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Parallel-Primary Series-Secondary Flyback Converter with Stepped-Up Output Voltage

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***Abstract*— In the present paper, a converter in which two flyback converters with their secondary windings connected in series, is presented. Irrespective of inductor currents on primary sides, the current on secondary side are same as a result of which series combination of these does not affect the current wave on output side. The secondary voltages added together, is rectified to produce output voltage which results in higher value of later. Here, both of the secondary sides require only one diode and one capacitor at output side which eliminates the need of separate components for each sub-converter. Also at the input, single switch serves the purpose of connecting input supply to the converter. The sharing of power between the sub-converters is adjusted according to the output voltages of sub-converters. A converter with output rating of 36 W at 36 V, is presented for validation of the performance of the proposed circuit.**

***Index Terms*— parallel-input, series-output, stepped-up voltage, magnetizing inductance, power sharing.**

I. INTRODUCTION

Series connected outputs are useful for obtaining larger total output voltage while, on other hand, in parallel connection the current carrying capability of a converter, increases. Flyback converter is a basic topology which can be modified to yield different converters as mentioned in [1, 2]. In addition, many other structures are also presented that are found suitable for flyback converters [3, 4]. There are a number of structures where the outputs of different sub-converters are combined in series. Some of the common difficulties faced in such cases include complexity in control element, control of separate output, sharing of power etc. all such problems are addressed in [5]-[8]. In almost all the cases the main disadvantage is larger number of components and the complexity in the converter circuits. It, therefore, becomes necessary to ensure the component count to be as low as possible. In order to mitigate this problem, the idea here is to have a flyback converter having secondary windings themselves in series, to get larger output voltage. Contrary to the converters existing previously, where separate components for each sub-converters are used, only one diode and one output capacitor for all the secondary windings is required, resulting in compact size and reduced cost of the proposed converter. Next, apart from present section, rest of the paper is organized as follows:

In section 2, the proposed circuit is described and its operation is given by section 3. Mathematical analysis is presented in section 4. In section 5, the simulation is conducted and the essential waveforms are depicted. At last, the result and scope of further improvement, is presented in section 6.

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II. CIRCUIT DESCRIPTION

The proposed circuit is shown in figure. 1. In it, there are two flyback sub-converters whose secondary windings are combined in series and supplies power to the load, simultaneously. At the output side, a diode Df and a capacitor Co, are employed. The secondary voltages of the sub-converters are combined in series and the resultant of these is rectified and the output voltage is produced at the load.

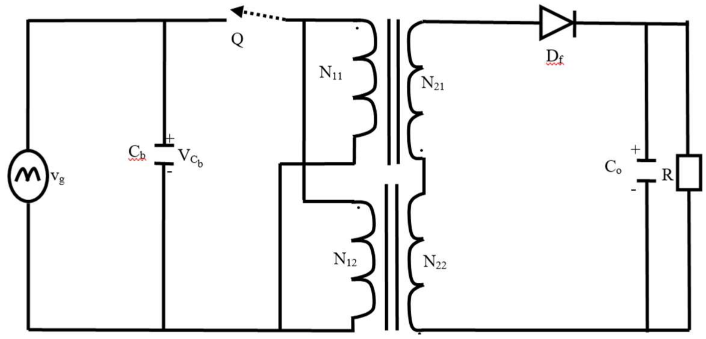

Figure 1. The Proposed Converter

III. OPERATION

In a switching cycle, the operation consists of following stages:

Stage I ($t_0 \leq t \leq t_1$). This stage begins when Q turns on at t= t_0, as a result of which the current begins to flow through primary windings of both the transformers. At the output side, the current to the output is supplied by output capacitor C_o. At t = t_1, Q turns off. Equivalent circuit for the same is shown in figure 2 (a).

Stage I I ($t_1 \leq t \leq t_2$). At t = t_1, the magnetic energy stored in the inductors of the transformers on primary sides are redistributed and results in the beginning of flow of current through the output load via secondary windings. At t = t_2, the energy stored in the inductors in exhausted and hence the current through secondary windings fall to zero, as depicted by equivalent circuit in figure 2 (b).

