Applied Dual switching mode with a Negative-Output High Quadratic Conversion Ratio DC-DC Converter

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Abstract: This paper demonstrates the applied duty-cycle with selecting the low values of components which gives a very high negative output (NO) voltage gain of DC-DC converter. The applied concept is proposed. This converter is applied to maximize and succeed the high step-up of the output voltage gain. The experiment is separated into two objectives, one is by introducing the new small values of inductor L1, L2 and C2 of the initiative converter in order to reduce the cost and sizing of the converter. Another objective is to find out the new proper switching logic to control the main circuit with S1 and paralleled auxiliary circuit S2. Moreover, the low input voltage can be used with the applied duty-cycle from two combined methods step-up and step-up/step-down and is also generated for the significant conversion ratio of output voltage and better in gain. Thus, the results of very high negative output voltage gain compared with those of the classical converter. The operational principle and the analysis of steady state, electrical stress analysis of the switching device of the three steps are also presented. The experimental and simulation results are compared to demonstrate the efficiency or gain of the converter.

***Keywords*— Duty cycle, DC-DC Converter, Component Optimization, Step logic of switching**

I. INTRODUCTION

With the increasing of industry energy uses and strong recommended environment of sustainability in generation is taking the important role. Nowadays, the trend of renewable and clean energy from the natural source can generate the electricity without polluting environment and it can save our earth for the next generation. Consequently, the necessity of the converter with high conversion ratio is required for reaching the maximum level of the high voltage gain from the low input voltage. The DC-DC converter is the tool to generate for improving the DC input to the desired high DC level at the DC output side.

Power electronics is recommended to convert the vary low input voltage to archive the high output demand voltage. Thus, a very high negative output (NO) voltage gain DC-DC converter is become a primary application relating to convert the undisrupted power input supply. It is well known that the conversation voltage ratio is M (M= Vout/Vin) where Vout and Vin are the output voltage and input voltage, respectively. Many applications such as Solar cell, Full cell, Wind energy, Wave energy movement in the sea are dramatically expanded in worldwide [1],[2]. Nevertheless, the constraint point of the low input voltage is significantly presented and compared with [1]. Moreover, the traditional converter [1] is tropically required a high value of component which directly effects to the size of the converter and budget. These kinds of issue are imperatively conduced to the needs to develop the high output voltage gain converter with the best cost optimization. The duty-cycle ratios between S1 and S2 have been proposed. Also, in term of component selection. The new small values of the component inductor being less than 30% are presented. In this case, the appropriate duty cycle of S1 and S2 can provide the higher negative output (NO) voltage gain. The duty cycle of S2 is 95% with no delay. Furthermore, the duty cycle of

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S1 is 75% with the delay of 5µs. Regarding the control of the logic switching is realized by working on the micrologic controller programming on the C2000 device. The clean energy from various source. As indicating Fig. 1, the renewable and clean energy transform from many natural sources. Solar PV, Wind, Solar Hot water, Biomass, hydropower energy, Geothermal energy, etc. are recommended for the high conversion ratio due to their unstable and limit of input.

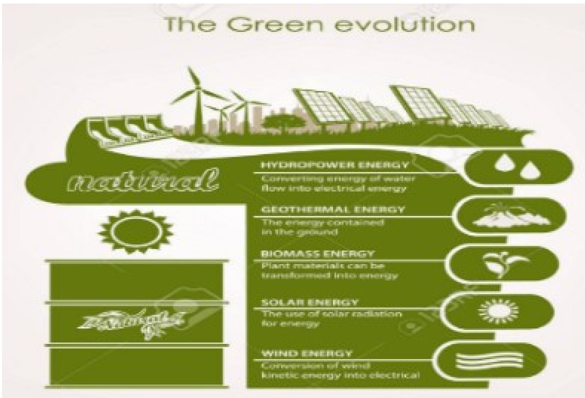

Fig. 1 Clean energy and natural source [3].

