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Design of Single-Stage Balanced Forward-Fly back Converter

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ABSTRACT: In this paper, we study about fly back and forward converter analysed it and calculate power factor and efficiency of both the converters. The fly back converter gives good power factor but efficiency is low because of transformer magnetic inductor, which results large core loss which gives less efficiency. The forward converter has good efficiency but the power factor is low because of the input current dead zone near zero cross AC input voltage deteriorates the power factor. To overcome all such problem, and to achieve high power factor and high efficiency by comparing the advantages of fly back and forward converter we proposed a converter called single-stage balanced forward-flyback converter. This proposed converter operates in both modes forward and fly back. So the losses will be decreased and current zero crossing near input side will be decreased by the balancing capacitor. The power transfer will be efficient in the proposed converter by which we get high efficiency and high power factor. We operate the proposed converter, theoretical analysis and experimental results from a prototype of 24W resistive load is presented.

KEYWORDS: Single-stage, Forward, Flyback converter and Proposed forward-fly back converter with Resistive load.

I.INTRODUCTION

Fly back converter is dc-dc converter which is widely used in regulated switch-mode dc power supplies and in dc motor drive applications. It is originated from buck-boost converter. Often, the input to this converter is an unregulated dc voltage, which is obtained by rectifying the line voltage and therefore, it will fluctuate due to changes in the line voltage magnitude. Switch-mode, dc-to-dc converters are used to convert the unregulated dc input into a controlled dc output at a desired voltage level. The name “flyback converter” is descriptive of the inductive energy flyback action typically encountered in this type of converter operation.Fly-back converter is the most commonly used SMPS circuit for low output power applications where the output voltage needs to be isolated from the input main supply. The output power of fly-back type SMPS circuits may vary from few watts to less than 100 watts. Input to the circuit is generally unregulated dc voltage obtained by rectifying the utility ac voltage followed by a simple capacitor filter.In respect of energy-efficiency, fly-back power supplies are inferior to many other SMPS circuits but its simple topology and low cost makes it popular in low output power range.

Forward converter is originated from buck converter.The commonly used fly-back converter requires a single controllable switch like, MOSFET and the usual switching frequency is in the range of 100 kHz.Forward converter is another popular switched mode power supply (SMPS) circuit that is used for producing isolated and controlled dc voltage from the unregulated dc input supply. The energy is temporarily stored with the flyback converter before it is transferred to the secondary side, in the forward converter; energy is transferred directly between the primary and secondary sides.The forward converter, when compared with the fly-back circuit, is generally more energy efficient and is used for applications requiring little higher power output (in the range of 100 watts to 200 watts). However the circuit topology, especially the output filtering circuit is not as simple as in the fly-back converter.The transformer used in the forward converter is desired to be an ideal transformer with no leakage fluxes, zero magnetizing current and no losses.

By comparing the advantages of both the converters, proposed a converter called single-stage balanced forward-flyback converter, it can operate as the forward and flyback converters during switch turn-on and off periods, respectively.

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Therefore, it cannot only perform the power transfer during an entire switching period but also achieve the high power factor. And when the switch is off the proposed converter perform the forward operation regardless of the input voltage, the magnetizing inductor offset current, core loss and transformer size can be minimized to achieve high efficiency.

