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# An Optimized PI-Controller Design by Efficient Modular of High Step-up Interleaved Boost Converter

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**Abstract:** A High step converter is proposed to achieve high voltage conversion ratio and high efficiency. Generally, a conventional boost converter has been used to obtain higher output voltage than the input voltage. The conventional boost converters are proposed for high ratio it leads to high voltage and current stress on the switch. In this proposed paper, the interleaved boost converter is used. This converter is used for reducing input current ripples and output voltage ripples; then it combines a flyback transformer. The energy from transformer leakage inductance is recycled and its efficiency is greatly improved. Thus switching and conduction losses are reduced. The simulation results are proposed by MATLAB\SIMULINK environment and illustrate that CSO technique in terms of various time domain specifications.

**Keywords:** CSO (cuckoo search optimization), the boost converter, an interleaved boost converter, the flyback inverter.

## 1. INTRODUCTION

Renewable energy sources such as wind energy, fuel cells, photovoltaic, geothermal energy receive a lot of attention around the world. The renewable energy sources such as photovoltaic and fuel cell require a high step-up converter due to the low output voltage. Theoretically, boost, buck-boost and flyback converter, are the excellent candidate for renewable energy system due to their simplest topologies and a high step-up voltage gain with extremely high duty ratio. As a matter of fact, the voltage gain is limited by the effect of the rectifier, the diodes, the power switches, leakage inductances and equivalent of series resistances (ESR) of inductor and capacitor. Besides, large current ripples and diode reverse recovery problem is induced by the extreme duty ratio related to increasing of conduction losses many quadratic converters and cascade structure have been investigated to raise the step-up voltage gain and prevent converters from operating an extreme duty cycle. However, two stages structure induces not only the complex topology and the efficiency degradation. But also poor stability and also the reverse recovery loss of the output diode is severe. The isolated type converter can easily offer a high step-up and with a transformer. However, the leakage inductance of the transformer not only causes voltage

and current spikes and induces high voltage stress of switches but also increases loss and noise, resulting in a low efficiency. A resistor-capacitor-diode (RCD) clamp circuit and an active clamp circuit can reduce the voltage stress and switching losses, but at the cost of topology complexity and some losses related to the clamp circuit. A number of non-isolated converters based on coupled inductor have been investigated for their simple structure and lower conduction loss. However, they use snubber such as voltage clamp, active clamp passive regenerative to limit the voltage spike across switches caused by the existence of leakage inductance of coupled inductor. However, all of these approaches lead the complex structure with increased number of switches and the capacitors. The non-isolated high step-up converters, which based on boost integrated fly back and SEPIC-converter, are proposed. A high step-up voltage conversion ratio is achieved by changing coupled inductor's turn ratio. In addition, the energy of leakage inductance is used to the output terminal directly, so that the main switch's voltage spike and the output diode's turn OFF current are limited. However, due to the turn ratio of coupled inductor increased, the voltage stress of output diode is increased as well as the severe diode reverse recovery problem. These converters are not suitable for high-power and high current applications because their input current ripple is large with one switch operating in spite of avoiding extreme duty ratio. The conventional interleaved boost converter is an excellent candidate for high power applications and power factor correction due to its simple structure and small input to output ripples. However, it connected to the output terminal, the energy of leakage inductance can be recycled, and the voltage spikes across the main switches can also be alleviated to improve the efficiency.

