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Further Development of Boost Chopper for Power Conditioners
- Pursuit of ideal PCS for photovoltaic power generations -

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ABSTRACT

Under an environment of praise for renewable energy, photovoltaic power generations (PVG) have been applied generally and spread broadly. Various power conditioning systems (PCS) used in those have been also studied by many researchers. In addition to usual utilization, such PVG is often considered for the time of disaster. Usually such PVG systems having limited power are almost installed in limited area such as on top of the roof of the building. Some medical institutions have fairly desire to install such PVG since they must avoid the medical service interruption. The generating power in such case is fairly limited, so the system construction should balance the reduced power. Thus, it is necessary to improve the construction toward simple one. In usual PCS, power is converted by two stages, that is boost converter and normal inverter. In first stage, the dc power is adjusted to appropriate voltage level. The conversion methods are considered in many strategies. In this paper, in order to pursue an ideal one, simple and concise power converter, especially novel boost chopper is proposed. Considering fair reduced power and narrow space of installation, the system constructions should be compact. The circuit that gratifies their operating characteristic is presented and analytically discussed about circuit construction as a novel boost converter. The circuit operation is confirmed by using the circuit software and a few experiments.

KEYWORDS: Power Conditioners, PCS, Solar cell, Boost chopper, Photovoltaic power generation, PVG , Power delivery flowchart

1 INTRODUCTION

In modern medical care, the development of the structural function in the operating room is remarkable. The endoscopic surgery including surgical robot and the catheter intervention has been applied, so that such remarkable operating technics have been developed with robotic operating room and hybrid operating room. For almost electrical equipment using in such medical facilities, even instantaneous interruption could not be permitted.

In general, by means of large capacity uninterruptible power supply installed by generator and batteries, the medical service may be kept and provided. In such system, however, the installed scale becomes large accompanied by extremely high cost.

The power conditioners-PCS including boost converter have been presented in various systems so far [1,2]. However, it is necessary to reduce the cost even more. It is said that the system is approaching to an ideal one with respect to efficiency and construction strategy, but that cost would prevent widespread. In such discussions, there are many subjects to be resolved to utilize the PV power effectively. Even more, various safeguard equipment required according to regulations make the cost increase. Thus, it is required to obtain even lower cost PCS. In fair reduced power PCS as mentioned, the equipment are installed in limited facilities. In such case of reduced generating power, that is, in such PV power generation systems, there are so many subjects to be resolved [3].

The authors have been pursuing an ideal PCS in a series of the small power PV system [4,5]. In this paper, some simple PCS systems, especially the boost chopper is presented and discussed toward simple construction with some experiments. The whole result is analytically performed and discussed.

2 DISCUSSIONS ON VARIOUS UNIQUE BOOST CHOPPERS

2.1 Prologue of Boost Chopper

In the early years, the usual interconnected PCS is provided through the bulky transformer which cuts off the dc component from the output power system. As shown in Fig.1 of the conventional system, the transformer is necessary. However, such construction prevents the low cost and size reduction. In recent methods, by means of high performance and high reliability, dc power can be easily removed as shown in Fig.2. Just mentioned PCS without transformer is superior with respect to low cost, downsizing and lightening in weight. However, with respect to the conversion efficiency even in such PCS using transformer-less converter, there is some room to improve that efficiency of conversion by means of varying combination of circuit component. In this section, some original circuit configurations are presented, which are compared with some conventional schemes. Fig.3 shows various converters which includes original ones in Fig.3(b), (c) and (f), those are proposed by one of the authors [5,6].

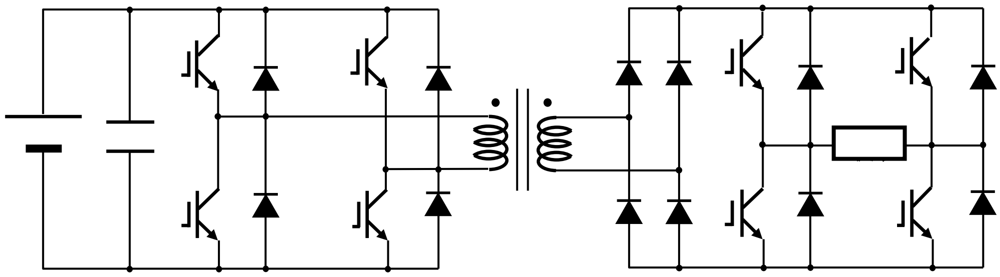

Figure 1. General PCS in early times.

