Low-Cost Buck Converter and Voltage Sensing Method for Low-Voltage Systems

Jong-cheol Kim, Seong-mi Park, Sung-jun Park

Abstract Background/Objectives: Small, low-voltage buck converters commonly used in the renewable energy industry, the micro grid, and the automotive industry require insulated gate amplifier voltages, which can be a significant economic burden on the system.

Methods/Statistical analysis: Therefore, in this paper, we propose a voltage detection method that detects the voltage of the converter and the low side buck converter that does not require the insulation gate amplifier voltage by changing the switch position from + side to - side. To verify this, we used simulations and compared them with existing converters.

Findings: Unlike the conventional buck converter, the Modified buck converter can sense the voltage when the switch is turned on, but when the switch is off, the output voltage and the voltage of the switch are added to the output terminal, Accurate sensing is impossible. For this reason, a voltage sensing method different from the conventional one is required for the Modified converter.

Improvements/Applications: low-side Buck-converter that does not require isolated gate amplifier voltage and a voltage detection method to detect the voltage of this converter.

Keywords: Buck converter, voltage sensing method, low-voltage, low-cost

I. INTRODUCTION

Nowadays, using dc–dc converters is rapidly expanding in computer equipment, medical equipment, servomotors, lighting systems, power factor correction (PFC), and portable computers. Generally the inputs of these converters are unregulated DC voltages, and the DC-DC converter makes these inputs the desired voltage level.[1-5]

These DC-DC converters are divided into isolated and non-isolated converters.

Isolation converters are types in which the input and output terminals are isolated through the primary and secondary sides of the transformer. Non-isolated converters use the same input / output ground voltage level without a transformer.[6-10]

A commonly used non-isolated converter requires an isolation voltage for the gate driver, which takes up a lot of space and cost in configuring the non-isolated converter. In this paper, we propose a buck converter that does not require isolation voltage for gate driver, but a buck converter that requires isolation voltage for conventional gate driver, and proposes a method for detecting the output voltage of this converter. To verify this, we compared the output voltage sensed by the conventional converter with the output voltage sensed by the Modified converter by PSIM simulation.

Revised Manuscript Received on May 22, 2019.

Jong-cheol Kim, Department of Electrical Engineering, Chonnam National University, Gwangju 61186, Korea

Seong-mi Park, Department of Lift Design, Korea Lift College, Geochang 50141, Korea

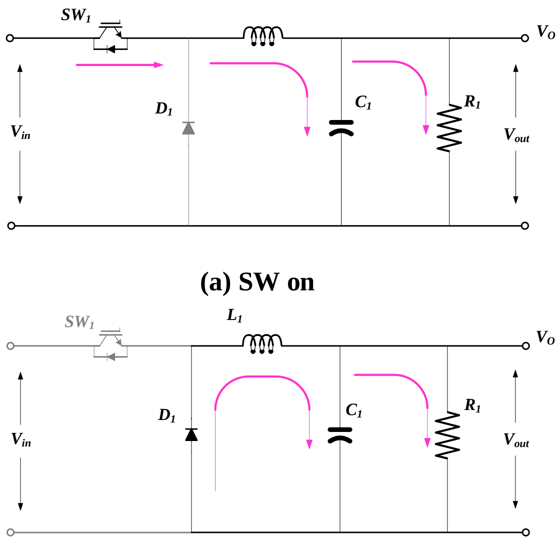
Sung-jun Park, Department of Electrical Engineering, Chonnam National University, Gwangju 61186, Korea

Sacredwind4@gmail.com[1],soengmi@klc.ac.kr[2], sjpark1@jnu.ac.kr[*3]

II. CONVENTIONAL BUCK CONVERTER AND PROPOSES BUCK CONVERTER

Generally used non-isolated converters require isolation voltage in the gate driver, which is a lot of space and cost in constructing non-isolated converters.[11-15] However, the proposed low-side buck converter does not require a separate isolation voltage, which saves space and costs compared to conventional buck converters. However, the voltage detection method applied to the conventional buck converter requires a new voltage detection method because the voltage detection value changes according to the switch on / off operation.