## 2. TOPOLOGY DERIVATION AND OPERATION PRINCIPLE

The boost converter with interleaved is a good candidate for renewable energy system due to its simple structure and small input and output ripples. However, the voltage conversion ratio of the conventional interleaved boost converter has been proposed. The converter cannot only achieve a high step up gain but also reduce the voltage stress of switches and diodes compared to the converter. However, the forward-Cuk integrated circuits are relatively complex and expensive. In generally, the flyback converter can provide a much higher step-up gain and its circuit structure is simpler compared to the forward-type Cuk-type converter. Therefore, similar to the converter, the flyback converter is another choice to integrate to the converter. Figure 1 is the circuit diagram and key waveforms of the two-phase interleaved converter. From Figure 1 (a), it can be seen that the converter is composed of two-phase interleaved circuits. The boost converter in the first phase composes of inductor  $L_1$ , switch  $S_1$ ,  $S_2$ , switched capacitor  $C_1$ ,  $C_2$  and diode  $D_1$ . The second phase combines a boost converter and flyback converter including inductor  $L_2$ , capacitor  $C_0$ ,  $C_1$ , Load R. The turn ratio  $N$  is  $N_S/N_P$ . The primary winding of the transformer is connected to the output terminal directly. Thus, not only a high step-up gain is achieved by adjusting the transformer turn ratio but also the leakage energy stored in the leakage inductance is recycled. In addition, to reduce the voltage stress of switches and diodes, the switched capacitors  $C_1$  and  $C_2$  are used for the two phase circuits. However, the interleaved converter in Figure 1 has some drawbacks that cannot be neglected. From the key waveforms, it can be seen that when the switch  $S_2$  turns ON, the large currents of inductor  $L_2$  and magnetizing inductance of the transformer across to the switch  $S_2$ . Therefore, there are very high current stress and conduction loss on switch  $S_2$ , and the efficiency drops. Besides, a huge amount of energy dissipates on the primary winding of the transformer when switch  $S_2$  turns off. After the energy of the leakage inductance is released to zero on a short time interval, there will be no energy transferred to the output capacitor and load from the dc Source  $V_{IN}$ . At time  $t_4$ , the current of the inductor  $L_2$  start to flow into the primary winding of the transformer rather than the output, as the dash area shown in Figure 1. Though the energy stored in the  $L_2$  can be transferred to capacitor  $C_1$  through the flyback transformer and the large energy dissipated on the transformer and other components. Thus, the efficiency of the converter is decreased. Furthermore, the input current ripples are very large due to the second phase cannot transfer the energy of the dc source  $V_{IN}$  to the output after time  $t_4$ .

In order to overcome these aforementioned questions, the proposed circuit topology depicted in Fig. 2 requires only one additional switch  $S_3$  and one diode  $D_4$ . The switch  $S_3$  is added to provide another path for the current of magnetizing inductance of the transformer to the output of the converter and reduce the current stress and conduction loss and the switch  $S_2$  and the input current ripples. The diode  $D_4$  is added to prevent the energy stored in inductor  $L_2$  from transferring to the primary side winding of the transformer, but let the energy transfer to the output terminal when the switch  $S_2$  turns off. Meanwhile, the leakage inductance energy of transformer can be recycled to the output diode  $D_4$ . And the voltage stress of diode  $D_4$  is nearly zero, which significantly reduces the reverse recovery problem of diode  $D_4$ , resulting efficiency is improved. It should be noted that the switch  $S_3$  is added to provide another path for the current of magnetizing inductance of the transformer to the output of the converter and reduce the current stress of switch  $S_2$ . The lower current stress MOSFET for these two switches can be used. Though one more switch is used in the structure, the cost is not increased significantly. The proposed converter illustrated in Figure 2. Has better performance and is more suitable for renewable energy system than the interleaved converter in Figure 1. The following discusses the entire proposed converter.

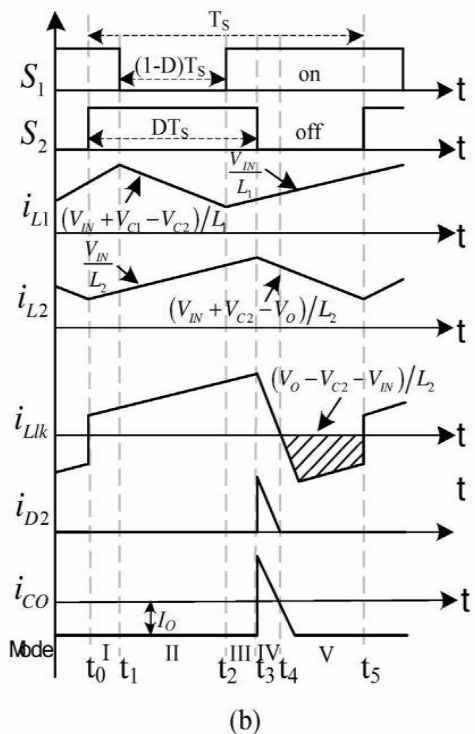
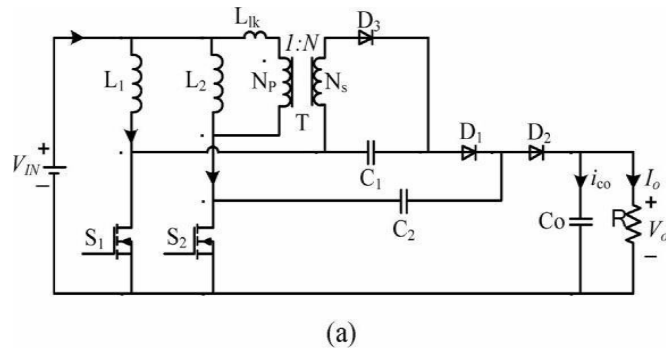


