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Low-Stress and Efficient Design of Integrated Boost Series Parallel Fly-Back Converters

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ABSTRACT

This paper Presents comparative analysis of IBSPFC &QSC Based IBSPFC by using FPGA. By using this IBSPFC the voltage stress is reduced across the switch when compare to conventional fly-back converters. The multi winding transformer gives higher reliability i.e. if any one of the winding damages other one supplies power to the load. On the other hand, QSC based IBSPFC will achieved Zero voltage & Zero current switching, which will increase more efficiency when compare to conventional single stage integrated converters and IBSPFC. Operating modes of QSC, based IBSPFC&IBSPFC have been introduced. The primary side winding of the fly-back transformer is coupled in series across with bulk capacitor to minimize switch voltage stress and the secondary winding of the 1:1 fly-back transformer. Basic voltage mode control Techniques are used to control the output voltage and current. An input voltage of 25V primary side and 50V battery at secondary side, 100v output, 100W and 100KHz DC-Dc isolated QSC based IBSPFC is implemented using FPGA SPARTAN6LX9 and experimental results and comparative table have been presented.

1. INTRODUCTION

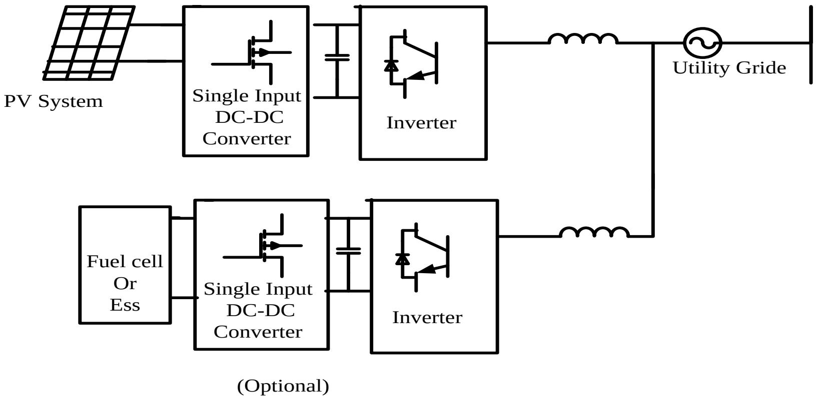
Existent Solar Power creation has addition leads in finding and running price different to more energy sources. Solar power is a clean method with nil least preservation. Mainly PV cells can be built on the topmost of apartments or homes and trade in metropolitan cities. In solar power, there is chance of irradiation fluctuation, which makes use of battery storage system to provide the required power to load [1]. Due to separate sources, an individual power electronic converter is required which increase the complexity of the circuit shown in Figure 1 (a). To reduce the cost and complexity of the circuit a multi input dc-dc converter is preferred [2] which are shown in Figure 1(b). Presently dual input topologies are classified into two ways. One is non-isolated another one is isolated [2-14]. The basic non-isolated topologies of dc-dc converters are again classified as Buck, Boost and Buck-boost converters suffering from isolation and at the load side it requires large AC Transformers [3, 4]. Otherwise, the utility grid may affect leakage current in between solar panels and earth. The isolated converters of dual input dc/dc help to avoiding the line frequency transformer [5, 6]. The basic isolated dc/dc converters are fly back, half bridge, forward, push pull and full bridge converters [7-9]. To transfer the power from multiple sources to the output a separate isolated transformer is required for each source and the number of switches are increased followed by cost [10-15]. To eliminate this problem a two winding transformer is used [16-24]. By losing the isolation between the energy sources of single side of the isolation transformer the total number of switches in this type of topologies are reduced and Battery is connected at secondary side of the isolation transformer, the battery does not require any isolation to the output of the load [25-32].

Therefore, this type of topology is better than using multiple transformers. As the application in this paper is 100w or 200w, hence fly back converter is chosen. The basic fly back converter requires two snubber circuits one is at primary winding of transformer another one is at switch, which is connected in series with the transformer.

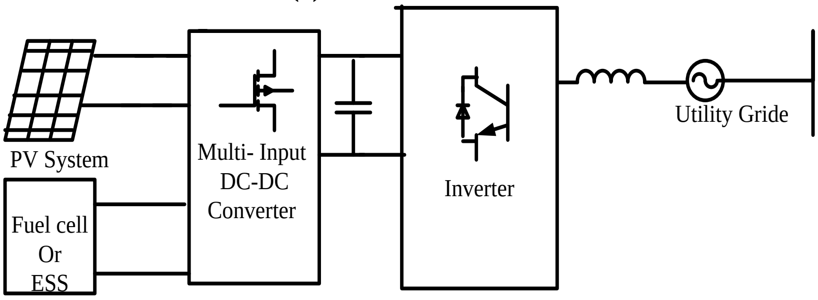
Generally, the fly back converter duty cycle is limited to 0.5.

To eliminate these problems IBSPFC and QSC based IBSPFC is preferred for 100w or 200w applications. In this paper single switch IBSPFC and QSC based IBSPFC is introduced. The main advantage of QSC based IBSPFC is it will reduce voltage stress on the switches, high reliability and ZVS and ZCS will achieve hence efficiency of the converter is improved [32].