II.OPERATIONAL PRINCIPLES

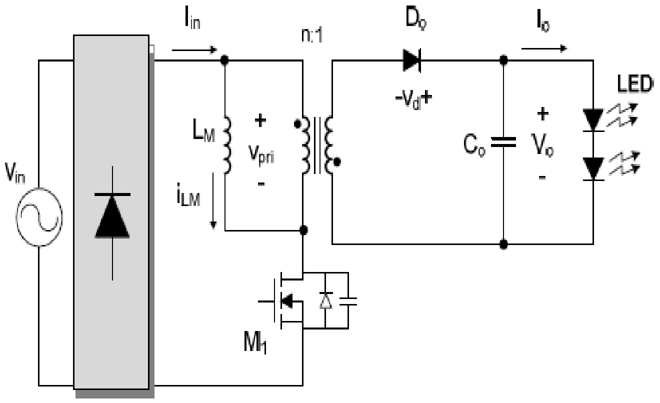

Fig. 1 Single-stage flyback converter

The circuit for conventional flyback converter is shown in fig. 1. Conventional flyback converter has input as $V_{in,}$ diode rectifier, magnetizing inductor, Mosfet switch M_1, transformer with n: 1 ratio, diode D_O, and capacitor C_O with LED as load which is resistive load. While the flyback converter can transfer the input energy to the output side over an entire range of input voltage, the forward converter cannot at lower input voltage than the reflected output voltage nV_O to the transformer primary side. This is because the forward converter is originated from the step-down buck topology.

Therefore, the input current dead zone near zero cross AC input voltage is always observed and deteriorates the power factor in the forward converter. Therefore, the flyback converter is superior to the forward converter in terms of the power factor performance.

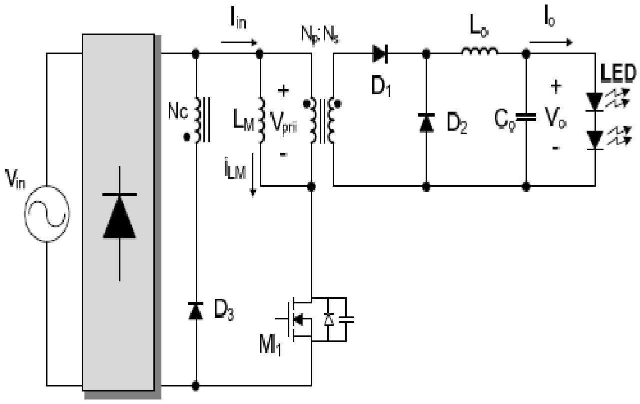

Fig. 2 single-stage forward converter

The circuit for conventional forward converter is shown in fig. 2. Conventional forward converter has input as $V_{in,}$ diode rectifier, magnetizing inductor, Mosfet switch M_1, transformer with N_p:N_s:N_c ratio, diodes D_1,D_2, and D_3 and capacitor C_O with LED as load which is resistive load. The magnetizing inductor offset current of flyback converter is larger than the forward converter. While the magnetizing inductor offset current of flyback converter is dependent on load current I_O, that of forward converter is not. Therefore, as the load current is more increased, the offset current of flyback converter becomes larger, which might result in the larger core loss and volume of transformer. For these reasons, the forward converter is superior to the flyback converter in terms of the transformer size and energy conversion efficiency.

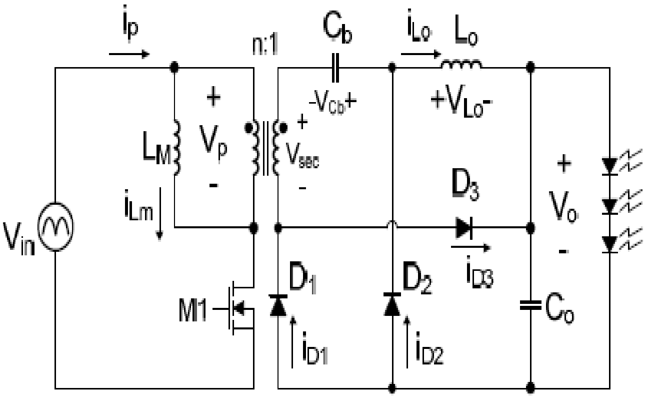

Fig. 3 Circuit diagram of the proposed forward-flyback converter

The circuit for proposed forward-flyback converter is shown in fig. 3. Its primary side is exactly same as that of the conventional flyback converter consisting of one power switch (M_1) and one transformer.On the other hand, its secondary side consists of one outputinductor (L_o) for forward operation, one DC blocking capacitor (C_b) for balancing operation and three output Diodes (D_1, D_2, D_3).When M_1 is conducting, the proposed converter operates as a forward converter as shown in Fig. 3. On the other hand, when M_1 is blocked, the proposed converter operates as a flybackconverter.If the balancing capacitor C_b is serially inserted with the transformer secondary side, it can make theaverage current through C_b during forward operation becomeexactly same as that during flyback operation by the charge balance principle of C_b. In other words, since the voltage across C_b charged by flyback operation is added to the $V_{sec}=V_{in}/n$ during forward operation, $V_{in}/n+V_{cb}$ becomes higher than $V_o$and thus, the forward operation is possible even at $V_{in}/n<V_o$. Therefore, the proposed forward-flyback converter with the balancing capacitor C_b can always operate as both forward and flyback converters regardless of the input voltage.