Figure 1: (a) Two-phase Interleaved Converter (b) Key waveform of the converter

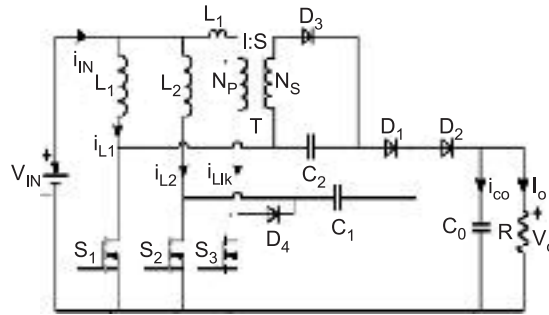


Figure 2: Proposed converter

### 3. OPERATION PRINCIPLE OF THE PROPOSED CONVERTER

Figure 3 illustrates the key waveform of the proposed converter. Assume that all components in Figure 2. An ideal except for the transformer of the flyback converter, under steady state condition.

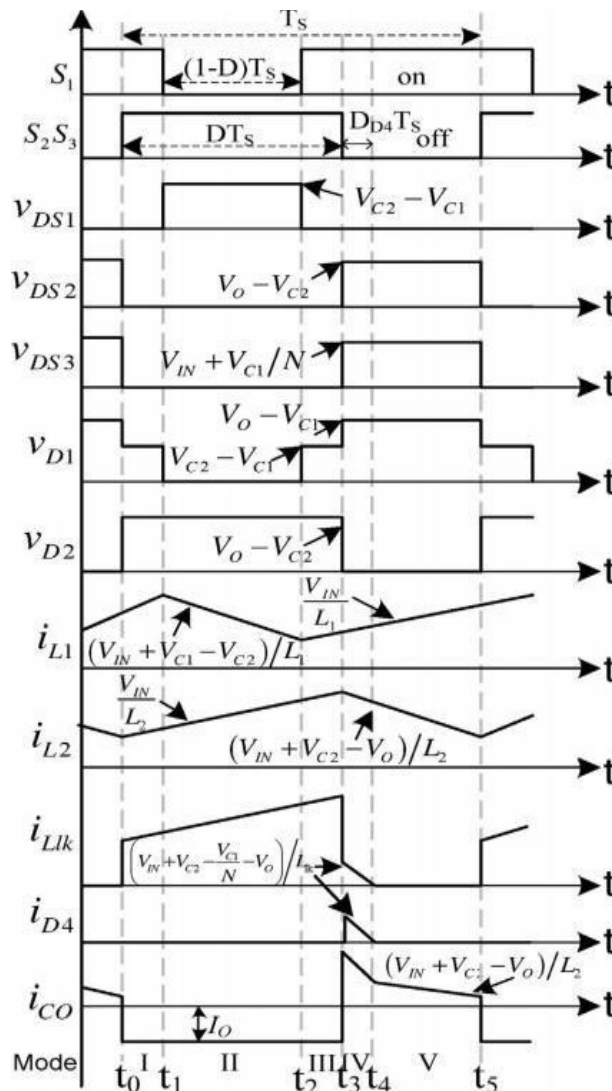


Figure 3: Key waveform of proposed converter

For describing the function of added switch  $S_3$  and diode  $D_4$ , the leakage inductance of the transformer is considered. In the circuit analysis, the proposed converter operates in continuous conduction mode, and the duty cycles of the switches during steady state operation are greater than 0.5 and are interleaved with a  $180^\circ$  phase shift between  $S_1$  and  $S_2$ , a  $0^\circ$  phase shift between  $S_2$  and  $S_3$ . The key steady waveforms in one switching period contain five modes depending on the status of the switches, which are depicted in Figure 3 and Figure 4. The operating modes are described as follows;

**Mode I [ $t_0, t_1$ ]**

During this time interval, switches  $S_1, S_2$  and  $S_3$  are turned on, diodes  $D_1, D_2, D_3, D_4$ , are all turned off. The path for current flow is illustrated in Figure 4(a) that  $i_{L1}, i_{L2}$ , are increasing and energy is stored in  $L_1$  and  $L_2$  as well the energy is stored in the transformer.