The research study along with experimental results of IBSPFC with QSC is presented in this paper for closed loop control. The design considerations for inductor in boost circuit, quasi switched capacitor and output capacitor are evaluated. This presents design of QSC based IBSPFC operating at 100 kHz with DC input voltage magnitude of 25V on primary side, producing 50V and 100V at secondary side and at load with 100W of output power. The operating modes of IBSPFC are presented in Section 2 Present Necessity of IBSPFC and QSC based IBSPFC. Section 3. Section 4 presents mathematical Analysis; experimental results of the proposed circuit are shown in Section 5 for closed loop, Section 6 Working Methods of QSC Based IBSPFC. Section 7 Mathematical Calculations of QSC based IBSPFC. Section 8 Experimental Results of QSC based IBSPFC. Section 9 conclusion. and References related to the performance of the proposed circuit is discussed in this above Sections.



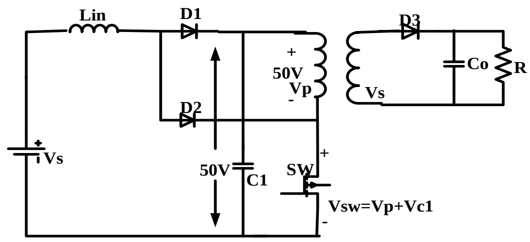
(a). Present formation



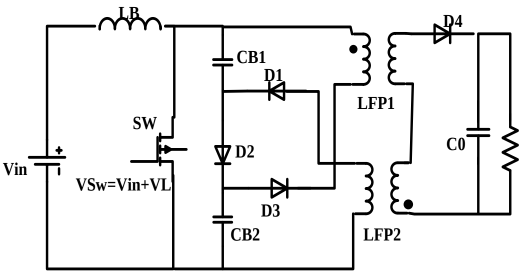
(b). System formation with a multiple-input dc/dc converter

Figure 1. Different system configurations with both PV and Fuel cell or ESS

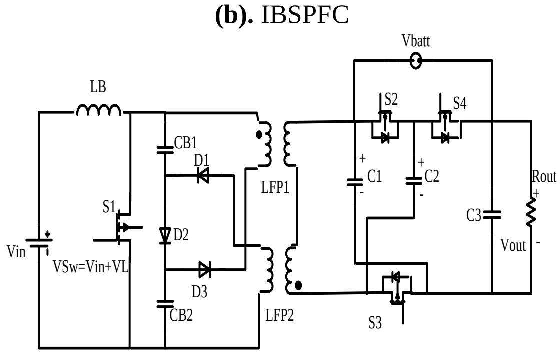
2. NECESSITY OF IBSPFC AND QSC BASED IBSPFC



(a). IBFC



(b). IBSPFC



(c). IBSPFC with QSC based Dual Input Converter

Figure 2. Different topologies Boost Fly-back converter

Figure 2 Shows the different topologies of Boost Flyback converter and the Figures shown below 2(a) is Integrated Boost fly back converter (IBFC) but here the problem is the voltage across the switch is $V_{sw}=V_p+V_{c1}$. Let us consider one example that V_s=25V, D=0.5V&V_{c1}=50V (boost operation) and V_p=50V then the switch voltage becomes $V_{sw}=V_p+V_{c1}$=100v and in transient period the voltage may goes to 10kv hence switch may go to damage. To overcome this problem IBSPFC is used.

In this IBSPFC shown in Figure 2(b) the voltage stress is reduced because $V_{sw}=V_{IN}+V_{LB}$ Let us consider one example V_{IN}=25V, D=0.5&$V_{sw}=V_{IN}+V_{LB}$=50V, only and the capacitors CB1 and CB2 will acts as snubber circuit as well as bulk capacitor energy storage. The reliability is also present in this circuit because if any one of these capacitors or if any one of the fly-back transformers will damage the other transformer will transfers the half of the power to the load. To improve the efficiency and power transfer QSC based dual input configuration is used shown in Figure 2(c). The main advantage is Soft switching is implemented for both primary and secondary MOSFETS.

3. OPERATION OF IBSPFC

The main circuit diagram of IBSPFC shows in Figure 3. The functioning modes in single switching cycle can be indicated in four intervals, shown in Figure 4 and the pulse waveforms and the corresponding current waveforms are shown in Figure 5.

In mode 1 [0 < t < t1: Figure 4(a)]: When the SW is in on state then the input current start flowing through +Vin – LB – SW – (-Vin). Therefore, inductor current starts increasing and no current flows through the remaining part of the circuit.

In mode 2 [t1< t < t2: Figure 4 (b)] when the switch is in off state, then the current flows through +VIN - LB - CB1 - D2 -

CB2 - (-VIN) and the inductor LB discharges and capacitors CB1 and CB2 will charge through diode D2.