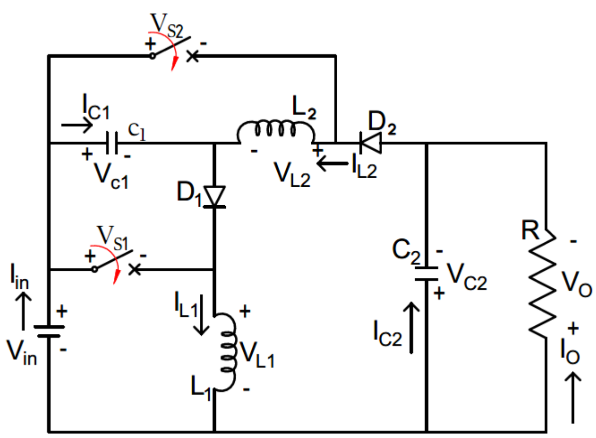

Fig. 2 High quadratic conversion ratio DC-DC Converter.

The high quadratic conversion ratio converter is shown in the Fig. 2. The optimized converter components are demonstrated to the switches S1 and S1, two capacitor C1 and C2, two power diodes, a resistor load R together with the input DC power supply. In this paper, two inductors L1 and L2 are selected by the same value [1]. In addition, the values of the inductors have been optimized with optimized amount of 30% from the actual component setup [1].

II. THE TIME DOMAIN DURING THE OPERATION MODE

The time domain in Fig. 3 is shown. The waveforms during the switches S1 and S2 are in the operation mode.

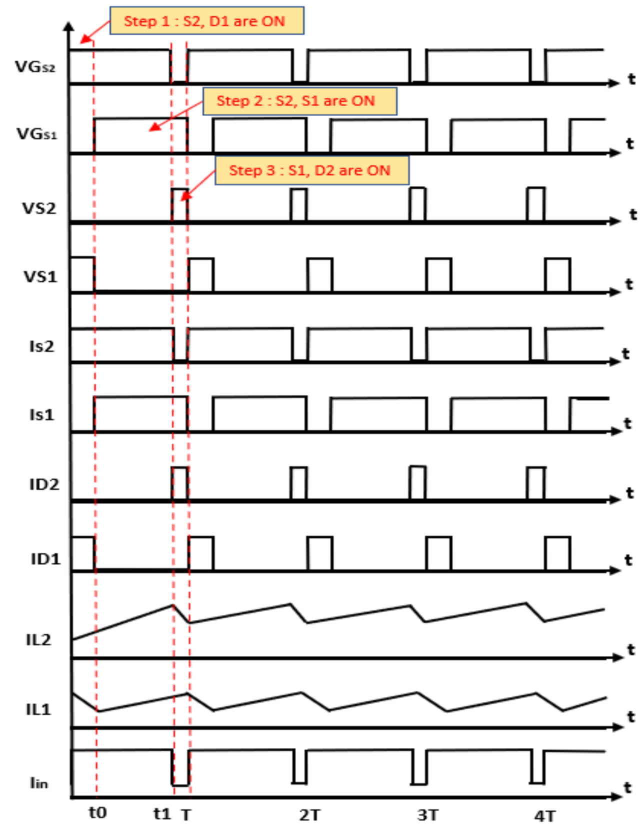

Fig. 3. Waveform of the switch S1&S2 in operation mode

A. The working step logic of the switch

The operation principle of the converter shows in Fig. 2. It contains of three working steps of logic switches S1 and S2. For the first working step logic switches, the switch S2 will turn ON and the switch S1 will turn OFF with the delay time as per the specific time domain period. This first mode is the step-up mode which means that the S2 and S1 operate with complementary in continuous current mode (CCM). For the second working step logic switches, the switch S2 is continuously turn ON and the switch S1 is also turn ON with its delay of turning ON. This second mode consists of the step up/step down mode which means the switches S1 and S2 operate with simultaneously in CCM mode. For the last working step logic switches, the switch S2 will turn OFF and the switch S1 will continuously turn ON till the end of its period. The step-3 mode become back to the step-up mode which means that the switches S1 and S2 operate with simultaneously in CCM mode.

B. Study of the converter structure and operation principles

To make simpler in analysis, we consider that all components of the converter are ideal. During the switching period, both capacitors C1 and C2 are large enough to maintain the voltage across each capacitor nearly constant. In the same way, the inductor L1 and L2 are also considered large enough to maintain the current constant.