2.1. Conventional buck converterand voltage sensing method



(a) SW on

(b) SW off

Figure 1. Conventional buck converter

Figure 1 shows the structure, operation, and current flow of a typical buck converter. The buck converter uses the same input / output ground voltage level as non-isolated converter. In addition, a gate driver with separate isolation voltage is required to drive the switch. Generally, for the circuit configuration of a gate driver having a separate insulation voltage, an insulation voltage supply element corresponding to the number of switches is required to

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

drive one or two switches. However, the cost of this element is typically around $ 12, so the more the number of switches, the higher the cost.

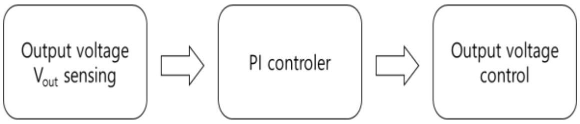
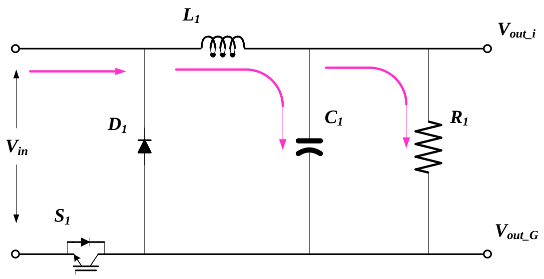


Figure 2. Conventional voltage sensing method

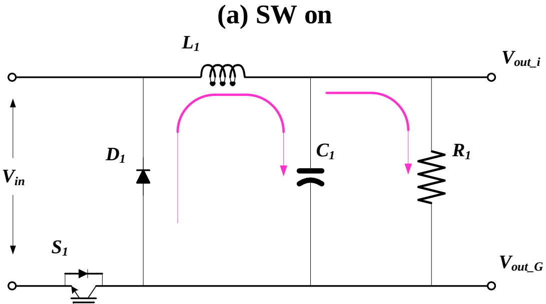
As shown in figure. 2, a conventional voltage sensing scheme detects an output voltage and controls an output voltage according to a reference voltage. The sensing of the output voltage can be always detected irrespective of whether the switch is operating or not, so there is no problem. However, as described above, since the conventional buck converter requires a separate device for supplying the insulation voltage to the switch, there is a problem that the circuit configuration is expensive.

2.2.Modified buck converter and proposed voltage sensing method

Figure 3 shows a proposed topology buck converter that does not require isolation voltage for the gate driver. Figure 2 (a) and (b) show that the current flowing when the switch is on and the current flowing when the switch is off are the same.The voltage sensing method proposed in this paper is a method of sensing the voltage only when the switch is turned on.



(a) SW on



(b) SW off

Figure 3. Modified buck converter and operation

However, unlike the conventional buck converter, the modified buck converter can sense the voltage when the switch is turned on, but when the switch is off, the output voltage and the voltage of the switch are added to the output terminal, Accurate sensing is impossible. For this reason, a voltage sensing method different from the conventional one is required for the Modified converter .

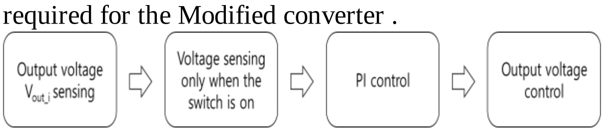


Figure 4. proposed voltage sensing method

As shown in figure 4, since the output voltage of the modified buck converter is detected only when the switch is on, the proposed voltage sensing method detects the output voltage through the voltage sensor only when the switch is on. The detected voltage value is given, and the output voltage can be controlled by the reference voltage value.

As described above, the output voltage of the improved buck converter is detected as a normal voltage when the switch is on, and the sum of the voltage of the switch and the output voltage is detected when the switch is off. Therefore, when the voltage is sensed only when the switch is ON, the normal voltage value can be detected.