In mode 3 [t2< t < t3: Figure 4(c)] the switch is again turned on and the supply current flows through +Vin- LB - SW – (-Vin). And the small amount of current flows through +CB1 - SW – Lfp2 – D1 – (-CB1) and +CB2 – D3 – Lpf1 - SW – (-CB2). Due to reverse polarity of dot convention of fly-back transformer diode D4gets forward biased and the current flows through the output capacitor C0 and load resistance R.

In Mode 4 [t3< t < t4: Figure 4(d)] the switch is again turned off the bulk capacitors CB1 and CB2 get charged through +VIN - LB - CB1 - D2 - CB2 - (-VIN) and +Lpf1- CB1- D2 – D3 – (-Lpf1) and +Lfp2 – D1 – D2- CB2 – (-Lfp2). Due to reverse polarity of dot convention diode D4 gets reverse biased then the output capacitor C0 will discharges its energy to the load R.

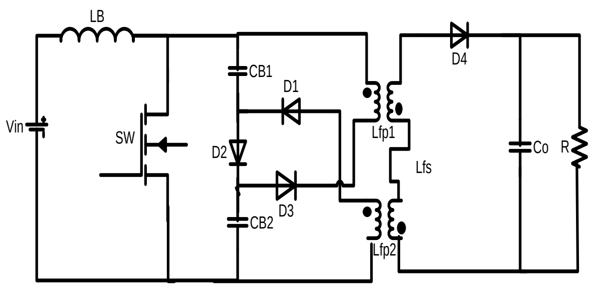
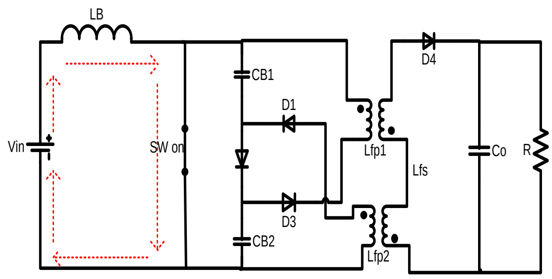
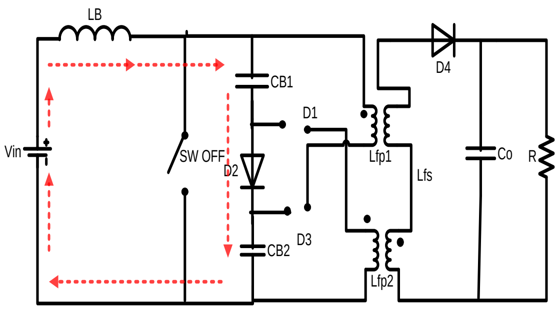


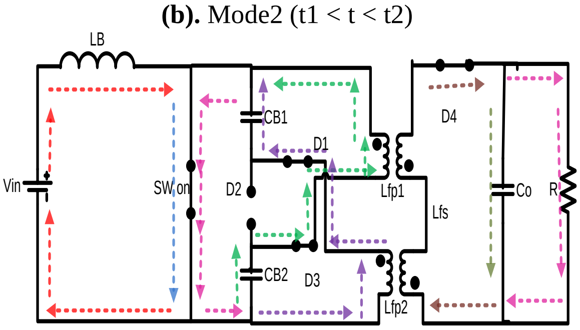
Figure 3. Integrated Boost Series Parallel Fly-back converter (IBSPFC)



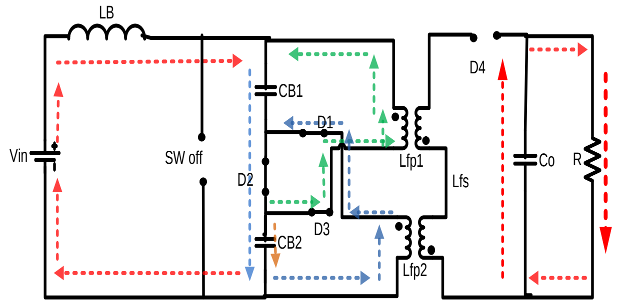
(a). Mode1 (0 < t < t1)



(b). Mode2 (t1 < t < t2)



(c). Mode3 (t2 < t < t3)



(d). Mode4 (t3 < t < t4)

Figure 4. Functioning modes of IBSPFC

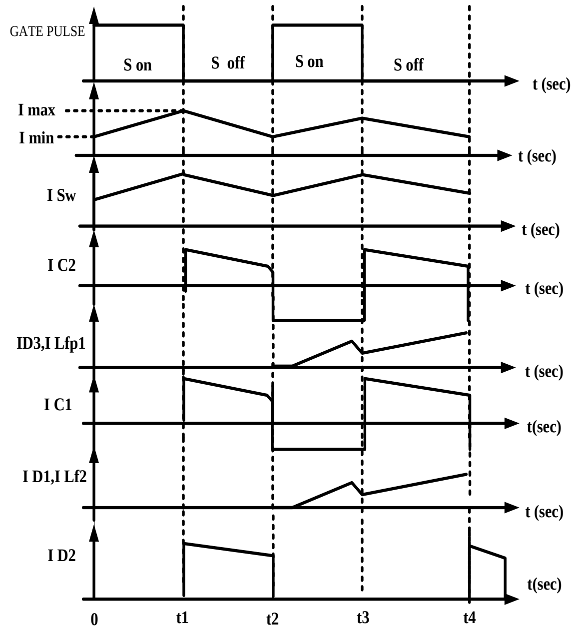


Figure 5. Current waveforms

4. MATHEMATICAL ANALYSIS

Input voltage $V_S = 24$ V
Output Voltage $V_0 = 48$ V
Output Current $I_0 = 1.2$ A
Output Power $P_0 = 48 \times 1.2 = 58$ W
R= 40 Ω
For the step changer R = 65 Ω