C. Step 1: Switch S2 and diode D1 are turn ON

The switch S2 is taking role to turn ON and the switch S1 is taking role to turn OFF. Once, the switch S2 is turn ON. At the same time, the power diode D1 conducts and allows the current to flow. During this step 1, the switch S1 is turn OFF. Once the switch S1 is open, the current stored in the inductor L1 is not changed the direction of flowing simultaneously. Thus, the energy and the current stored in L1 continues flows through the input power supply Vin and both of energy sources Vin and L1 become a double power supply source to charge the capacitor C1 and energize the inductor L2. For more details, the inductor L1 is de-energized to the power supply Vin, the inductor L2 is magnetized by the current from power supply Vin. In parallel period, the capacitor C1 is also charged by the power supply Vin and in the same interval of time, the capacitor C2 is discharged to the load resistor R. To providing more understanding how the converter reacts during this step 1.

The equivalent circuit of the step 1 is shown in Fig. 4.

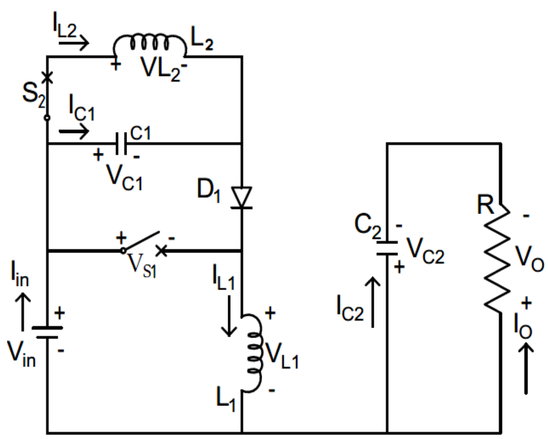

Fig. 4 Equivalent circuit of step 1.

Therefore, the equation during S2 and D1 being turn ON can be developed as following (1) and (2).

$$V_{L1} = V_{in} - V_{C1} \quad (1)$$

$$V_{L2} = V_{C1} \quad (2)$$

D. Step 2: Switch S2 and S1 are turn ON

The switches S1 and S2 are taking role to turn ON at the same time. Due to this outstanding, the power diodes D1 and D2 are turn OFF. Once, the diodes D1 and D2 do not conduct. Thus, the inductor L2 and the capacitor C1 is become in parallel. Also, the capacitor C1 discharges its current which is charged from the power supply Vin during the step1 to the inductor L2. As the current of the inductor L2 can not simultaneously change its direction due to the induced current of L2 itself. The current of L2 is continuing to flow in the same direction to C1. After L2 is charging by C1. The energy stored in L2 will be ready as a standby power supply to charge the capacitor C2 and R load, at the moment where the switch logic changes from the step 2 to the step 3. During this period, the inductor L1 is back to charge by input power supply Vin. At this step 2, the capacitor C2 is discharged to the load resistor R. To give more details of this step 2, the switch S2 is continuously turn ON since the step 1. On this step 2, we define for both switches S2 and S1 are turn ON for 70% of its duty cycles. To have more clarity how the converter works during this step 2. The equivalent circuit of the step 2 is shown in Fig. 5.

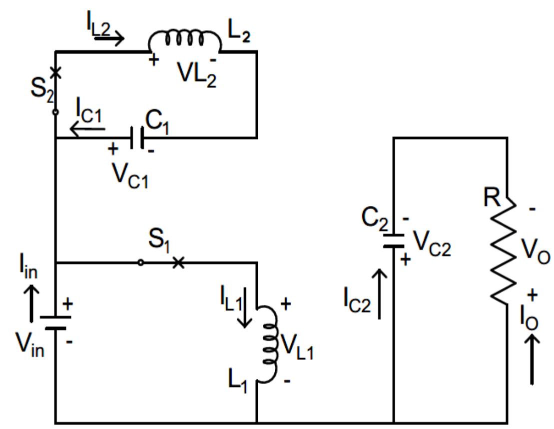

Fig. 5 Equivalent circuit of the step 2.