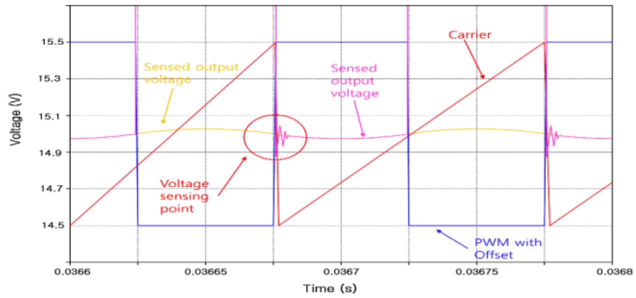
If the switch that can be seen in Fig. 4 senses the voltage when it is on, the reading part of the AD value changes according to the variation of the output voltage, and the read voltage value changes accordingly.

If the real voltage value is Vo, a completely different value can be read in accordance with the output voltage fluctuation. Therefore, the portion for sensing the AD must be clearly set.

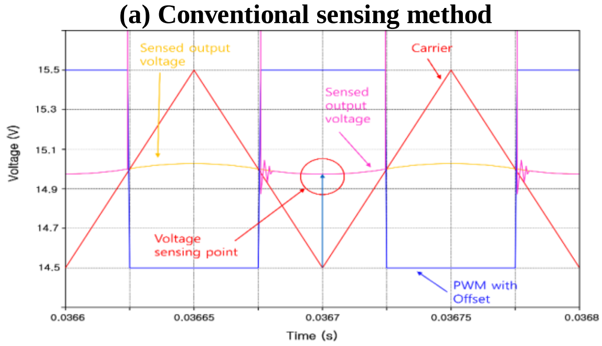
The PWM of a typical buck converter uses a up counter to generate the PWM.When the up counter is used, the detection is performed when the SOC signal of the separate ADC becomes 0. Therefore, if the voltage is detected at the starting point as shown in Fig. 5, the average voltage can be detected in the simulation. However, And a difference from the average voltage value is generated.

An up-down counter should be used to control this.In the case of the up-down counter, as shown in Fig. 5, the ADC module operates because the SOC occurs at the portion where the up-down carrier becomes zero, so that there is no danger that the initial ripple component is sensed as in the up counter.

As a result, when the voltage is sensed in the middle part of the PWM On signal, the voltage is detected at the middle part of the output voltage, so that a more accurate value can be detected.



(a) Conventional sensing method



(b) Proposed sensing method

Figure 5. Comparison of extended sensing

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

voltage waveforms

In order to solve this problem, we can detect the output voltage value close to the average value using the up - down counter and set the error rate to less than 0.5%, so that the voltage can be detected more accurately than the conventional method.

In order to set the capacitor ripple ratio to 0.5%, the capacitors are constructed as shown in the following equations (1), (2), and (3).

$$\Delta v_o = \frac{1}{C}\Delta i_L \frac{T}{8} \quad (1)$$

$$\Delta i_L = \frac{V_{in} - DV_{in}}{L} DT = \frac{V_{in}}{L}(1-D)DT \quad (2)$$

$$\Delta v_o = \frac{1}{C}\frac{1}{L}\frac{V_{in}(1-D)DT^2}{8} \quad (3)$$

If Δv_o is calculated so that $\frac{\Delta v_o}{15} = 0.005$ to limit the capacitor ripple rate to 0.5%, $\Delta v_o = 0.08$, and the input voltage 30 [V], the duty ratio 0.5, and the switching frequency 10 [KHz] Expressed as substitution, it is expressed as the following expression (4).

$$C = \frac{1}{L}\frac{30(1-0.5)(0.5)\left(\frac{1}{10^4}\right)^2}{(8)(0.08)} \quad (4)$$

The inductor current change value Δi_L is set to 2 [A], and the value is obtained through the following equations (5) and (6) to obtain the L value due to this change.