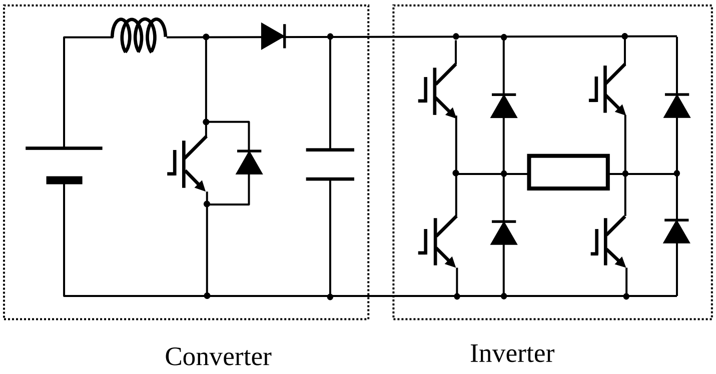

Figure 2. General PCS in recent years.

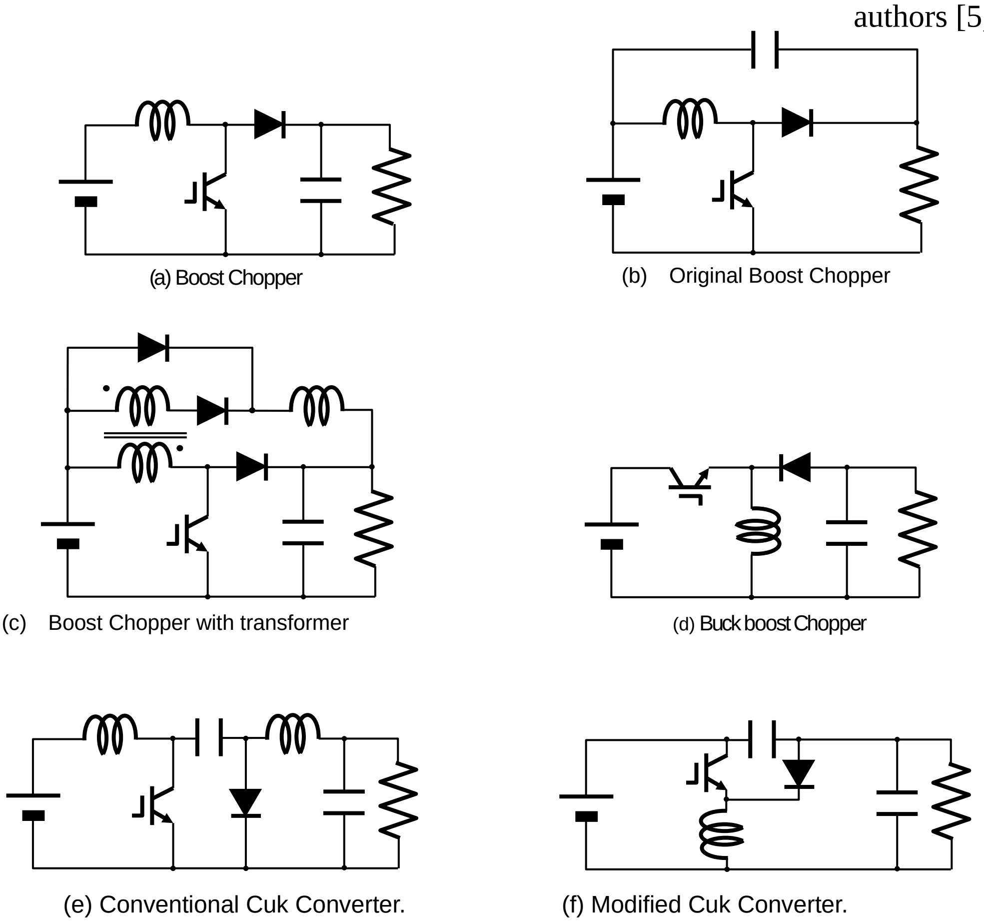

Figure 3. Various DC-DC Converters.