$$V_0 = \frac{V_S}{(1-D)} \tag{1}$$
$$\therefore D = 0.5$$

$$I_S = \frac{I_0}{(1-D)} \tag{2}$$
$$= 2.4$$

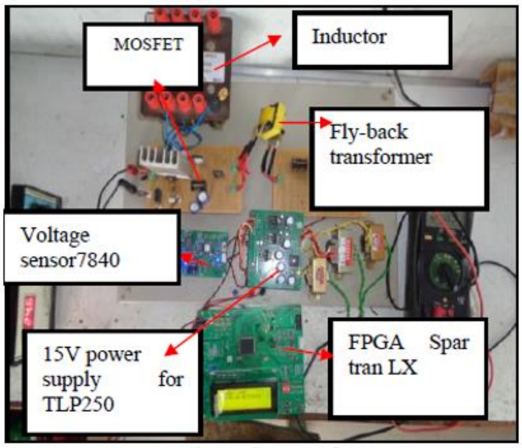
But practically
I_S=3.4A is Obtained

$$\eta = \frac{OUTPUT}{INPUT} = \frac{58}{(24*3.4)} = 68.2\% \tag{3}$$

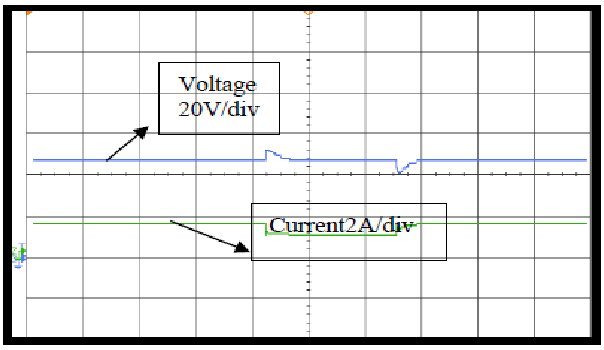
To improve the efficiency & More Reliability QSC Based IBSPFC is used.

5. EXPERIMENTAL RESULTS

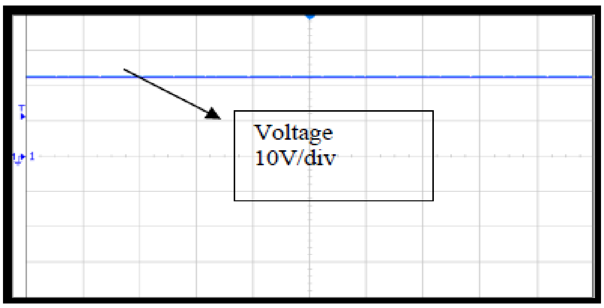
Experimental results are shows Figure 6(a). Home based kit, Figure 6(b): Output voltage and current (48 v n 1.2 amp), Figure 6(c): Capacitor Voltage (24 volts), Figure 6(d): Primary voltage and Current (24 volts n 2 amp), Figure 6(e): Secondary Voltage (48v only due to symmetrical), Figure 6(f): Gate pulse and inductor current (3.15Amp) and Figure 6(g): Switch voltage.



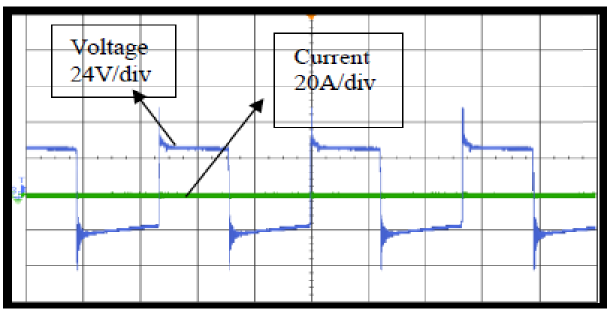
(a). Experimental set up of IBSPFC



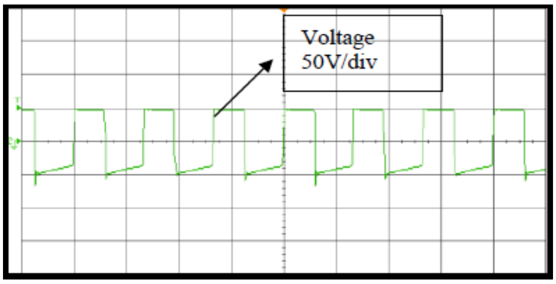
(b). Output voltage and current (48 V n 1.2 A)