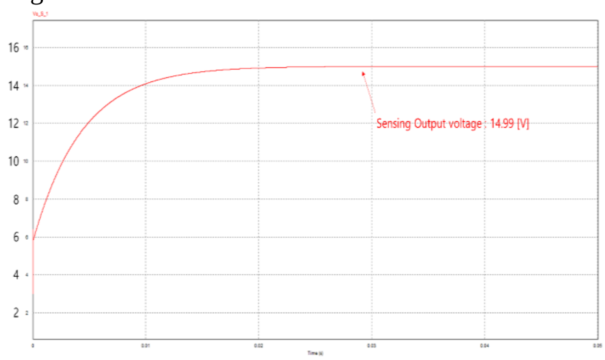
$$\Delta i_L = \frac{V_{in} - V_o}{L} DT \quad (5)$$

$$L = \frac{V_{in} - V_o}{\Delta i_L} DT \quad (6)$$

By substituting the input voltage 30 [V], output voltage 15 [V], Δi_L = 2 [A], duty ratio 0.5, and switching frequency 10 [KHz] into each term of equation (6), expressed as equation (7).

$$L = \frac{30-15}{2}(0.5)\left(\frac{1}{10^4}\right) \quad (7)$$

C is obtained by substituting L = 375 [μF] obtained from equation (7) into equation (4), C = 313 [μF]. check these values through simulation, you will see the waveform shown in Figure 6 below.



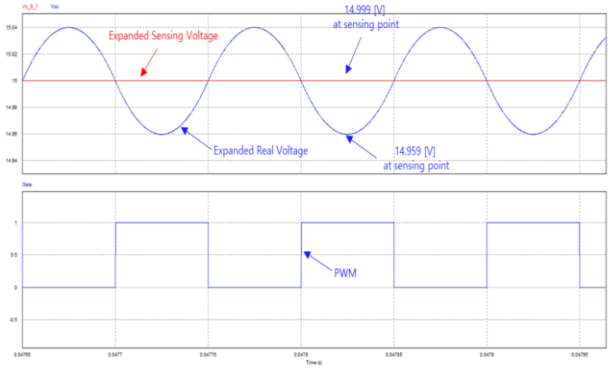


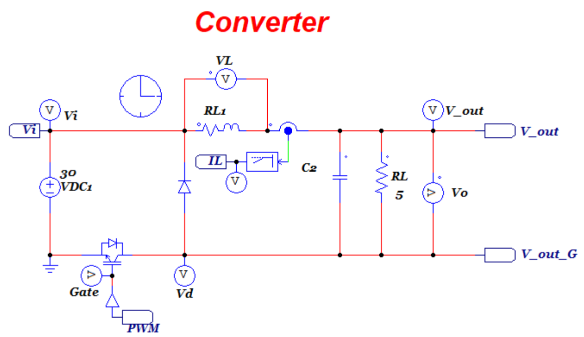
Figure 6. The output voltage waveform detected by the proposed method

Checking the output voltage waveform shows that there is a difference of about 0.04 [V] from the actual output voltage in the voltage sensing period (when the switch is on), and that the sensing error rate is controlled to be less than 0.5% Can be.

2.3.Simulation circuit

This is the simulation and voltage sensing method of the proposed low side buck converter. In the conventional voltage sensing method using the reference voltage of the PI controller, the output voltage is detected by using one voltage sensor and input to the PI controller. However, the proposed voltage detecting method uses positive voltage and negative voltage at the output side. The voltage is detected through the voltage sensor and the voltage is compared to detect the voltage only when the switch is ON. The voltage is sensed when the switch is on and is not sensed when the switch is off. Pi controller to control the switch PWM.

As you can see in Figure 7, the position of the switch is negative of the DC input voltage. The output voltage senses using voltage sensor at the positive terminals of the output and only senses the voltage when the switch is on. This is because when the voltage is detected in the conventional way, when the switch is turned off, the sum of the voltage of the switch and the output voltage is detected as the final output voltage.



Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

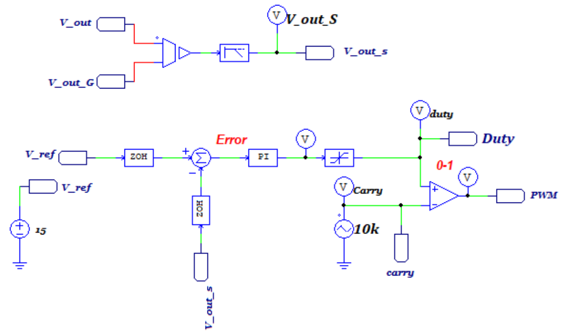


Figure. 7 Simulation of Conventional buck converter and output voltage sensing method

2.3.Output voltage waveform of each converter according to voltage detection method

2.3.1. Conventional Buck Converters and Waveform of output voltage

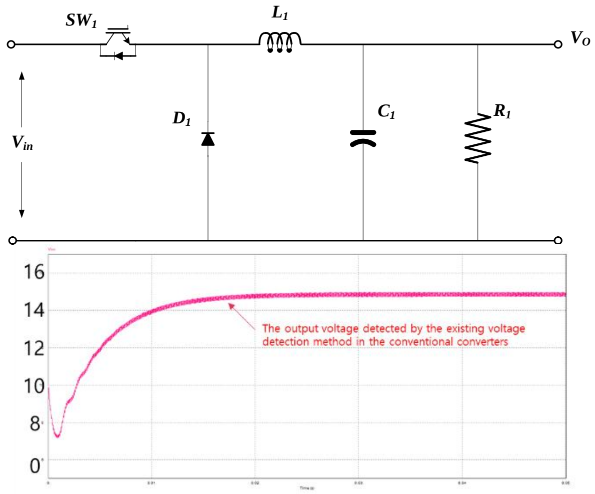


Fig. 8 Conventional Buck Converters and Waveform of output voltage

Figure 8 shows the waveform of the output voltage detected by the conventional buck converter and conventional voltage sensing method.We set the original voltage to 15V and notice that the output voltage is controlled according to the reference voltage. It can also be seen that the voltage is properly detected.

2.3.2. Modified buck Converters and Waveform of output voltage

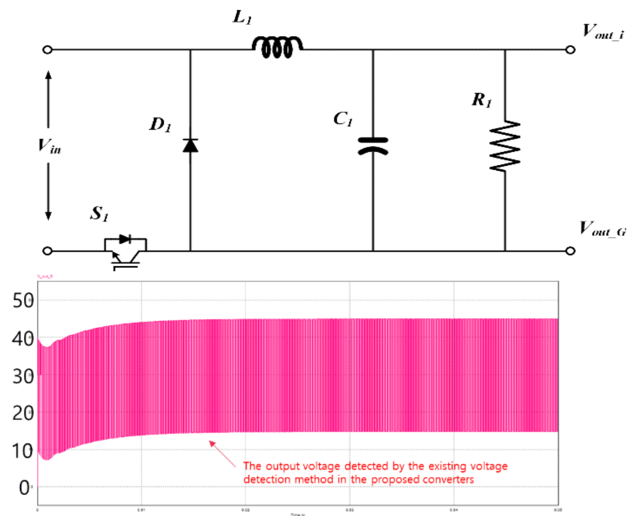


Fig. 9Modified buck Converters and Waveform of output voltage

Figure 9 shows the waveform of the output voltage detected by the modified buck converter and conventional voltage sensing method. Although the reference voltage is set to 15V, as described above, when the switch is off, the value detected from the output voltage is the sum of the conventional output voltage and the voltage across the switch. As a result, the final output voltage fluctuates very much depending on the on / off state of the switch and can not be confirmed by the reference voltage.

2.3.3. Analysis of Output Voltage Detected by Modified Buck Converter and Conventional Voltage Sensing Method

Figure 9 shows the output voltage waveform and switch PWM voltage waveform detected by the conventional method. When you zoom in on the output waveform, can see the output voltage is controlled by the reference voltage when the switch is turned on. When the switch is off, the sum of the voltage on the switch and the output voltage is sensed and the switch is turned on, it is detected by the conventional method.