2.2 Operation of Conventional Boost Chopper

The boost chopper is to boost the input dc voltage, which is often used for general power conditioners-PCS under discussion about photovoltaic power generation. As the output voltage becomes higher than the input solar panel voltage, so the diode D prevents the reverse current flow. The output capacitor voltage E_o is smooth and constant due to the large capacitance *C*. The equivalent circuit at switch S turning on or off are represented by Fig.4(a) and (b), respectively. Analytical operation can be obtained as follows;

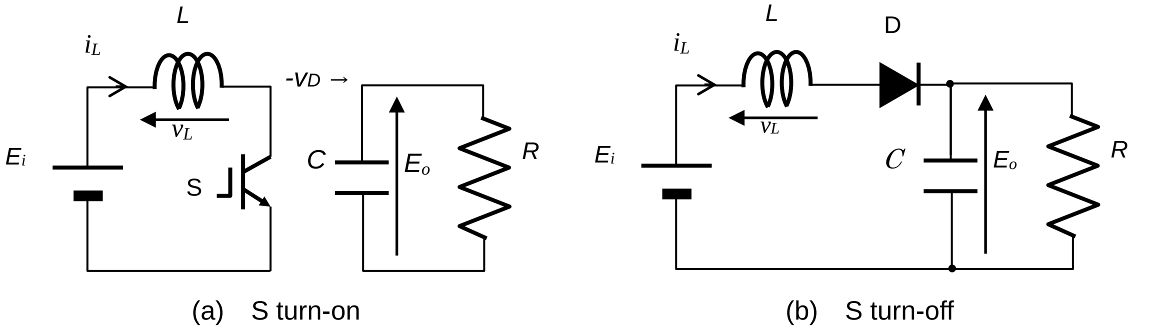

Figure 4. Operating Circuits of Usual Boost Chopper.

When switch S is turned on, the diode D in Fig.4(a) is reverse-biased. The input voltage is applied across the inductor L as shown in the figure. In the boost chopper operating in the current continuous mode, inductor voltage and its current can be obtained as following expressions;

$$v_L = L\frac{di_L}{dt} = E_i \quad (1)$$

$$i_L = \frac{E_i}{L}t + i_L(\mathrm{O}) \quad (2)$$

At $t = T_{off}$ when S is turned off, the reversed voltage across L is added to the supply voltage and the current is flowing into the load. The stored energy in the inductor is delivered towards the load. The relationship is given by