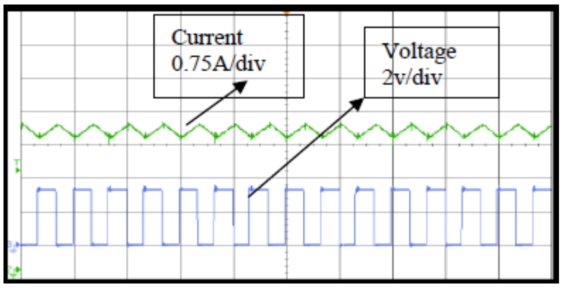
(c). Capacitor Voltage (24 V)



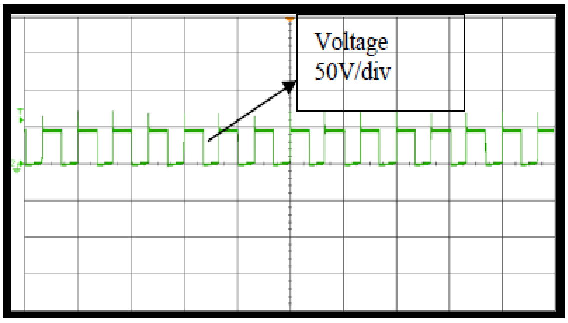
(d). Primary voltage and Current (24 V n 2 A)



(e). Secondary Voltage (48V only due to symmetrical)



(f). Gate pulse and inductor current (3.15A)



(g). Switch voltage

Figure 6. Output DC-DC closed loop waveforms

6. WORKING METHODS OF QSC BASED IBSPFC

Figure 7 shows the circuit diagram of QSC based IBSPFC. The working methods in particular switching cycle can be indicated in two-time intervals, shown in Figure 8 (a) & 8(b) and the corresponding waveforms are shown in Figure 9(a) &9(b).

In mode 1(M1) [0< t < t1: Figure 8(a)]: When the switches S1, S2, S3 are in ON condition. The current starts flowing through primary (Vin-L-S1) Therefore the boost inductor current starts increasing. Capacitor C1'C2' will be discharging through (C1'-S1-D1) & (C2'-D3-S1) and supplied to load [33]. On secondary side C1, C3 will be charging and C2 will be discharging though (C2-S2-Vbatt-C3-S3-C2).

In mode 2(M2) [t1< t < t2: Figure 8(b)] the switch S1, S2, S3 are switched off and S4 switched on. In this mode of operation, the current flows through the path of +Vin –L-C1'-D2-C2'-(-Vin). In this mode, the discharging of boost inductor takes place through the capacitors and diodeD2.and on secondary side capacitor C1, C3 are discharging and C2 is charging through-C2-Vbatt-S4-(+C2).

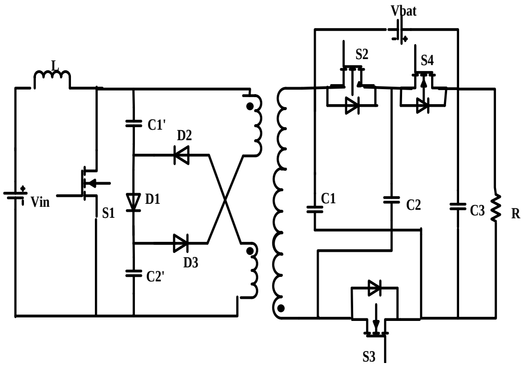
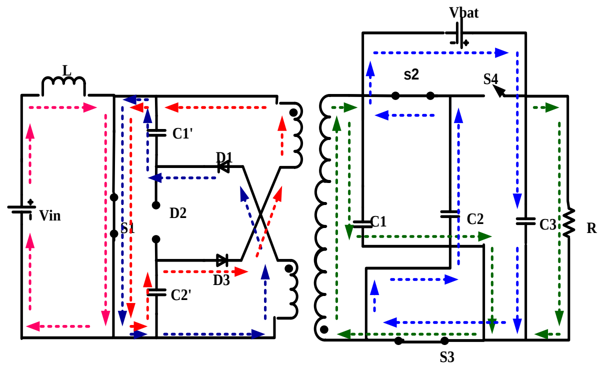
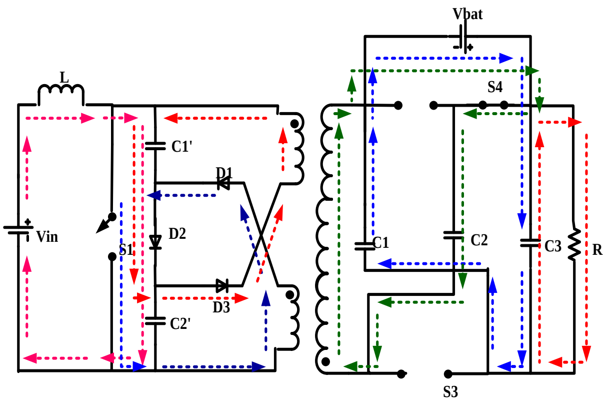


