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Series-Input-Connected Flyback-Forward Converter with Enlarged Duty Cycle

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***Abstract*—In this paper, a structure consisting of combination of a flyback and a forward converter capable of making the power switch conduct at wide duty cycle, is presented. The configuration suggested employs sub-converters having their inputs combined in series with each other. In a forward converter, the maximum duty cycle by conventional manner becomes insufficient to utilize the isolation transformer, optimally. Under such condition, it becomes more important to extend the duty cycle, further. Bearing its importance and need in mind, present scheme is employed. By combining a forward with a flyback sub-converter in such a way that the inputs to both the sub- converters are in series, very wide switch duty cycle is obtained. The sub-converters are named as modules, and these are combined with their inputs connected in series with each other. A forward sub-converter is essentially a main module while flyback module is treated as auxiliary module. The configuration consisting of two modules is proposed and examined for the establishment of the results. The duty cycle for the switch has been extended to the expected level. For the validation of the performance, a 24 W, 24 V converter is presented.**

***Index Terms*— series-input, parallel-output, main module, auxiliary module, enlarged duty cycle, magnetization and demagnetization.**

I. INTRODUCTION

The need of extended duty cycle in a forward converter is essential for optimum utilization of the transformer core. Converters based on non-cascading structures, reported in [1-8], can be employed for widening of duty cycle. In [9], how the switch duty cycle in a forward converter, by way of demagnetization through secondary side, is presented. In [10], extended switch duty cycle has been realized through a non-cascading structure based operation of the converter. But the stress on the main power switch is more which needs to be reduced to minimum value. A novel scheme based on so called flyboost cell is presented in [11] which when modified becomes suitable for the widening of the duty cycle in any converter. The converters based on non-cascading structures are reported [12-14] but their sole purpose is not widening duty cycle. However, under some circumstances, these are found suitable for use in widening of duty cycle also. But it is observed in these cases that the voltage stress on main switch becomes high.
As an alternative to the mentioned methodologies if the configuration is modified to have the inputs connected in series, the problem of excessive voltage stress on the switch can be overcome. A list of different series input based converters given in [15-21] has proved that this class is no less important than non-cascading structure

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based class is. In most of the cases, however, the main problem faced is the occurrence of circulating current between the input capacitors. A suitable analysis for the same is presented in [15]. Thus, keeping the problem of circulating current aside, the analysis of the converter becomes simple. Now, by increasing the number of modules, the duty cycle can be extended with the switch stress reducing further and further with increasing number of modules. Thus, it appears that this is a much useful scheme for extending duty cycle and also for stepping-up the output voltage. The overall efficiency of the converter also improves. Basic idea lying behind the proposed approach is based on the magnetization and demagnetization processes for isolation transformer in a forward converter. In a conventional forward converter, both actions take place at same voltage level. If, by anyway, the voltage levels become different, the duty cycle gets affected. To render the duty cycle, wide, it is essential that the demagnetization of the transformer core should take place at higher voltage than at which the magnetization occurs. More is the difference between the two voltages wider will the duty cycle be. The same fact is the basis of design of the said configuration and the maximum switch duty cycle has been found extending beyond 0.5. The description of the same is presented here asunder through different heads.

II. Circuit Description And Operating Principles

The circuit of the proposed converter is shown in Fig. 1. It consists of a forward sub-converter, which is to be operated at wide duty cycle, and a flyback sub-converter connected in series with the forward sub-converter. In addition to a main switch, S two power switches S_1 and S_2 are connected with each sub-converter, to supply the power to the load. Both of the switches are turned on simultaneously through PWM scheme. The outputs of the sub-converters are connected in parallel.

The rectified DC supply voltage on main bulk capacitor, C, is shared by the two sub-converters with the help of input capacitors C_1 and C_2. The magnetization circuit of forward transformer consists of tertiary winding consisting of turns N_{31}, capacitor C_1 and a diode, D_3. The demagnetization takes place through main capacitor, C. The circuit operation in a switching cycle consists of following stages:

Stage □ $\left(t_0 \le t \le t_1\right)$. At $t = t_0$, when all the switches turn on, the current flows as shown in the equivalent circuit in Fig. 2 (a). At the end of this stage, the switches turn off.

Stage □ $\left(t_1 \le t \le t_2\right)$. The equivalent circuit for this stage is shown in Fig. 2 (b). The power to the output is supplied by all the modules, partially. Also the demagnetization of the forward transformer takes place through input supply. At t = t_2, the output inductor L_o is fully discharged of its stored energy.