III.SIMULATION AND EXPERIMENTAL RESULTS

The simulation model of conventional flyback converter with resistive load and input voltage as V_{in} = 90V_{rms}.

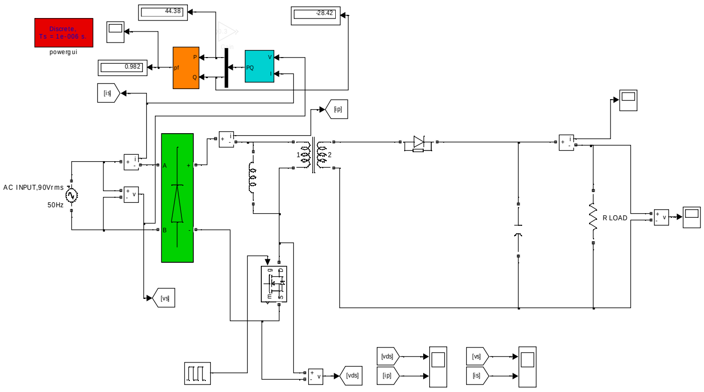

Fig. 4 Simulation Model of Fly back Converter (V_{in}= 90V_{rms})

The above fig. 4 is the simulation model of flyback converter. Display block shows the power factor of the flyback converter which is 0.982 at input side of the flyback converter. The power factor of flyback converter is good.

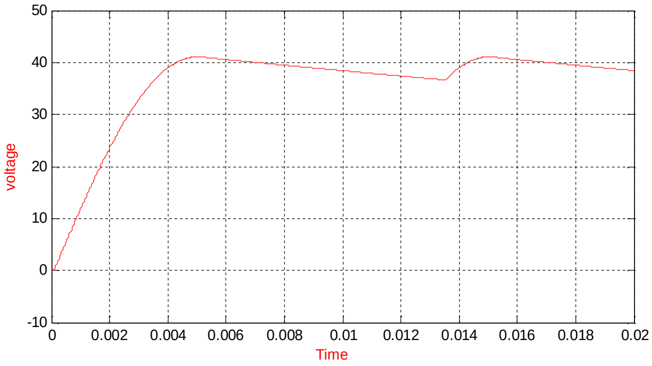

Fig. 5 Output voltage (V_O) waveform of flyback converter

Output voltage of the flyback converter V_o=41.0785volts, it use for the calculation of output power which is required for the calculation of efficiency for flyback converter.

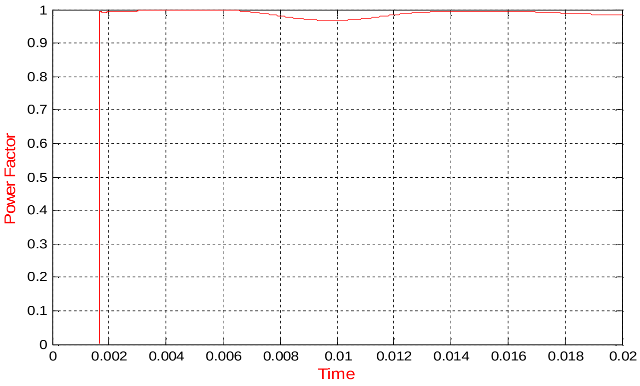

Fig. 6 Power factor of flyback converter

The above fig. 6 shows the power factor of flyback converter with respect to time. And the power factor of flyback converter is good.