Figure 7. QSC based IBSPFC

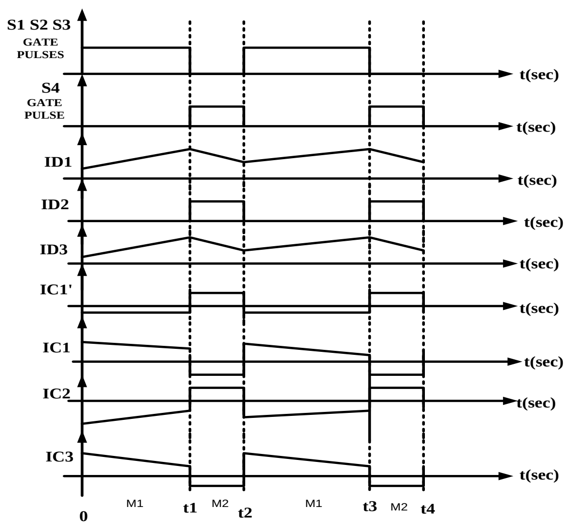


(a)

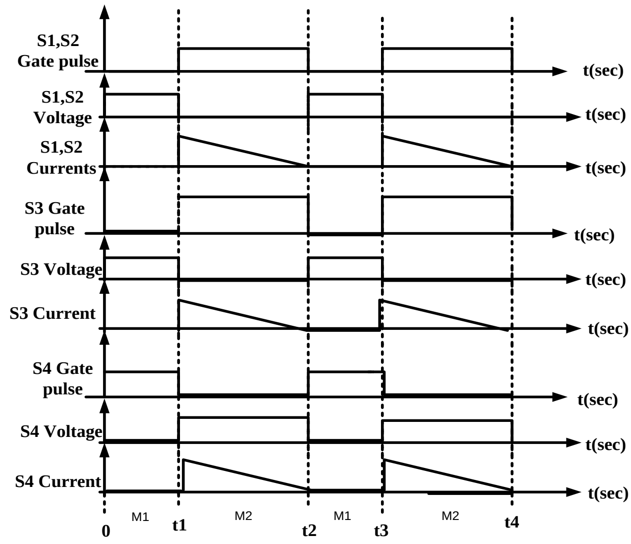


(b)

Figure 8. (a) Mode1 (0 < t < t1); **(b)** Mode 2 (t1 < t < t2)



(a)



(b)

Figure 9. (a) Waveforms -1; **(b)** waveforms - 2

7. MATHEMATICAL CALCULATIONS QSC BASED IBSPFC

Mathematical calculations are obtained for the QSC based IBSPFC. Design specifications are V_{in}=25V, V_O=100V, I_O=1A, R=100Ω, f_S=100 KHz, P_O=100W, V_B=50V and Battery=50V.The design calculations for QSC based IBSPFC are presented below based on the assumption that primary side source and secondary side battery will share total load.

The Boost Convertor Output Voltage (V_B), Input Current (I_L), Boost Inductance (L_B), Fly-back inductance (L_F), Bulk Capacitors C_{B1}, C_{B2} and output filter capacitor (Co) are given as follows [34-37].

Boost Output Voltage:

$$V_B = \frac{V_{in}}{(1-D)} \quad (4)$$

$$\therefore D = 0.5$$

Boost Inductor current:

$$I_S = \frac{I_{Ob}}{(1-D)} \quad (5)$$

$$= 1A$$

where, I_{ob} is the Boost Converter Current delivery and Practically Is =3A is obtained for 100W. From the Boost Converter design Assume $\Delta i = 0.05$.

Boost Inductance:

$$L_B = \frac{V_B D}{f_S \Delta i} \quad (6)$$

$$L_B = 3.5mh \quad (7)$$

Bulk Capacitance:

$$C_B = \frac{D}{(2 * f_s * R)} \quad (8)$$

$$C_B = 25nf \quad (9)$$

An approximation value of 100µF is chosen for practical case.

From the Fly-back Converter:

$$P = \frac{V_B{}^2 D^2}{(2 * L_F * f_S)} \quad (10)$$

$$L_F = 53\mu H \quad (11)$$

An approximation value of 40 to 50µH is chosen for practical case and the Secondary side Capacitors Values.

$$C_1 = C_2 = C_3 = 100\mu F \quad (12)$$

8. EXPERIMENTAL RESULTS OF QSC BASED IBSPFC

Figure 10 shows the experimental setup of QSC Based IBSPFC.