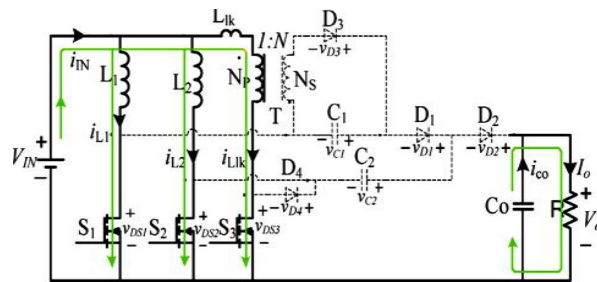


Figure 4: (a) Mode I ( $t_0, t_1$ )

The output capacitor ( $C_0$ ) discharges to load R. In addition, due to the switches  $S_2, S_3$  are turned on, the voltage of diode  $D_4$  is zero, thus, the reverse recovery problem alleviated and efficiency improved.

**Mode II [ $t_1, t_2$ ]**

During this time interval switches  $S_2$  and  $S_3$  remain turning on and  $S_1$  is turned off. In addition, diode  $D_2, D_3$ , and  $D_4$  remain OFF and  $D_1$  is ON. The path for current flow is illustrated in Figure 4(b) that the energy stored in  $L_1$ , together with the energy stored in  $C_1$  is

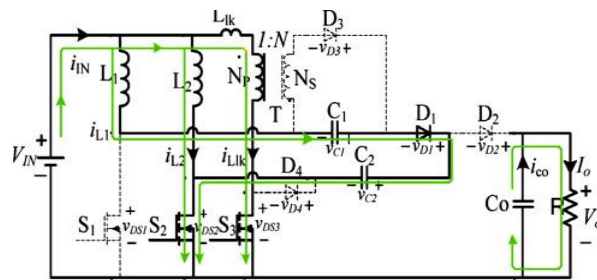


Figure 4: (b) Mode II [ $t_1, t_2$ ]

Discharged through diode  $D_1$  to capacitor  $C_2$ . The output capacitor still provides energy to the load R.

**Mode III [ $t_2, t_3$ ]**

During this time interval switches  $S_1, S_2$  and  $S_3$  are turned on, diodes  $D_1, D_2, D_3, D_4$ , are all turned off. The path for current flow is illustrated in Figure 4(c) that  $i_{L1}, i_{L2}$  and  $i_{Llk}$  are increasing and energy is stored in  $L_1, L_2$  and  $L_{lk}$  as well the energy is stored in the transformer. The output capacitor  $C_0$  discharges to load R. In

addition, due to the switches  $S_2, S_3$  are turned on the voltage of diode  $D_4$  is zero. The reverse recovery problem alleviated.

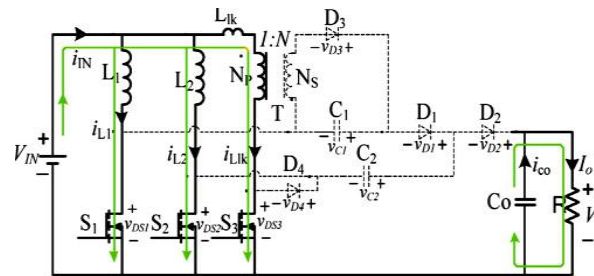


Figure 4: (c) Mode III [ $t_2, t_3$ ]

### Mode IV [ $t_3, t_4$ ]

During this time interval,  $S_1$  is turned ON;  $S_2$  and  $S_3$  are turned OFF. Diode  $D_1$  are reverse biased, and diodes  $D_2, D_3, D_4$  forward biased. The path for current flow is illustrated in Figure 4(d). The current of inductor  $L_1$  increases linearly. The energy stored in  $L_2$ , together with the energy stored in  $C_2$ , is discharged through diode  $D_2$  to output capacitor ( $C_O$ ) and load R. Meanwhile, the energy stored in leakage inductance is released through diode  $D_4$ , capacitor  $C_2$  and diode  $D_2$  to capacitor ( $C_O$ ) and load R. At time  $t_4$ , the current of diode  $D_4$  and the current of leakage inductance  $i_{Llk}$  are decreased to zero, thus, the zero-current switching turn-off of  $D_4$  is achieved. In addition, the energy is stored in the transformer is discharged through diode  $D_3$  to Capacitor  $C_1$  for recharging.