Stage I I I ($t_2 \leq t \leq t_3$). During this stage, the output power is supplied by C_o only. At t = t_3, this stage ends when Q turns on again. The equivalent circuit is shown in figure 2 (c).

The current waveforms in a switching cycle are depicted in figure 3.

IV. ANALYSIS

The currents through primary sides of the transformer as the switch turns on, are;

$$i_{L_{1p}} = \frac{v_g(t-t_0)}{L_1} \quad (1)$$

$$i_{L_{2p}} = \frac{v_g(t-t_0)}{L_2} \quad (2)$$

The peak currents through the inductors on primary sides are;

$$i_{L_{1ppk}} = \frac{v_g D_1 T_S}{L_1} \quad (3)$$

$$i_{L_{2ppk}} = \frac{v_g D_1 T_S}{L_2} \quad (4)$$

If peak value of current through series connected secondary windings is i_{L_p}, by conservation of energy principle;

$$\frac{1}{2}(n_{21}^2 L_1 + n_{22}^2 L_2) i_{L_p}^2 = \frac{1}{2} L_1 i_{L_{1ppk}}^2 + \frac{1}{2} L_2 i_{L_{2ppk}}^2 \quad (5)$$

Simplifying (5);

$$i_{L_p} = \sqrt{\frac{L_1 i_{L_{1p}}^2 + L_2 i_{L_{2p}}^2}{(n_{21}^2 L_1 + n_{22}^2 L_2)}} \quad (6)$$

L_1 and L_2 may have different values, due to this the peak currents on secondary sides are expected to have different values. The peak currents on secondary sides are;

$$i_{L_{1spk}} = \frac{v_g D_1 T_s}{n_{21} L_1} \quad (7)$$

$$i_{L_{2spk}} = \frac{v_g D_1 T_s}{n_{22} L_2} \quad (8)$$

The currents through secondary vary and finally reach an equilibrium value. These are;

$$i_{L_{1s}} = i_{L_{1s}} \quad - \frac{V_o(t-t_1)}{n_{21}^2 L_1} \quad (9)$$

$$i_{L_{2s}} = i_{L_{2spk}} + \frac{V_o(t-t_1)}{n_{22}^2 L_2} \quad (10)$$

The instant when the currents given by (9) and (10) attain the equilibrium as in (6) is;

$$\frac{v_g D_1 T_s}{n_{21} L_1} - \frac{V_o(t-t_1)}{n_{21}^2 L_1} = \frac{v_g D_1 T_s}{n_{22} L_2} + \frac{V_o(t-t_1)}{n_{22}^2 L_2} \quad (11)$$

This gives;

$$v_g D_1 T_s \left(\frac{1}{n_{21} L_1} - \frac{1}{n_{22} L_2}\right) = V_o(t - t_1)\left(\frac{1}{n_{21}^2 L_1} + \frac{1}{n_{22}^2 L_2}\right) \quad (12)$$

From (12);

$$t - t_1 = \frac{v_g D_1 T_s \left(\frac{1}{n_{21} L_1} - \frac{1}{n_{22} L_2}\right)}{V_o \left(\frac{1}{n_{21}^2 L_1} + \frac{1}{n_{22}^2 L_2}\right)} \quad (13)$$

At this instant;

$$\frac{v_g D_1 T_s}{n_{21} L_1} - \frac{V_o(t-t_1)}{n_{21}^2 L_1} = \sqrt{\frac{L_1 i_{L_{1ppk}}^2 + L_2 i_{L_{2ppk}}^2}{n_{21}^2 L_1 + n_{22}^2 L_2}} \quad (14)$$