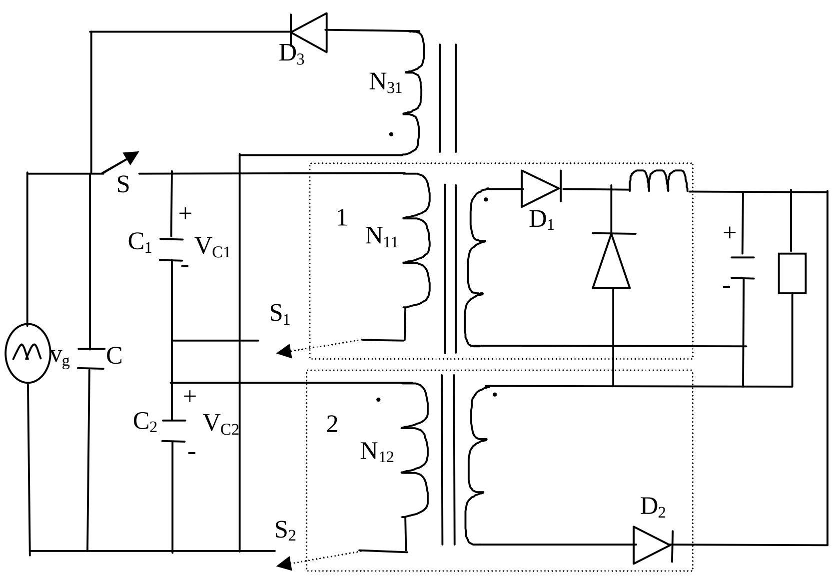
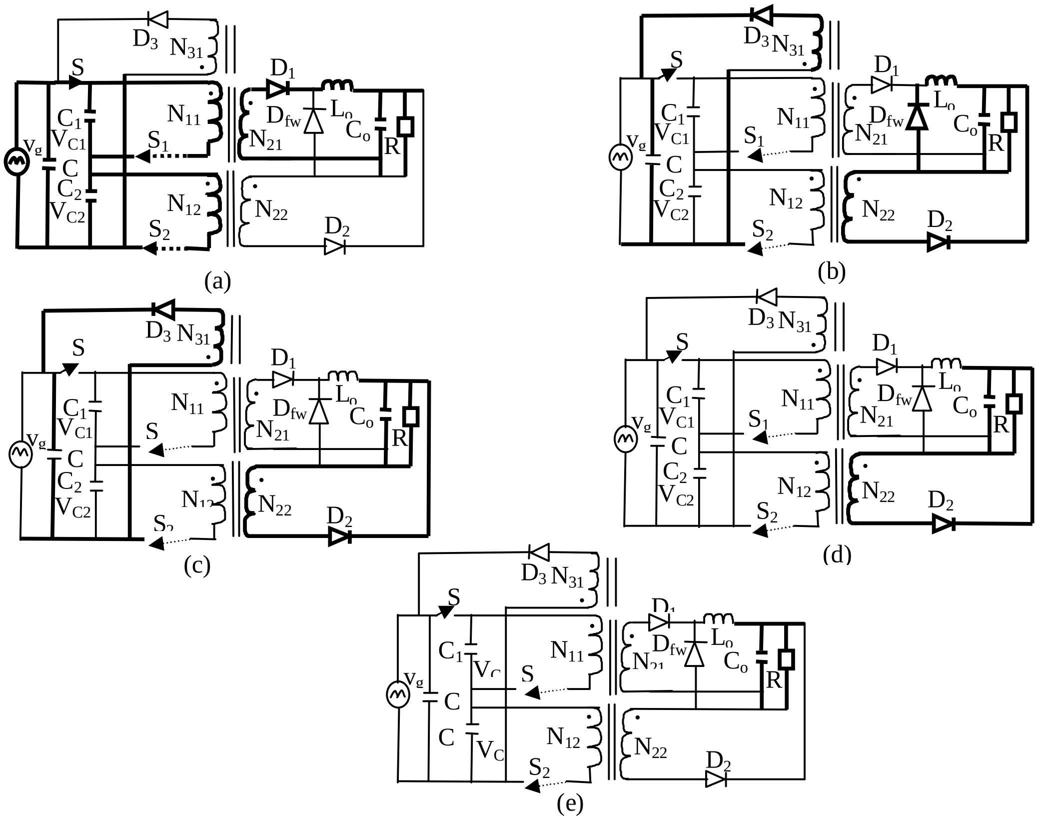


Figure 1: The proposed converter

Stage □ $\left(t_2 \le t \le t_3\right)$. After L_o is discharged the equivalent circuit is shown in Fig. 2 (c). The inductor L_m is fully discharged at the end of third stage.