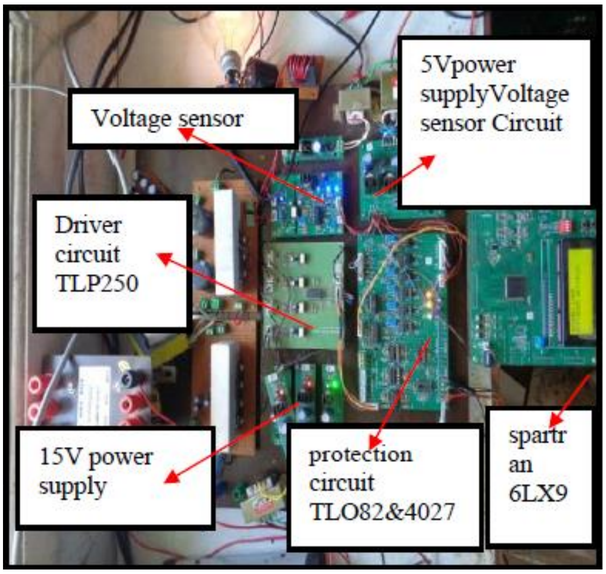


Figure 10. Experimental setup of IBSPFC with QSC

Figure 11 shows Zero voltage, Zero current Switching and Gate pulse of S2. Here the duty cycle is 50% and it is obtained from the FPGA SPARTRAN 6. From the FPGA the pulse magnitude is only 5V. But for the MOSFET minimum voltage requirement is 15V and to achieve this TLP250 driver circuit is used. It can be seen that the voltage across the switch S2 will reaches zero once the gate pulse reaches the threshold voltage value. Also, the switch current magnitude is zero. Again, when the gate pulse will reach zero the voltage across the switch will increases and the current becomes almost zero. Therefore, Switch S2 realises ZVS ON, ZVS OFF, ZCS ON and ZCS OFF. The same will be applicable for switches S3 and S4 also. Figure 12 shows Zero Voltage, Zero Current Switching S3 and Gate pulse of S3, Figure 13 shows Zero voltage, Zero Current switching and Gate pulse of S4, Figure 14 shows Output Current 2A when the load is connected, Figure 15 shows Output Voltage 100V for a small change in load the voltage variation is also shown in Figure 15, Figure 16 shows Input Source Current 3A when the load is connected, Figure 17 shows Battery input Current 0.7A. Figure 18 represents efficiency curves of IBSPFC and QSC based IBSPFC. Table 1 shows the hardware details of DC-DC Converters.