From (13) and (14);

$$\frac{v_g D_1 T_s}{n_{21} L_1} - \frac{v_g D_1 T_s \left(\frac{1}{n_{21} L_1} - \frac{1}{n_{22} L_2}\right)}{n_{21}^2 L_1 \left(\frac{1}{n_{21}^2 L_1} + \frac{1}{n_{22}^2 L_2}\right)} = \sqrt{\frac{L_1 i_{L_{1ppk}}^2 + L_2 i_{L_{2ppk}}^2}{n_{21}^2 L_1 + n_{22}^2 L_2}} \quad (15)$$

Substituting the peak values from (3) and (4);

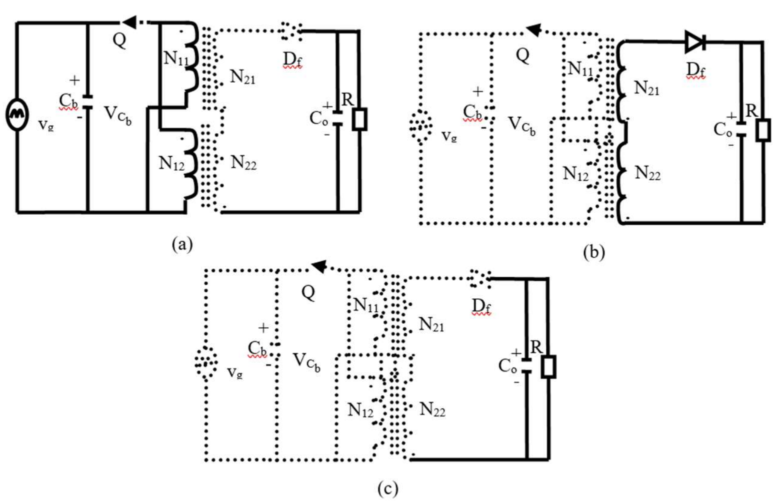

Figure 2. Equivalent circuits in different stages

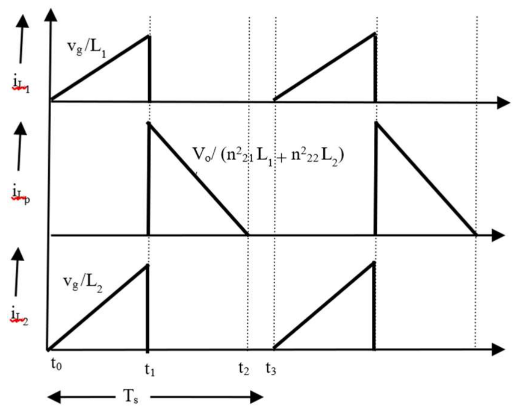

Figure 3. Current waveforms in a switching cycle

$$\frac{1}{n_{21}L_1}-\frac{(\frac{1}{n_{21}L_1}-\frac{1}{n_{22}L_2})}{n_{21}^2L_1(\frac{1}{n_{21}^2L_1}+\frac{1}{n_{22}^2L_2})}=\sqrt{\frac{(\frac{1}{L_1}+\frac{1}{L_2})}{n_{21}^2L_1+n_{22}^2L_2}} \quad (16)$$

Simplifying (16);

$$\frac{n_{21}+n_{22}}{n_{21}^2L_1+n_{22}^2L_2}=\sqrt{\frac{(\frac{1}{L_1}+\frac{1}{L_2})}{n_{21}^2L_1+n_{22}^2L_2}} \quad (17)$$

Squaring (17) and simplifying;

$$2(n_{22}L_2-n_{21}L_1)^2=0 \quad (18)$$

From (18);

$$\frac{L_2}{L_1}=\frac{n_{21}}{n_{22}} \quad (19)$$

Output power is shared by the sub-converters. If output power be P_o then the amounts of powers supplied by the converters are;

$$P_{o1}=\frac{V_{o1}}{V_{o1}+V_{o2}}P_o \quad (20)$$

and

$$P_{o2}=\frac{V_{o2}}{V_{o1}+V_{o2}}P_o \quad (21)$$

V_{o1} and V_{o2} are the secondary voltages of the sub-converters.