Calculation of Efficiency for Fly back Converter:

At Input side AC,

Input Power $P_{IN} = \sqrt{P^2+Q^2}$ …... (1)

Where P_{JN} = Input power (or)apprent power

P = Active power

Q = Reactive power

From fig. 4 P = 44.38watts, Q = -28.42watts

Substitute the P & Q values in equation (1)

We get$P_{IN} = \sqrt{(44.38)^2 + (28.42)^2}$ = 52.69

At Output side DC,

Output Power $P_O = \frac{V^2}{R_L}$ …... (2)

Where V = Output voltage

$R_L = Load\ Resistance$

From fig 5 and Table 1

V = 41.0785volts, $R_L = \frac{42^2}{24}$= 73.5ohms

Therefore, Output Power $P_O = \frac{V^2}{R_L} = \frac{(41.0785)^2}{73.5} = 22.9520\text{watts}$

Now efficiency $\eta = \frac{Output\ power}{Input\ power} \times 100$

$$\eta = \frac{P_O}{P_{IN}} \times 100$$

$= \frac{22.9520}{52.69} \times 100 = 43.55\%$. (Efficiency is low, Power factor is high.)

The simulation model of conventional forward converter with resistive load and input voltage as Vin = 90Vrms**.**

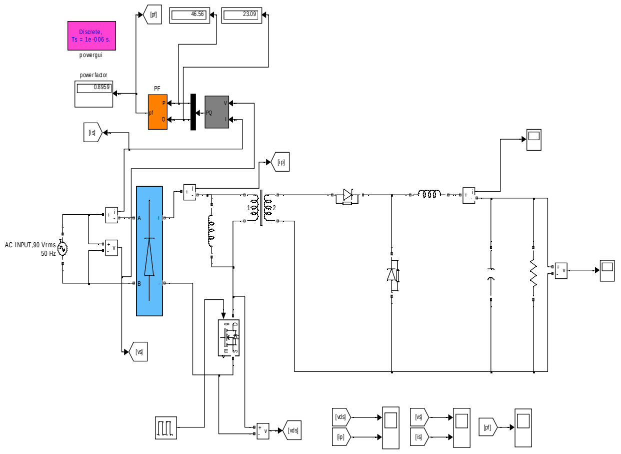

Fig. 7 Simulation Model of Forward Converter (V_{in}= 90V_{rms})

The above fig. 7 is the simulation model of forward converter. Display block shows the power factor of the flyback converter which is 0.8959 at input side of the forward converter. The power factor of forward converter is not good.

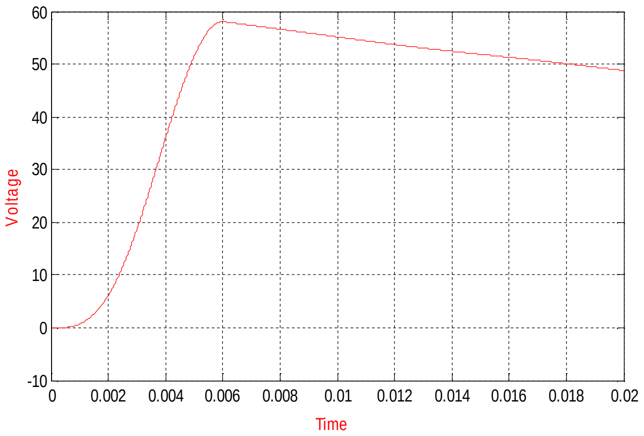

Fig. 8 Output voltage (V_O) waveform of forward converter

Output voltage of the forward converter V_o = 58.03volts, it use for the calculation of output power which is required for the calculation of efficiency for forward converter.