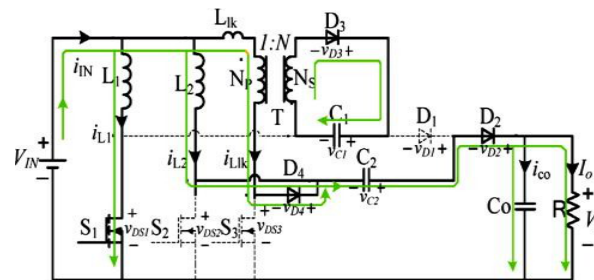


Figure 4: (d) Mode [ $t_3, t_4$ ]

### Mode V [ $t_4, t_5$ ]

During this time interval,  $S_1$  keeps turning on,  $S_2$  and  $S_3$  turning off. Diodes  $D_2, D_3$  remain forward biased and  $D_1, D_4$  reverse biased. Figure 4(e) illustrates the path for current flow. The current of  $L_1$  remains increasing linearly and energy stored in transformer remain releasing to capacitor  $C_1$ . The output power is now supplied by the inductor  $L_2$  and capacitor  $C_2$ . This completes one switching period.

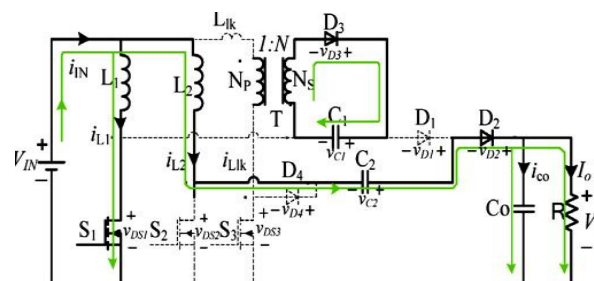


Figure 4: (e) Mode V [ $t_4, t_5$ ]

## 4. STEADY STATE ANALYSIS

For the convenience of the analysis, the magnetizing inductance  $L_m$  of the transformer in Figure 2 is considered. And assume that  $K$  is equal to  $L_m/(L_m + L_{lk})$ . At mode IV, the energy of the leakage inductance  $L_{lk}$  is released to the output through diode  $D_4$ .

### 4.1. Voltage Gain

In order to show the advantages of the proposed converter, the voltage gain  $M$  of output  $V_O$  to input  $V_{in}$  is first considered. By applying the volt-second balance principle on the inductors  $L_1$  and  $L_2$ .

$$V_{IN} + V_{C1}(1 - D) - V_{C2}(1 - D) = 0$$

$$V_{IN} + V_{C2}(1 - D) - V_O(1 - D) = 0$$

the ideal voltage gain versus the duty ratio of the proposed converter, and other boost converters in under  $K = 1$  and  $N = 3$ . Figure 5 shows that the voltage gain of the proposed converter is higher than that of the other two boost converters. The proposed converter can use smaller duty ratio to achieve the same voltage gain. Thus, the extreme duty ratio is avoided and the conduction losses are reduced.

### 4.2. Voltage Stress on Semiconductor Component

In order to simplify the voltage stress analysis of the components, the voltage ripples on capacitors are ignored. The Kirchhoff's voltage law, the open circuit voltage stress of switches  $S_1 - S_3$  and diodes  $D_1 - D_4$ . For convenient comparison, neglected the leakage inductance  $L_{lk}$  of the transformer, that is  $K = 1$ , the ideal voltage stress of switches and diodes are given as it can be seen that the voltage stress of the switches is obviously smaller than  $V_O/2$ . That is to say that the conduction and switching losses can be reduced. The lower voltage rate diode can be selected to further reduce the switching and conduction losses. It is obviously that the step up gain of the proposed converter is the highest, and the voltage stress of switches and diodes is the lowest. As a result, the lower rating switches and diodes can be selected to achieve higher efficiency.

## 5. SIMULATION RESULT

The simulation result of the high step-up converter in the closed loop using Proportional-Integral (PI) controller.