$$v_L = L\frac{di_L}{dt} = E_i - E_o \quad (3)$$

Because of $E_i \leq E_o$,

$$i_L = \frac{E_i - E_o}{L}(t - T_{on}) + i_L(T_{on}) \quad (4)$$

From these equations,

$$E_o = \frac{1}{1-d}E_i \quad (5)$$

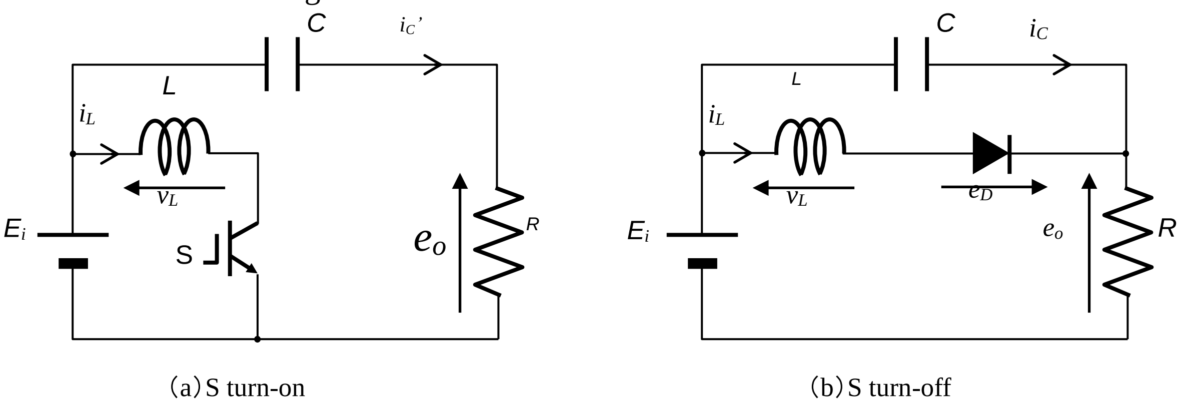

Figure 5. Operation Circuits of Original Boost Chopper.

3 PROPOSAL OF NOVEL BOOST CHOPPER

Fig.5 shows the original boost chopper. As compared with the circuit in Fig.4, instead of the smoothing capacitor, that capacitor connection is moved to the terminals between input supply and output load as shown. The circuit operation is a little different. However, the principle of the intrinsic operation is the same compared to just mentioned mechanism. The most important difference is to make possible to reduce the smoothing capacitor voltage.

4 POWER FLOWCHART OF ORIGINAL BOOST CHOPPER

The power transmission flowchart for original one is presented in Fig.7. In order to compare the operational mechanism with usual one, the power delivery flow chart for conventional boost chopper is described in Fig.6 at first. In the figure, d is on-duty cycle and d' is off- duty one. I_i is input current and I_o is output current. As S is turned on with duty cycle d, the power $E_iI_i d$ and $E_oI_o d$ are delivered from E_i to L and C to E_o, respectively. When S is turned off with off-duty cycle d', the power E_oI_od' and $(E_o-E_i)I_id'$ are delivered from E_i to E_o and L to C, respectively The power delivered process becomes different, and efficiency may be deteriorated accordingly. In comparing between Fig.6 and Fig.7, the difference of delivery mechanism can be confirmed.

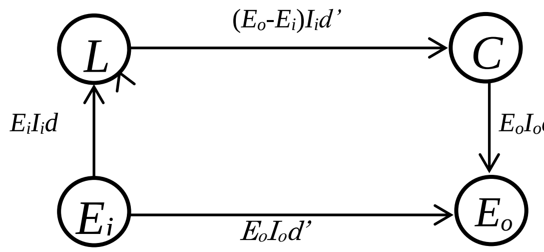

Figure 6. Power Flowchart of Conventional Boost Chopper.

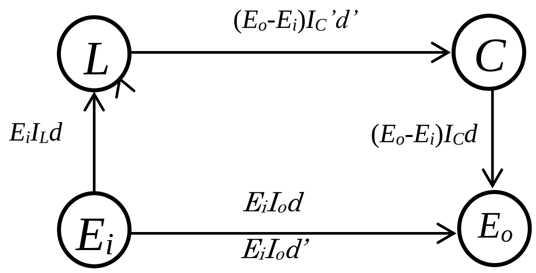

Figure7. Power Flowchart of Original Boost Chopper.

In Fig.7, when S is turned on in duty cycle d, the power $E_iI_L d$ and $(E_o-E_i)I_Cd$ are delivered from E_i to L and C to E_o, respectively. At the same time, the power is delivered from E_i to E_o as E_iI_od.

During period of d, C is discharged as shown in Fig.5.(a) as I_C'. When S is turned off, C is charged as I_C. The relationship of capacitor discharge current I_C and charge current I_C' can be given by following equations;

During charge period of d', the capacitor is charged by $I_C'\times d'$. On the other hand, during discharge period, C is discharged to $I_C\times d$ by inductor L. During discharge period, $I_C = I_O$.

Total electric charge q' for d' is

$$q' = I_C'd' \quad (6).$$

For discharge period when S is turned on, electric discharge q is

$$q = I_C d = I_O d \quad (7).$$

As $q = q'$, relationship of

$$I_C'd' = I_O d \quad (8)$$

can be obtained as

$$I_C' = I_O\times d'. \quad (9)$$

When S is turned off with off-duty cycle d', the power E_oI_od' and $(E_o-Ei)I_id'$ are delivered from E_i to E_o and L to C, respectively In comparison of these figures, the following description will be confirmed. For example, direct transmission from power supply to the load,

$$E_oI_od' = E_iI_id' = E_iI_od + E_iI_od' = E_iI_o \quad (10)$$

Since $I_id' = I_o$ (11)

this equation is confirmed by following establishment.