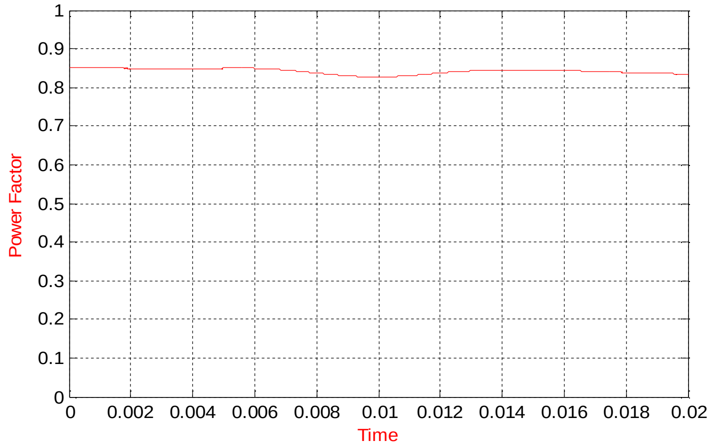

Fig. 8 Power factor for Forward converter

The above fig. 8 shows the power factor of forward converter with respect to time. And the power factor of forward converter is not good.

Calculation of Efficiency for Forward Converter:

At Input side AC,
Input Power $P_{IN} = \sqrt{P^2+Q^2}$ …… (3)
Where P_{JN} = Input power (or)apprent power
P = Active power
Q = Reactive power
From fig.7, P = 46.56watts, Q = 23.09watts
Substitute the P & Q values in equation (3)
We get $P_{IN} = \sqrt{(46.56)^2 + (23.09)^2}$ = 51.97watts
At Output side DC,
Output Power $P_O = \frac{V^2}{R_L}$ …… (4)
Where V = Output voltage
R_L = *Load Resistance*

From fig.8 and Table 1

V = 58.03volts, $R_L = \frac{42^2}{24}$= 73.5ohms

Therefore, Output Power $P_O = \frac{V^2}{R_L} = \frac{(58.03)^2}{73.5} = 45.81$watts

Now efficiency $\eta = \frac{Output\ power}{Input\ power} \times 100$

$$\eta = \frac{P_O}{P_{IN}} \times 100$$

$$= \frac{45.81}{51.97} \times 100 = 88.15\%$$. (Efficiency is high, Power factor is low.)

To confirm the validity of the operational principles and theoretical analysis of the proposed converter, a laboratory prototype applicable to the LED driver was implemented andtested with the following specifications.

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TABLE 1.SPECIFICATIONS OF LABORATORY PROTOTYPE

Parameters	Symbol	Value
Input Voltage	V_{in}	$90V_{rms} - 240V_{rms}$
Output Power	P_O	24W(42V/0.57A)
Load resistance	R_L	(42^2)/24
Trans. Turn ratio	$N_P : N_S(n:1)$	82:27(3:1)
Magnetizing Inductance	L_M	1.8mH
Output Inductance	L_O	100uH
Control Method		BCM
Control IC		SN03A
Output Diode	D_1, D_2, D_3	SB 560*2ea/UF5404

The above table shows the parameters and rated values of the proposed forward-flyback converter. Based on these values simulation has been done and calculation of efficiency and power factor is done.

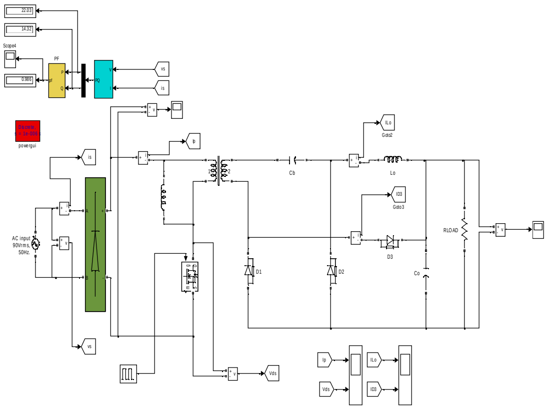

Fig. 9 Simulation Model of Proposed Forward-Fly back Converter

The above fig. 9 is the simulation model of proposed forward-flyback converter. Display block shows the power factor of the proposed forward-flyback converter which is 0.986 at input side of the proposed forward-flyback converter. The power factor of proposed forward-flyback converter is high which is good enough.