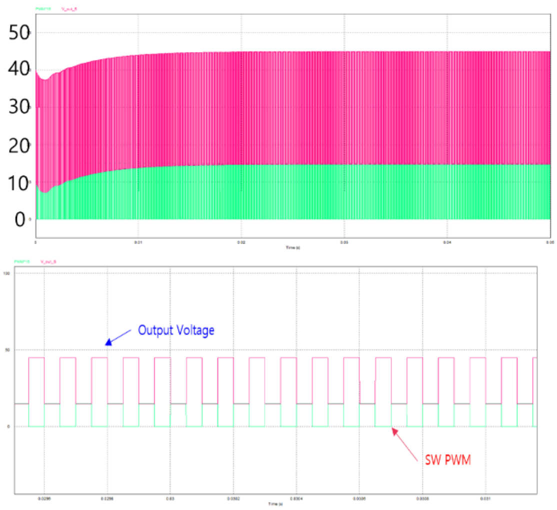
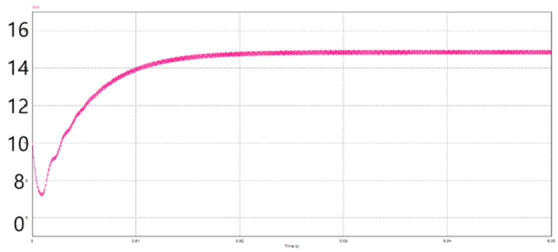


Fig. 10 Proposed sensing method for Modified buck converter

As shown in Figure 10, the output voltage sense is different depending on the operation of the switch, so if the output voltage is sensed only when the switch is on, the result is the same as that of a conventional buck converter.

2.3.3. Comparison of the output voltage



Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

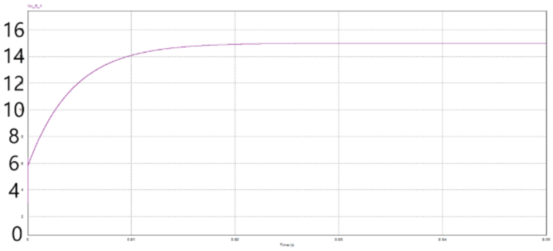


Fig. 11 Comparison of the output voltage detection values of the conventional voltage sensing method and the proposed voltage sensing method

In the figure 11. the above graph is the output voltage sensed by the conventional converter, and the graph below shows the output voltage detected by the Modified buck converter and the proposed sensing method. We simulated using the same parameters, and we can see that the output voltages are the same.

III. COST COMPARISON OF CONVENTIONAL CONVERTER AND VOLTAGE SENSING METHOD AND MODIFIED CONVERTER AND VOLTAGE SENSING METHOD

It is confirmed that the output voltage value detected by the Modified converter and the voltage sensing method is equal to the output voltage value detected by the conventional converter and the voltage sensing method. Key components for configuring conventional buck converters include switches, diodes, inductors, capacitors, voltage sensors, and isolation voltage supplies. [STMicroelectronics] STP35NF10 was selected as the switching device, and [ON SEMICONDUCTOR] MBR40H100WTG was selected as the diode. The voltage sensor was also configured using [Broadcom Limited] ACPL-C87A. Also, a voltage supply element for supplying an insulation voltage was [Texas Instruments] DCH010505D. In the following Table 1, the cost and the quantity of each major element are summarized and the cost is calculated.

Table 1: Cost comparison of major devices

Conventional Converter				Modified converter			
Device	Name	Amount	Cost ($)	Device	Name	Amount	Cost ($)
Switch	STP35NF10	1	1.79	Switch	STP35NF10	1	1.79
Diode	MBR40H100WTG	1	4.88	Diode	MBR40H100WTG	1	4.88
Voltage Sensor	ACPL-C87A	1	3.68	Voltage Sensor	ACPL-C87A	1	3.68
insulation voltage supply Device	DCH010505D	1	8.53	insulation voltage supply Device	DCH010505D	0	0
Total Cost ($)		18.88		Total Cost ($)		10.35	

Table 1 compares the cost of the basic components that make up the buck converter and the isolation voltage supply to supply the isolation voltage. Other passive elements and commonly used devices are excluded because they are used in both converters.