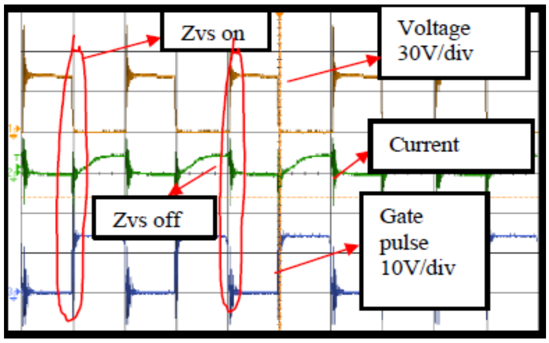


Figure 11. Zero voltage, Zero Current Switching S2

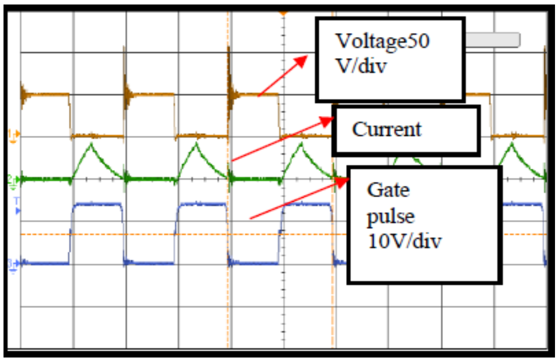


Figure 12. Zero Voltage, Zero Current Switching S3

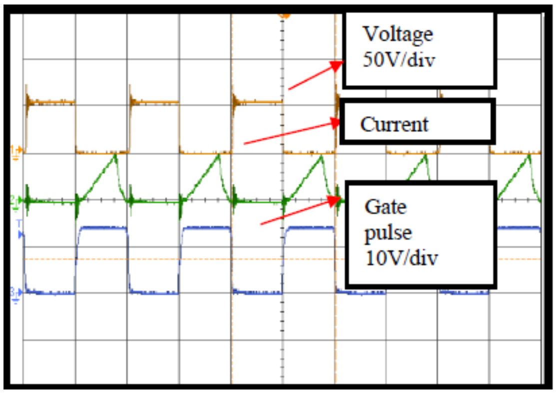


Figure 13. Zero voltage, Zero Current switching S4

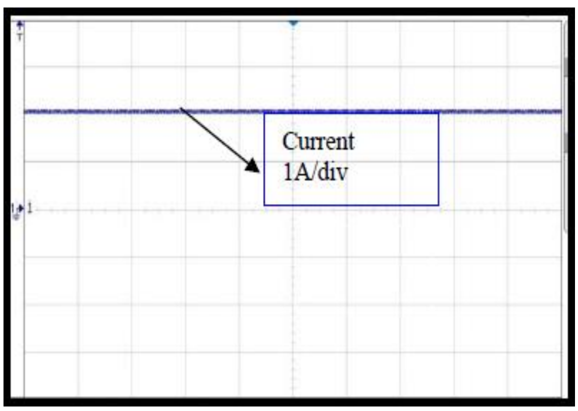


Figure 14. Output Current 2A

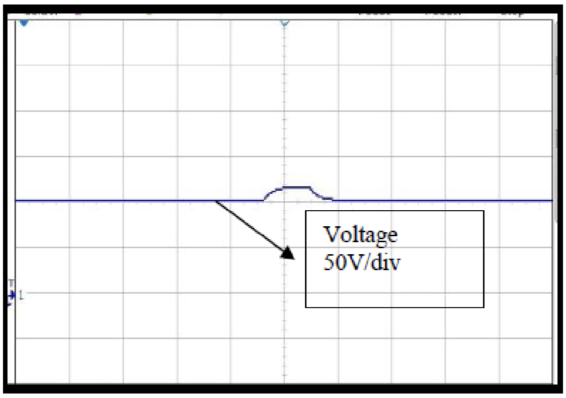


Figure 15. Output Voltage 100V

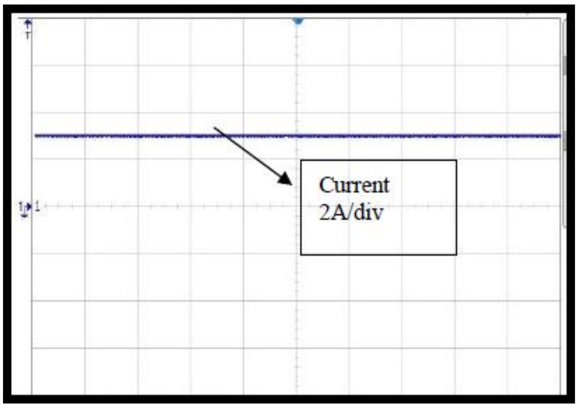


Figure 16. Input Source Current 3A

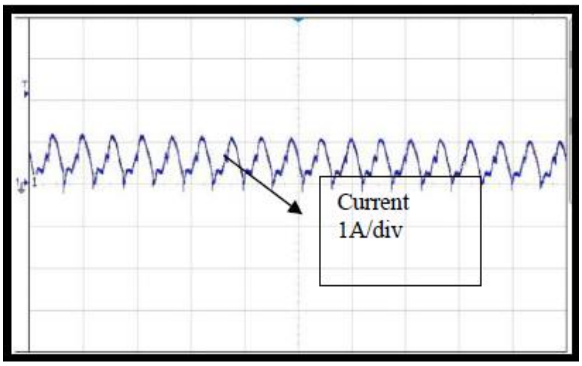


Figure 17. Battery input Current 0.7A

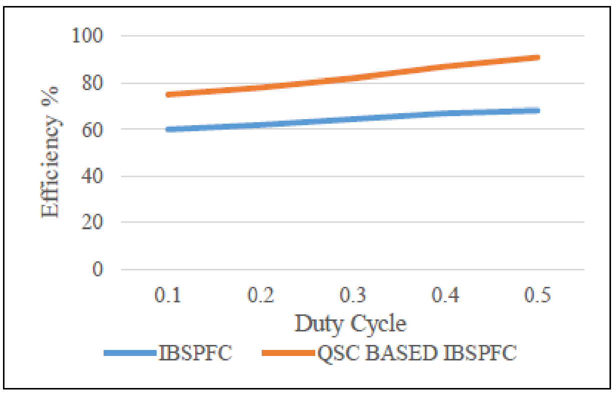


Figure 18. Efficiency curves of IBSPFC and QSC Based IBSPFC

Table 1. Hardware details

Name	Number	Ratings
Inductor	100Khz,1m	10A
MOSFET	K2611	Toshiba 900V, 9A
Diode	MUR3060	600V,30A
Capacitors (Primary)	63V,100µF	
Capacitors (Secondary)	100µF,100V	
Transformer (ratio)	1:1	50V/50V
Transformer Inductance		45µH
Protection circuit	TL082	
Spartan	8LX	

Table 2. Comparison of IBSPFC & QSC Based IBSPFC

IBSPFC	QSC Based IBSPFC
Less Reliability when compare to QSC Based IBSPFC	High Reliability when compare to IBSPFC
Up to100W	Up to 200W
Efficiency is 68.2%	Efficiency is 91%
No Snubber Circuit is Required	No Snubber Circuit is Required

The Table 2 shows comparision of IBSPFC and Qsc Based IBSPFC. Here the IBSPFC reliablity is high when compare to conventional flyback converter, because of using mid-point transformer though if any one of the winding damages the power can be transferred with other winding of the transformer and also les swithing stress. But when compare to QSC Based IBSPFC the reliability is less because QSC based IBSPFC used to power supplies therefore if any power supply is not working other one will supply the power to the load.

9. CONCLUSION

This paper presents analysis and working methods of IBSPFC and QSC based IBSPFC. With this proposed connection of boost converter and fly back converter, the observations made are low switch voltage stress, tight voltage regulation with which the efficiency is improved. For the input voltage levels of 25 V, 50 V an output voltage of 100 V is obtained with the help of developed proto type which produces an output power of 100 w at switching frequency of 100 KHz. The converter has the ability to operate at 200 w also. The applications of this developed model are battery charging and series connection LED drives etc. With the combination of IBSPFC with QSC, the efficiency of the convertor increases that i.e. 91% and because of soft switching used in QSC helps to increase overall converter efficiency.

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