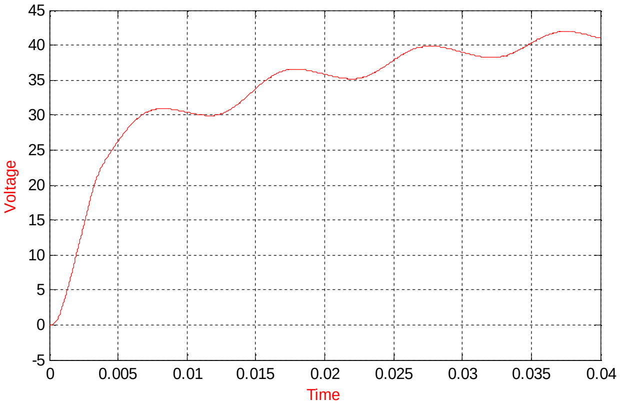

Fig. 10 Output voltage (V_O) waveform of Proposed Forward-Flyback converter

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Output voltage of the proposed forward-flyback converter V_o = 41.94volts, it use for the calculation of output power which is required for the calculation of efficiency for proposed forward-flyback converter.

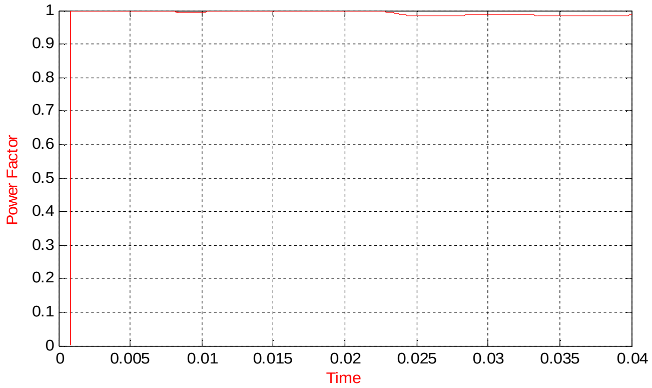

Fig. 11 Power Factor for Proposed Forward Fly back converter

The above fig. 11 shows the power factor of proposed forward-flyback converter with respect to time. And the power factor of proposed forward-flyback converter is high which is good enough for the power transfer in circuit.

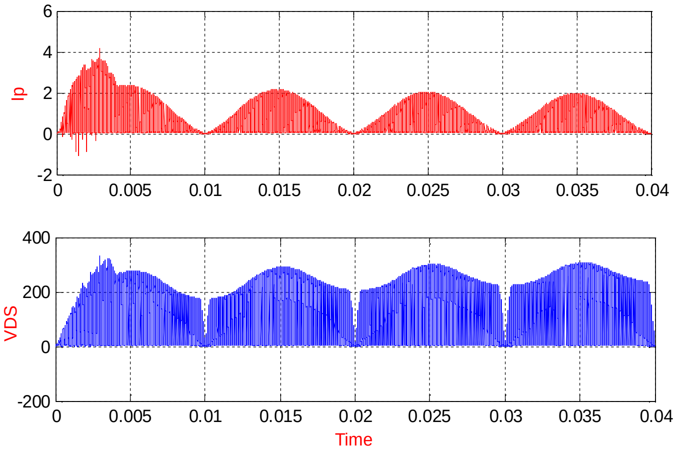

Fig. 12 Primary currentI_P and Mosfet voltage V_{DS}

Since the average current I_{sec} of transformer secondary side is zero due to the serially connected balancing capacitor C_b, the offset current I_{LM} though L_M is equal to the average primary current I_p.The offset current of transformer magnetizing inductor generally determines the volume and core loss of the transformer. Therefore, the smaller offset current of L_M is the better. The offset current I_{LM} though transformer magnetizing inductor L_M can be calculated by the sum of average primary current I_p and reflected average secondary current I_{sec}/n to the transformer primary side. When M_1 is turned off, the voltage V_{DS} across M_1 is the sum of input voltage V_{in} and reflected voltage $n(V_o+V_{cb})$ to the transformer primary side. The higher turn ratio can moredecrease the diode voltage stress but more increase the switch voltage stress, and vice versa. Especially, the switch voltage stress of the proposed converter is somewhat higher than that of the conventional one due to the balanced capacitor voltage V_{cb}. Therefore, in designing the transformer turn ratio, the switch voltage stress must be carefully considered.