Thus, the equation during S1 and S2 is ON can be developed as shown in (3) and (4).

$$V_{L1} = V_{in} \quad (3)$$

$$V_{L2} = +V_{C1} \quad (4)$$

E. Step 3: Switch S1 and diode D2 are turn ON

The switch S1 is taking role to continuously turn ON from the step 2 and the switch S2 is taking role to turn OFF. Once, the switch S1 is turn ON. During the same period, the power diode D2 is turn ON. Based on these two phenomenal actions of switch S1 and diode D2, they are turn ON at the same time. The capacitor C1 and inductor L2 are become in series circuit. Consequently, the Capacitor C1 and inductor L2 are discharged and demagnetized, respectively to charge the capacitor C2. In the meantime, the inductor L1 is also magnetized by charging from the input power supply Vin. To be more precise, the switch S1 is still turn ON and the switch S2 is also turn OFF. The equivalent circuit of the step 1 is shown in Fig. 6.

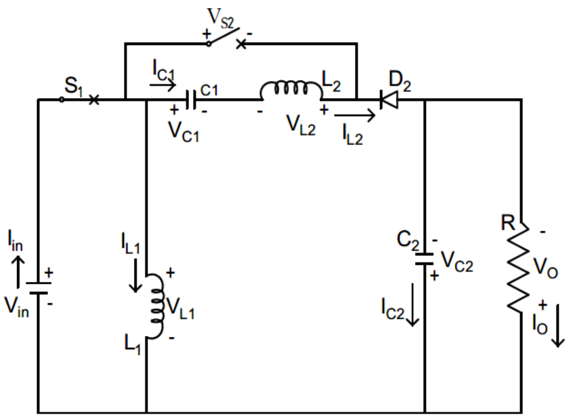

Fig. 6 Equivalent circuit of the step 3.

Hence, the equation during S1 and D2 is ON can be developed as shown (5) and (6).

$$V_{L1} = V_{in} \tag{5}$$

$$V_{L2} = -V_{in} + V_{C1} - V_{C2} \tag{6}$$

III. Analysis of the Steady-State Operation

To analysis the circuit on the steady state operation[4], all components of the converter; inductor, resistor and capacitor will be considered as a constant. Also, the analysis is made on the CCM mode only.

A. Step 1 and Step 3 : S1 and S2 is turn ON and OFF not the same time

The voltage gain and the conversion ratio G of the step 1 and the step 3 are applied. During applying the voltage across C1, the total volt-second applied to the inductor L1 and L2 must be zeros in steady state. The voltage gain and relation between the input voltage Vin and output voltage Vo are obtained as following (7) and (8). During the step 1, the duty cycle D of S2 is defined for 25%. And the step 3, the duty cycle D of S1 is defined for 25%.

$$V_{C1} = \frac{1}{(1-D)} V_{in} \tag{7}$$

$$G = \frac{V_{C2}}{V_{in}} = \frac{1-D+D^2}{D(1-D)} \tag{8}$$

B. Relation between the power input and power output of the step 1 and the step 3

The power input and the power output can be expressed as (9).

$$V_{in} I_{in} = V_o I_o \tag{9}$$

Where the input current can also be described according to the above equation of the input/output power.

$$I_{in} = \frac{1-D+D^2}{D(1-D)} I_o \tag{10}$$

C. The electrical stress analysis of the switching devices during step 1 and the step 3

During the step 1 and the step 3, the switches S1 and S2 is turning ON/OFF in complementary. Once S1 is turn ON. The same period S2 will turn OFF. In another hand if S2 is turn ON, S1 will turn OFF imperatively. The voltage stress of the four switches S1, S2, D1, D2 are described as per below.

$$V_{S1} = \frac{1}{(1-D)} V_{in} \tag{11}$$

$$V_{S2} = \frac{1}{(1-D)D} V_{in} \tag{12}$$

$$V_{D1} = \frac{1}{(1-D)} V_{in} \tag{13}$$

$$V_{D2} = \frac{1}{(1-D)D} V_{in} \tag{14}$$

The current stress of the four switches D1, D2, S1, S2 during the step 1 and the step 3 are defined as per following equation.