The significant difference is the input current flowing situation. For the usual boost chopper, the input current value is constant because of large value of inductor. On the other hand, for the proposed boost chopper, during S turned on period, the current is flowing towards load. As a result, The input current is

$$I_i = I_o + I_L \quad (12)$$

During S turning off

$$I_i = I_L - I_C \quad (13)$$

From these equation, the average input current,

$$I_{avi} = (I_L d + I_C d') \quad (14)$$

The withstanding capacitor voltage is given as shown.

For conventional one,

$$V_{Cwith} = E_O \quad (15),$$

For the original one,

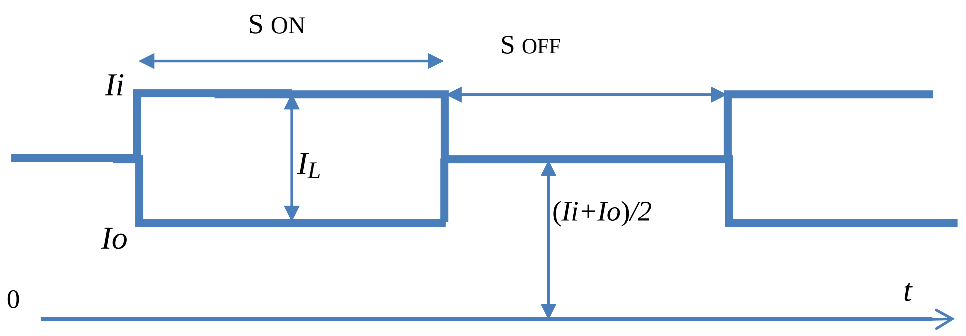

Figure 8. Input and Output Current.

$$V_{Cwith} = E_O \times d \quad (16)$$

It is said that the capacitor price is increasing according to the applied voltage. So, this characteristic may be favorable construction.

5 EXPERIMENTS

Fig.9 shows the experimental results for various choppers to boost the input dc voltage. The results for original boost chopper is favorable one, whose results is almost the same compared to conventional boost chopper even by reduced voltage of capacitor. The results for converter having the transformer is showing the next favorable result. If on the design procedure, the transformer is taken for larger size, the efficiency will be given for the best one. With respect to the Cuk ones, the conversion efficiency is going to a little worse. The reason is due to the many stage for power conversion. Finally, we can say that the buck boost type is the worst result. The reason is there is no direct power transmittal operation.