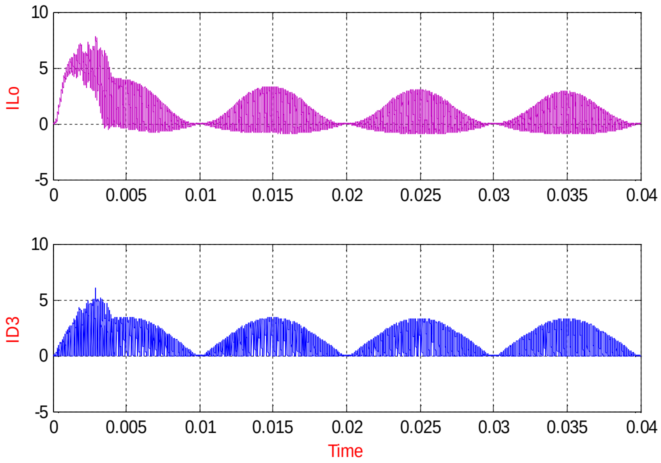

Fig. 13 Output Inductance currentIL_0 and Diode ID_3current

The experimental waveforms ofoutput inductor current I_{Lo} and output diode current I_{D3} at90V_{rms} respectively, where I_{Lo} corresponds to the forward operating current and I_{D3} flyback operating current. As can be seen in the above fig. 13, $I_{Lo}$and I_{D3} continuously flow even at the low input voltage, which proves that the proposed forward-flyback converter can always operate as both forward and flyback converters regardless of the input voltage.

Calculation of Efficiency for Proposed Forward-Fly back Converter:

At Input side AC,

Input Power $P_{IN} = \sqrt{P^2+Q^2}$ …... (5)

Where P_{IN} = Input power (or)apprent power

P = Active power

Q = Reactive power

From fig. 9 P = 22.08watts, Q = 14.32watts

Substitute the P & Q values in equation (5)

We get$P_{IN} = \sqrt{(22.08)^2 + (14.32)^2}$ = 26.2751watts

At Output side DC,

Output Power $P_O = \frac{V^2}{R_L}$ …... (6)

Where V = Output voltage

$R_L = Load\ Resistance$

From Table 1 and fig. 10

V = 41.94volts, $R_L = \frac{42^2}{24}$= 73.5ohms

Therefore, $P_O = \frac{V^2}{R_L} = \frac{(41.94)^2}{73.5} = 23.760$watts

Now efficiency η = $\frac{Output\ power}{Input\ power} \times 100$

$\eta = \frac{P_O}{P_{IN}} \times 100$

$= \frac{23.760}{26.2751} \times 100 = 90.42\%$. (Efficiency is high, Power factor is high.)

IV.CONCLUSION

The below table shows the calculation of power factor and efficiency for forward, flyback and proposed forward-flyback converter. And when compare the efficiency and power factor of forward and flyback converter with the proposed forward-flyback converter. Therefore the proposed forward-flyback converter has high efficiency and high power factor.

TABLE 2 COMPARISON OF POWER FACTOR AND EFFICIENCY OF FORWARD, FLY BACK AND PROPOSED FORWARD-FLY BACK CONVERTER.

Converters	Power factor	Efficiency
Forward converter with R-load $V_{IN} = 90V_{RMS}$	0.8959	88.15%
Fly back converter with R-load $V_{IN} = 90V_{RMS}$	0.9825	43.55%
Proposed Forward-Flyback converter with R-load $V_{IN} = 90V_{RMS}$	0.9864	90.42%

A single stage power-factor-correction balanced forward-flyback converter for resistive load application is presented, and itsoperation principle analyzed in this paper. The proposed forward-flyback converter with the balancing capacitor can always operate as both forward and flyback converters regardless of the input voltage. Therefore, it has a smaller magnetizing offset current, resultant smaller core loss and more reduced transformer core volume. For this reason, theproposed converter can be obtained high efficiency and high power factor.

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