As can be seen in Table 1, conventional voltage detection schemes and conventional buck converters can be compared with the proposed voltage detection method and the Modified buck converter.

The modified buck converter and voltage sensing method can save about 45% of cost compared to conventional buck converter and voltage detection method.

IV. CONCLUSION

In this paper, we proposed a buck converter that does not require isolation voltage for gate driver and a method to sense the output voltage of the modified converter . The output voltage was compared with the conventional converter with the same parameters through the PSIM simulation, and the output voltage sensed by the proposed sensing method was verified to be the same.

In addition, we compared the major device cost of the conventional buck converter with the conventional detection method and the major device cost of the modified buck converter using the proposed detection method.

As a result, it was confirmed that the modified buck converter using the proposed detection method can save 45% of the cost compared with the conventional buck converter.

ACKNOWLEDGMENT

This research was supported by Korea Electric Power Corporation. (Grant number:R18XA04)

REFERENCES

1. Min Gu Kang. A Comparison of DC-DC Buck Converter Controller. Journal of the Institute of Electronics and Information Engineers, 2013;50(7): 281-285.http://www.dbpia.co.kr/Journal/ArticleDetail/NODE02223209 (website)
2. Mohan, Underland and Robbins, Power Electronics Converter, Application and design;1995. pp. 323-336.
3. R. D. Middlebrook, “Topics in multiple loop regulators and current mode programming,”IEEE PESC Record;1985. pp. 716-732
4. R. B. Redly, “A New continuous time Model for current mode control,” PCIM conference record;1989. pp. 16-20.
5. V. Vorperian, “Analysis of current mode controlled PWM convertor using the model of the current controlled PWM switch,” PCIM conference record; 1990.
6. F. Mohammadzadeh Shahir, E. Babaei and M. Farsadi, "Analysis and design of voltage-lift technique-based non-isolated boost dc–dc converter," in IET Power Electronics, 2018 MAY 29;11(6): 1083-1091.
7. N. Mohan, T. M. Undeland, W. P. Robbins, Power Electronics: Converters Applications and

Design, Hoboken, NJ, USA:Wiley, 2007.
8. K. Varesi, S. H. Hosseini, M. Sabahi and E. Babaei, "Modular non-isolated multi-input high step-up dc–dc converter with reduced normalised voltage stress and component count," in IET Power Electronics,2018 MAY 29; 11(6):1092-1100.
9. Y.P. Siwakoti, F. Blaabjerg, P.C. Loh, " High step-Up trans-inverse (Tx -1) DC-DC converter for the distributed generation system ", IEEE Trans. Ind. Electron., 2016; 63(7):4278-4291,.
10. T. Nouri, N. Vosoughi, S.H. Hosseini et al., "A novel interleaved Non-isolated ultra high step-Up DC-DC converter with ZVS performance", IEEE Trans. Ind. Electron., 2017; 64(5): 3650-3661, 2017.
11. F. Sedaghati, S.H. Hosseini, M. Sabahi et al., "Extended configuration of dual active bridge DC-DC converter with reduced number of switches", IET Power Electron. 2015;8(3): 401-416.
12. S. Miao, F. Wang, X. Ma, "A New transformerless buck-boost converter With positive output voltage", IEEE Trans. Ind. Electron.,2016; 63(5): 2965-2975.
13. M. Banaei, H. Bonab, "A novel structure for single switch Non-isolated transformerless buck-boost dc-dc converter", IEEE Trans. Ind. Electron., 2017; 64(1):198-205.
14. H.M. Maheri, E. Babaei, M. Sabahi et al., "High step-Up DC-DC converter with minimum output voltage ripple", IEEE Trans. Ind. Electron., 2017; 64(5): 3568-3575.
15. K. Varesi, S.H. Hosseini, M. Sabahi et al., "An improved Non-isolated multiple-input buck dc-dc converter", Proc. 8th Power Electronics Drive Systems & Technologies Conf. (PEDSTC);2017. pp. 119-124.