The PI Controller reduces the oscillations in the output waveform. Further, increases the voltage gain when compared to the open loop system. The voltage gain obtained in the closed loop system is nearly 8.33. The output voltage obtained will be 200V for the reference voltage of 200V. The output voltage is drawn between voltage and time. Implementation of the Novel high step-up converter using CSO. The Cuckoo search optimization is implemented in the PI controller so as to obtain the voltage at the desired value. Using, this optimization the rise time and the settling time gives better time responses compared to the conventional PI controller.

The Cuckoo search optimization is implemented in the PI controller so as to obtain the voltage at the desired value. Using this optimization the rise time and settling time gives better time responses compared to the conventional PI controller. The simulation result of the high step-up converter in closed loop system using Cuckoo Search Optimization.

In this the output voltage obtained is 200V for the reference of 200V and the time domain specifications such as settling time and rise time are obtained are better when compared to the conventional PI controller.

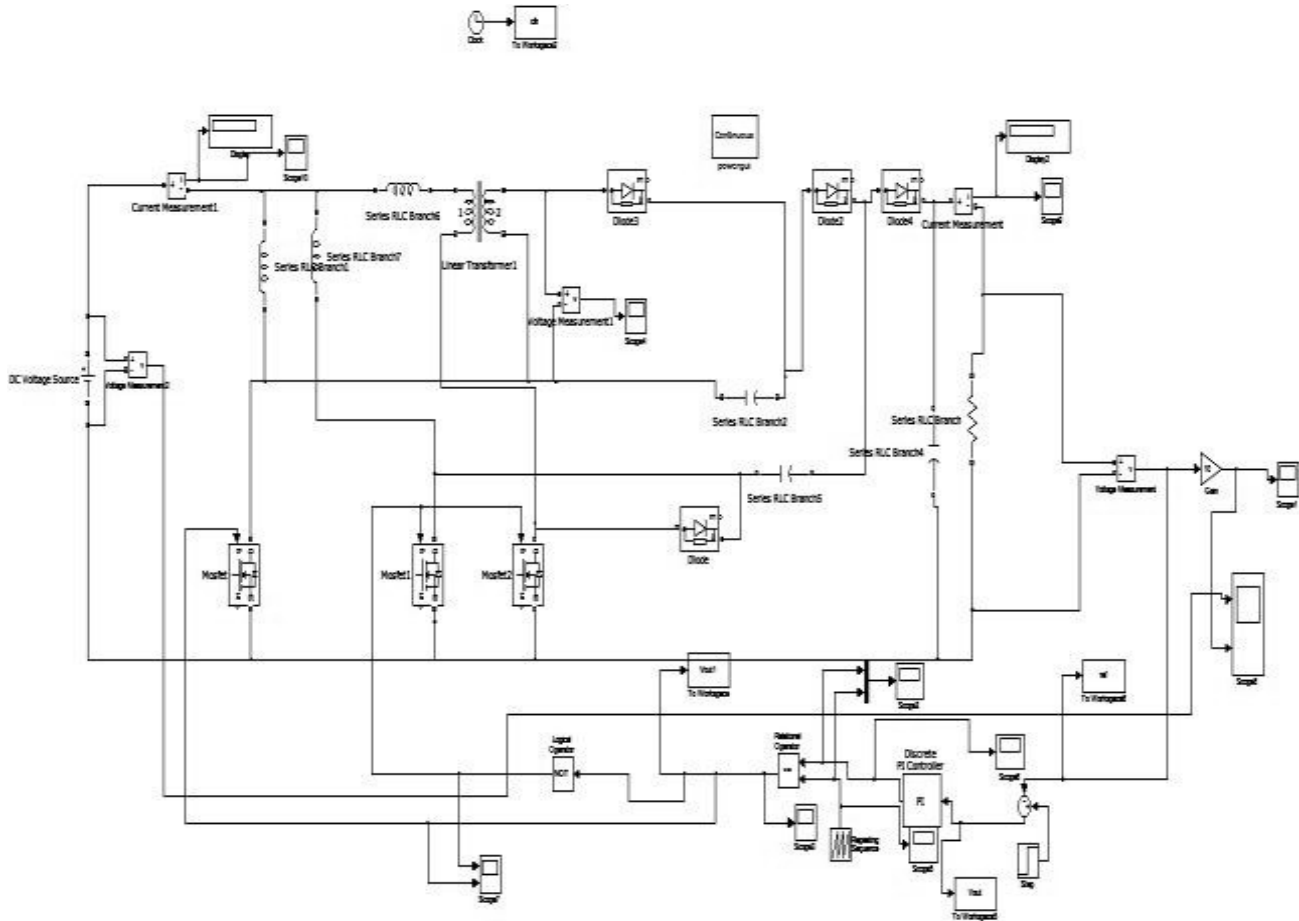


Figure 5: Simulation diagram

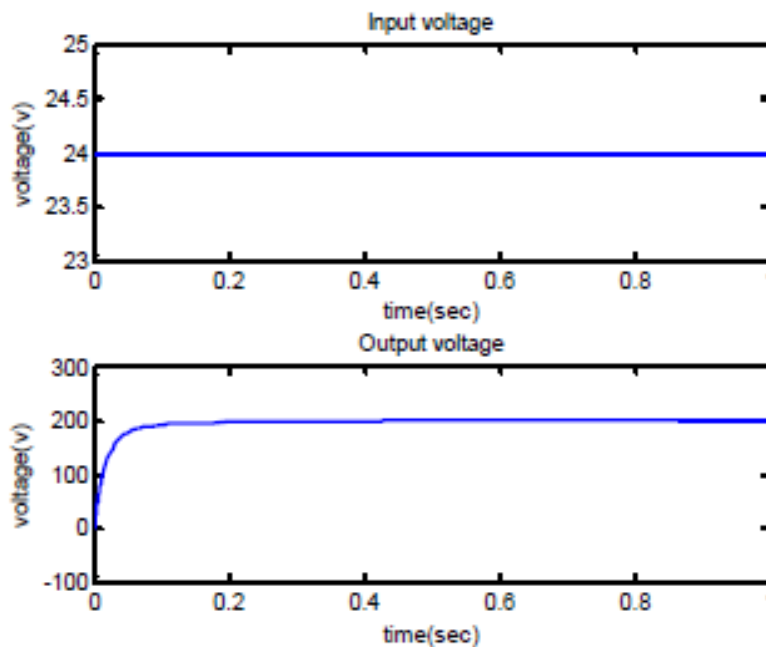


Figure 6: simulation result of closed loop controller



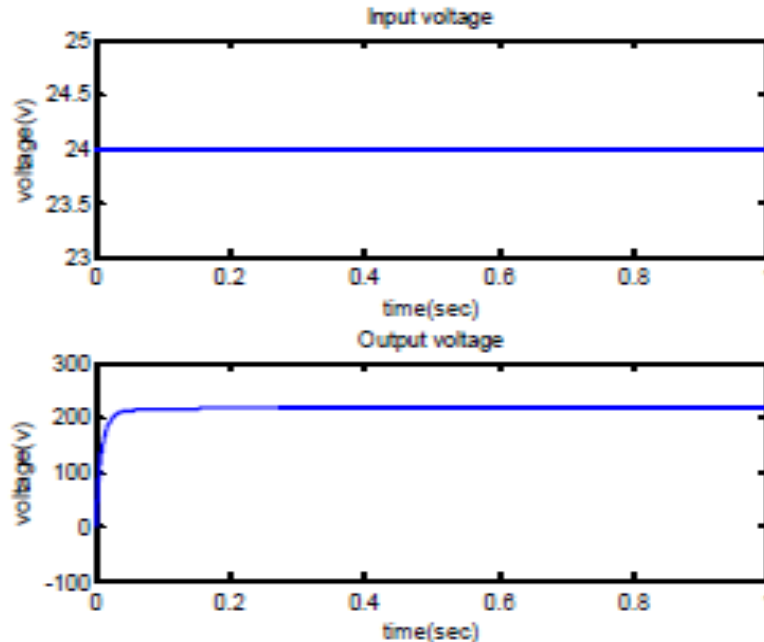


Figure 7: Simulation result of optimization process

## 6. CONCLUSION

In this paper, a high step-up converter for the renewable energy system has been proposed. It is adopted to reduce input current ripples and output voltage ripples and distribute the current through each phase. In addition, the voltage stress of switches and diodes can be reduced by added switched capacitors. A flyback converter integrated to the conventional interleaved converter, the high voltage gain achieved and the extreme duty cycle avoided. Moreover, the energy of the transformer leakage inductance is recycled to the output with only added a diode  $D_4$  and the efficiency is improved. Further, the performance of the converter is analyzed using PI controller and also the PI gains are optimized by using Cuckoo search Optimization. Simulation results prove that CSO performs better than conventional PI controller in terms of reducing the rising time and settling time.

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