$$I_{D1} = (1-D) I_{L1} = \frac{1}{D} I_o \tag{15}$$

$$I_{D2} = D I_{L2} = I_o \tag{16}$$

$$I_{S1} = D I_{L1} = \frac{1}{(1-D)} I_o \tag{17}$$

$$I_{S2} = (1-D) I_{L2} = \frac{(1-D)}{D} I_o \tag{18}$$

To obtain the value of the current of IL1 and IL2 at the steady state interval period, it needs to apply the ampere-second balance to the capacitor C1 and C2. The equation of IL1 and IL2 can be expressed as per below.

$$I_{L1} = \frac{1}{(1-D)D} I_o \tag{19}$$

$$I_{L2} = \frac{1}{D} I_o \tag{20}$$

D. Step 2 the switch S1 and S2 is turn ON and OFF at the same time

The voltage gain and the conversion ratio G of the step 2 are applied. For applying the voltage across C1, the total volt-second applied to the inductor L1 and L2 must be zeros in steady state. The voltage gain and relation between the input voltage Vin and output voltage Vo are obtained as (13) and (14). During the step 2, both duty cycle D of the S1 and S2 is defined for 75%.

$$V_{C1} = \frac{1}{(1-D)} V_{in} \tag{21}$$

$$G = \frac{V_{C2}}{V_{in}} = \frac{2D-D^2}{(1-D)^2} \tag{22}$$

E. Relation between the power input and power Output

The power input and the power output can be expressed as (15).

$$V_{in} I_{in} = V_o I_o \tag{23}$$

Where the input current can also be described according to the above equation of the input/output power.

$$I_{in} = \frac{2D-D^2}{(1-D)^2} I_o \tag{24}$$

F. The electrical stress analysis of the switching devices during step 2

During the step 2, the switches S1 and S2 is turning ON/OFF in simultaneously. Once S1 is turn ON. The same period S2 will also turn ON. In another hand if S2 is turn OFF, S1 will also turn OFF imperatively. The voltage stress of the four switches S1, S2, D1, D2 are described as per below.

$$V_{S1} = \frac{1}{(1-D)} V_{in} \tag{25}$$

$$V_{S2} = \frac{1}{(1-D)^2} V_{in} \tag{26}$$

$$V_{D1} = \frac{1}{(1-D)} V_{in} \tag{27}$$

$$V_{D2} = \frac{1}{(1-D)^2} V_{in} \tag{28}$$

In the working operational mode, the current stress of the four switches S1, S2, D1, D2 during the step 2 are defined as per following equation below.

$$I_{S1} = D I_{L1} = \frac{D}{(1-D)^2} I_o \tag{29}$$

$$I_{S2} = D I_{L2} = \frac{D}{(1-D)} I_o \tag{30}$$

$$I_{D1} = (1-D) I_{L1} = \frac{1}{(1-D)} I_o \tag{31}$$

$$I_{D2} = (1-D) I_{L2} = I_o \tag{32}$$

In the steady state of DC value, to calculate the IL1 and IL2, while apply the ampere-second balance to the

$$I_{L1} = \frac{1}{(1-D)^2} I_o \tag{33}$$

$$I_{L2} = \frac{1}{(1-D)} I_o \tag{34}$$

G. Comparative the voltage gain G of the initial converter with the new optimized component & new switching logic

Fig. 7 shows the comparative gain between traditional converter which is working with two switching modes logic. The graph in blue color shows the gain of the traditional converter working in step up mode. The grape highlights in orange color demonstrates the gain of the traditional converter working in the step up/ Step down mode. And the optimized component converter which is operated with the new proposed switching logic display the in green color. The result of the gain demonstrates the new proposed switching logic shown more better in gain than the traditional converter.