A. Determination of Inductances

Assuming 100% efficiency, the powers shared by the sub-converters on input side are;

$$P_{o1}=\frac{V_m^2D_1^2T_s}{4L_1} \quad (22)$$

Simplifying (20) and (22);

$$L_1=\frac{V_m^2D_1^2T_s(V_{o1}+V_{o2})}{4P_oV_{o1}} \quad (23)$$

$$P_{o2}=\frac{V_m^2D_1^2T_s(V_{o1}+V_{o2})}{4L_2} \quad (24)$$

Similarly, from (21) and (24);

$$L_2=\frac{V_m^2D_1^2T_s}{4P_oV_{o2}} \quad (25)$$

From (23) and (25), the inductors are determined.
A converter of 36 W at 36 V is considered. The components required are listed in Table I.

TABLE I. LIST OF COMPONENTS

Symbol	Description	Value	Unit
V_{rms}	Input ac voltage	220	V
L_f	Input filter inductance	5	mH
C_f	Input filter capacitance	0.2	μF
C_b	Bulk capacitance	1	μF
L_1	Magnetizing inductance of first flyback transformer	4936	μH
L_2	Magnetizing inductance of second flyback transformer	2468	μH
$n_{21}=N_{21}/N_{11}$	Turns' ratio first flyback transformer	0.072	-
$n_{22}= N_{22}/N_{12}$	Turns' ratio second flyback transformer	0.144	-
V_{o1}	Secondary voltage of first flyback transformer	12	V
V_{o2}	Secondary voltage of second flyback transformer	24	V
V_o	Output voltage	36	V
D_1	Duty cycle	0.35	-
f_s	Switching frequency	50	kHz
C_o	Output filter capacitor	4700	μF

V. SIMULATION

The simulation results are depicted in figures 4 (a) and 4 (b). A proportional plus integral (PI) controller is employed for the regulation of the output of the converter. The obtained results are in close vicinity with their expected values.

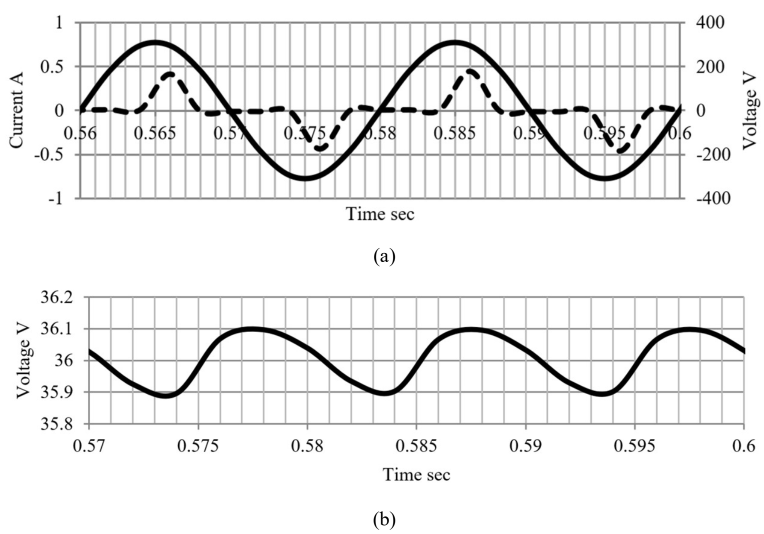

Figure 4. Simulation waveforms: (a) input voltage and current (b) output voltage

VI. CONCLUSIONS AND DISCUSSION

A combination of two flyback sub-converters with their secondary windings combined in series is found to exhibit the desired result. With properly designed transformers, the currents through the secondary windings of the transformers are rendered equal irrespective of difference in currents on primary sides. The glitches on the currents on secondary sides are absent. The output voltage is high compared with a single converter. With the success of present idea, in the future, for larger output voltage, combination of more than two sub-converters will be tested with the emphasis of design of the control part of the converter circuit.

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