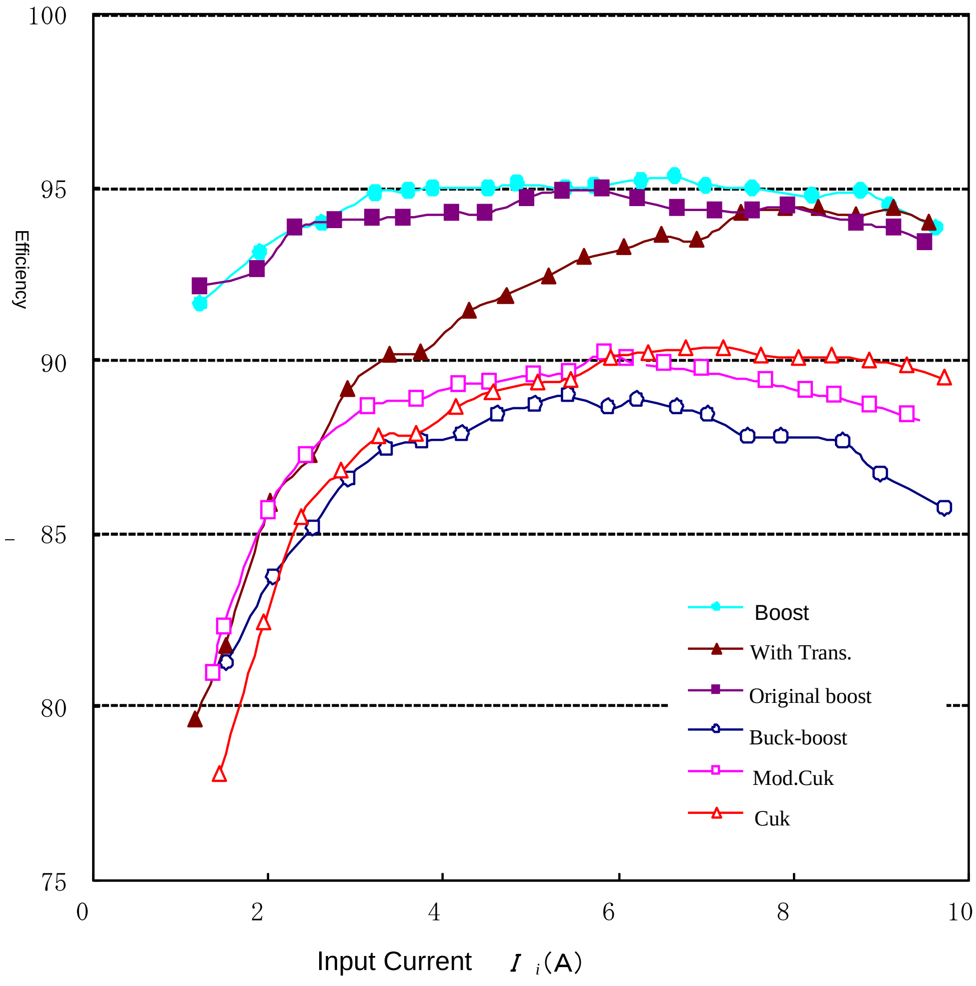

Figure 9. Experimental Results for Various Boost Choppers.

That is, once the whole power is stored in the inductor, after that, the whole power is delivered to the load. That operation needs the bulky inductor and creates large energy loss.

6 CONCLUSIONS

A few proposed circuit strategies are proposed and confirmed in theoretical and experimental procedures. Various ideas are applied to power conditioners for the photovoltaic power generation systems, whose idea is obtained from the usual PCS, which is constructed by chopper and inverter circuit. So far, various PCS have been devised and applied by many researchers. In this paper, about boost chopper of first stage, a few circuit strategies having novel ideas are presented and discussed. With respect to trans-less combination, a few boost chopper is treated and analyzed satisfactorily. In such a case, the high cost and high voltage smoothing capacitor could be avoided. In addition, the rest of the other choppers can also present its superior feature.

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APPENDIX

A. Buck Boost Chopper

This converter is presented in Fig.3(d) as the most well-known converter. The obtained characteristic is the worst one. The reason is explained with using original power flowchart as following description;

In this converter in Fig.3(d), in order to prevent direct short current from the input to output load, reverse direction diode is connected. As the switch S is turned on, input inductor current i_L is given by

$$i_L = -\frac{E_o}{L}(t - T_{on}) + i_L(T_{on}) \quad \text{(A1)}$$

When S is turned off.

$$v_L = L\frac{di_L}{dt} = E_o \quad \text{(A2)}$$

The output voltage E_o can be expressed shown as

$$E_o = \frac{d}{1-d}E_i \quad \text{(A3)}$$

When duty cycle can be given from 0 to infinity, the obtained voltage region of buck boost chopper can be also given from 0 to infinity. For example, as above experimental result, in order to obtain double output voltage, 200 V compared to the input voltage, 100 V, d = 2/3 is given as duty cycle. As explained, if adequate value of duty cycle is given as setting value, the boosted output voltage can be obtained as desired value. According to mentioned procedure, the power flowchart of buck boost chopper is presented in Fig.A. In the figure, as it can be seen, all energy of delivering is temporarily stored in the inductor L, then those energy is delivered to each component and the load. From this reason of the operation, efficiency becomes deteriorated. As shown in the experimental results, this deterioration due to such operation mechanism is described clearly.

