). ***Switching controller for a buck+boostconverter and method of operation***. U.S. Patent No. 6,037,755. Washington, DC: U.S. Patent and Trademark Office.

[19]. Chen, J., Maksimovic, D., & Erickson, R. W. (2006). ***Analysis and design of a low-stress buck-boost converter in universal-input PFC applications***. Power Electronics, IEEE Transactions on, 21(2), 320-329.

[20]. Dwelley, D. M., & Barcelo, T. W. (2000). ***Control circuit and method for maintaining high efficiency in a buck-boost switching regulator***. U.S. Patent No. 6,166,527. Washington, DC: U.S. Patent and Trademark Office.

[21]. Duran, E., Sidrach-de-Cardona, M., Galan, J., & Andujar, J. M. (2008, June). ***Comparative analysis of buck-boost converters used to obtain I–V characteristic curves of photovoltaic modules.*** In Power Electronics Specialists Conference, 2008. PESC 2008. IEEE (pp. 2036-2042). IEEE.

[22]. Kondrath, N., & Kazimierczuk, M. K. (2012). ***Comparison of wide-and high-frequency duty-ratio-to-inductor-current transfer functions of DC-DC PWM buck converter in CCM***. Industrial Electronics, IEEE Transactions on, 59(1), 641-643.

[23]. Huang, P. C., Wu, W. Q., Ho, H. H., & Chen, K. H. (2010). ***Hybrid buck-boost feedforward and reduced average inductor current techniques in fast line transient and high-efficiency buck-boost converter***. Power Electronics, IEEE Transactions on, 25(3), 719-730.

[24]. Lee, Y. J., Khaligh, A., & Emadi, A. (2009). ***A compensation technique for smooth transitions in a noninverting buck-boost converter***. Power Electronics, IEEE Transactions on, 24(4), 1002-1015.

[25]. Chen, J., Maksimovi C, D., & Erickson, R. (2001). ***Buck-boost PWM converters having two independently controlled switches***. In Power Electronics Specialists Conference, 2001. PESC. 2001 IEEE 32nd Annual (Vol. 2, pp. 736-741). IEEE.

[26]. Nanda k. k, & Giri R. (2013). ***A Positive Buck-Boost Converter Controlled By Digital Combination Of Buck And Boost Converters To Improve The Output Transients***" Vol.2, No.2, Pages: 139-148Special Issue of NCRTECE 2013 - 8-9 February.