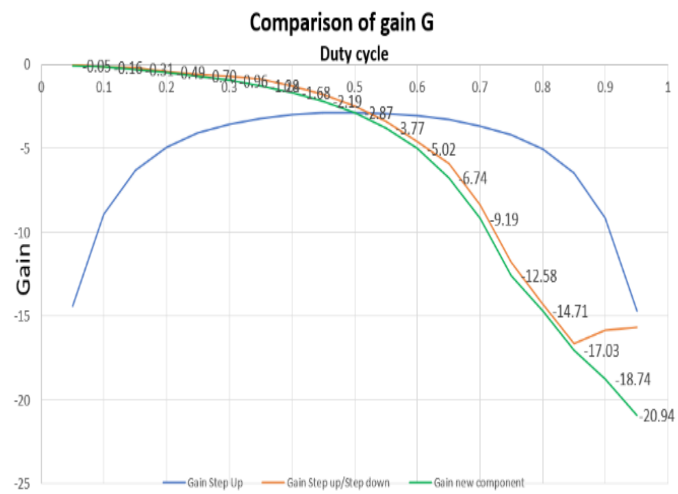

Fig. 7 Comparison of gain G.

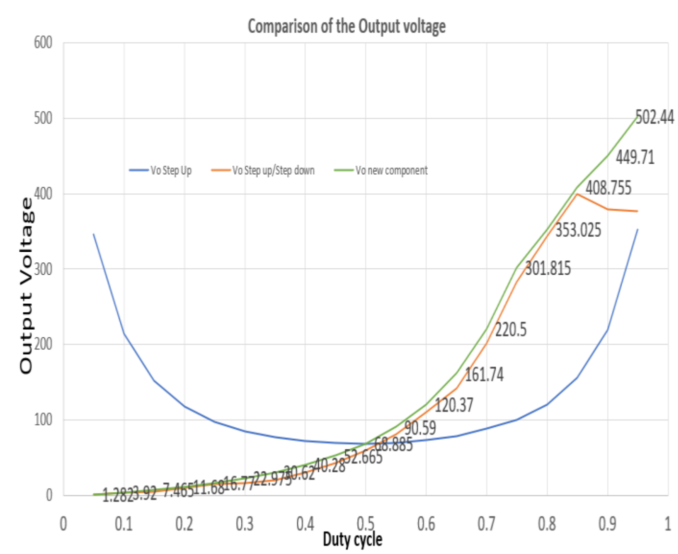

Fig. 8 Comparison of output voltage.

The comparative converter components are shown in Table 1.

Table 1: Values of the components using for the converter.

Components	Ref. values [1]	New values (proposed)
Inductor L1	935µF	670µH
Inductor L2	1035µH	720µH
Capacitor C1	4.7µF	4.7µF
Capacitor C2	40µF	40µF
Switch S1	IRFP4668	IRFP4668
Switch S2	IRFP4668	IRFP4668
Diode D1	MBR40250	MBR40250
Diode D2	MBR40250	MBR40250

IV. CONCLUSION

For reaching the maximum level of the high voltage gain from the low input voltage with the optimization of cost, new duty-cycle values between S1 and S2 have been proposed. Also, the new small values of the components: inductor L1 670µF and L2 720µF are presented. In our case, the appropriate duty cycles of the main switch S1 and the paralleled auxiliary switch S2 providing the higher negative output (NO) voltage gain are 75% with the delay of 5µs for S2 and 95% with no delay for S1. Fig. 2 depicts the structure of the converter and operation principle. The proposed duty cycle on the step up/step down mode can convert the low voltage level input 24VDC from the nature energy source and boost up into high voltage level of 500VDC where we can supply to the DC load or we can apply for the DC-AC inverter as an primary DC source to energize the AC application. Consequently, the negative output with high conversion ratio converter is very good essential to apply as a power transformation system.

This paper demonstrates the innovative DC-DC converter with very high negative output (NO) voltage gain. By identifying the new logic duty cycles to the proposed converter, it can be developed from [1]. Under the static low input voltage which is in parallel with the varied auxiliary DC power supply source, two switching logic functions are the main role which uses to control the function of step-up and step-up/step-down mode. The new switching logic can give a high conversion in efficiency and important voltage gain output comparing to the initiative converter [1]. As per the result of output voltage and the gain from the Fig. 7&8. In order to have more efficiency in term of applying to the application. It would be recommended to operate the converter with the step up mode for the duty cycle less than 0.5 and operate the converter with step up/step down mode with using the new proposed duty cycle when duty cycle is more than 0.5. In the final, the experimental and simulation results are highlighted to demonstrate the efficiency or gain of the optimized component of converter.

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