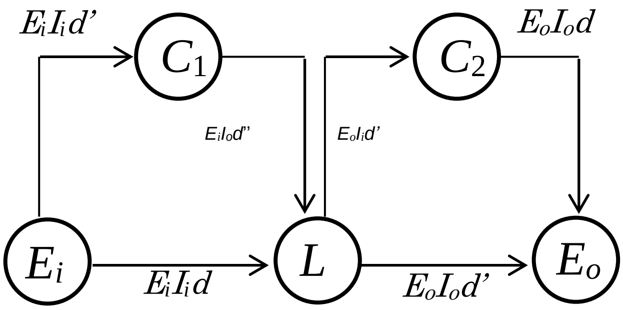

Figure A. Power Flowchart of Buck boost Chopper.

B. **Boost Converter Having Auxiliary Transformer**

Fig.B shows the original boost converter having the auxiliary transformer. The auxiliary transformer is added in the circuit configuration. In the figure, the primary winding inductor is L_1, and the secondary winding is given by L_2. In the auxiliary transformer circuit, another inductor is connected as L_3. Let the turn ratio of winding of L_1 and L_2 be N_1 and N_2, respectively. In the transformer, if the relationship of turn ratio is, $N_1 : N_2 = 1 : 2$, the output voltage of L_2 becomes double with respect to that of L_1. The operation circuits for turn-on and turn-off are represented in Figs.B(a) and B(b), respectively. One cycle operation is obtained as follows; Firstly, in Fig.B(a), when S is turned on, the supply voltage is applied across the inductor L_1. As a result, the output L_2 voltage is generated as double voltage in this case. In the load, the current i_2 is flowing whose energy is stored into L_3 On the other hand, the operation circuit for S turned off is shown in Figs.B(b). During this period, the analogous operation compared to usual boost chopper is executed. At the same time, the stored energy of L_3 in the last period is delivered to the load. The operation circuits for turn-on and turn-off are represented in Figs.B(a) and B(b), respectively. Thus, we can say that both during turn-on and turn-off period, the output current i_4 is kept flowing in this boost converter having auxiliary transformer. As the voltage polarity of primary and secondary sides of transformer is opposite direction, the direction of v_{L1} and v_{L2} is shown in opposite ones each other.

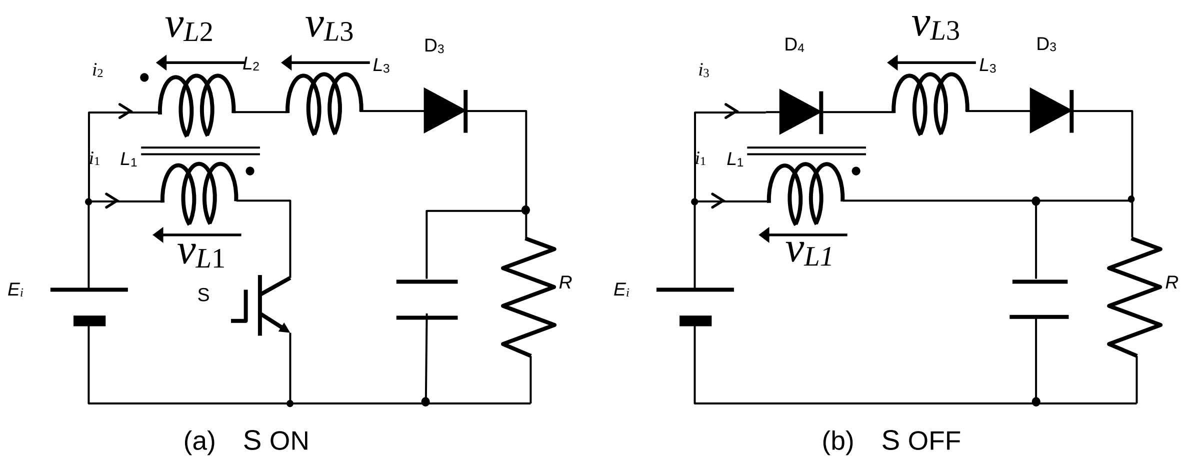

Figure B. Boost Chopper Having Auxiliary Transformer.