Figures 2 (a)- 2(e): Equivalent circuits for different stages

Stage □ $(t_3 \le t \le t_4)$. The power to the output is being supplied by inductor L_1. The equivalent circuit for the same is given in Fig. 2(d). L_1 is fully discharged at $t = t_4$.

Stage □ $(t_4 \le t \le t_5)$. During this last stage only the output capacitor, C_o supplies power to the load until $t = t_5$ when the next switching cycle begins. The equivalent circuit is given in Fig. 2 (e).

The associated voltage and current waveforms in a switching cycle are shown in Fig. 3.

III. Analysis

Assuming maximum efficiency, the input current is given as;

$$I_{inrms} = \frac{P_{in}}{V_{inrms}}. \qquad (1)$$

The average bulk capacitor voltage is;

$$V_C = \frac{V_{Cmax}+V_{Cmin}}{2} = \frac{P_{in}}{I_{inrms}}. \qquad (2)$$

For the selection of bulk *c*apacitor;

$$C\frac{{V_{Cmax}}^2-{V_{Cmin}}^2}{2}2f_L = P_{in}. \qquad (3)$$

The magnetizing inductance, L_m of forward transformer is charged due to voltage V_{C_1} during the switch turn on period and discharges through voltage V_c during switch turn off period. By volt-second balance for L_m;

$$V_{C_1}d_1 = V_c(d_2 + d_3) \qquad (4)$$

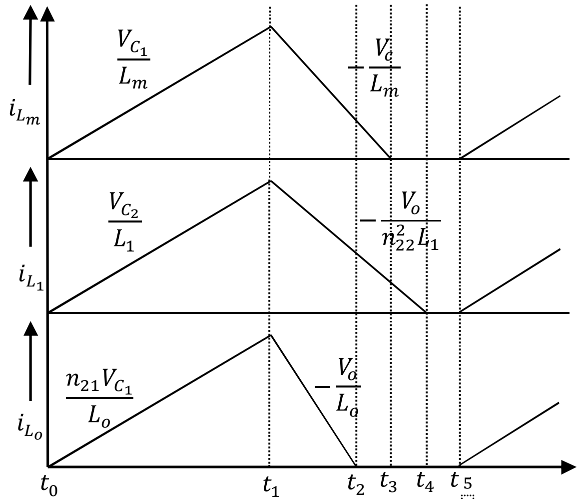


Figure 3: The current and voltage waveforms in a switching cycle

yielding;

$$\frac{d_1}{(d_2+d_3)} = \frac{V_c}{V_{C_1}} \tag{5}$$

From eqn.(5), it is observed that the maximum turn on time of the switch exceeds its turn off time which means the maximum duty cycle exceeds 0.5.

The series capacitor voltages are;

$$V_{C_1} = \frac{C_2 V_c}{C_1+C_2} \tag{6}$$

and

$$V_{C_2} = \frac{C_1 V_c}{C_1+C_2} \tag{7}$$

The powers supplied by the modules are;

$$P_{in_1} = \frac{V_{C_1} P_{in}}{V_c} \tag{8}$$

and

$$P_{in_2} = \frac{V_{C_2} P_{in}}{V_c} \tag{9}$$

A. Selection of Inductors

Output inductor, L_o, is;

$$L_o = \frac{(1-d_{1max}) R_{fw} T_s}{2} \tag{10}$$

The inductor, L_1, of auxiliary module, is;

$$L_1 = \frac{\left(\frac{C_1 V_c}{C_1+C_2}\right)^2 d_1^2 T_s}{4 P_{in_1}} \tag{11}$$

There is no circulating current between the capacitors which means;

$$C_1 \frac{dV_{C_1}}{dt} = C_2 \frac{dV_{C_2}}{dt} \tag{12}$$

The converter currents relate with each other as;

$$i_{L_1} = i_{L_m} + n_{21} i_{L_o} \qquad (13)$$

In (13), the magnetization current is given as;

$$i_{L_m} = \frac{V_{C_1}}{2L_m} d_1^2 T_s \qquad (14)$$

For a 24 Watts, 24 Volts converter, the components list is given in Table I

TABLE I. COMPONENT VALUE SELECTION

Parameter Name	Symbol	Description
Input AC voltage	V_{rms}	220 V
Input filter inductor	L_f	5mH
Input filter capacitor	C_f	2μF
Bulk capacitor	C	6 μF
Series capacitor	C_1	17 μF
Series capacitor	C_2	17 μF
Magnetizing inductance	L_1	7516 μH
Magnetizing inductance	L_m	4050 μH
Output filter inductor	L_o	163 μH
Output filter capacitor	C_o	6600 μF
Turns ratio	$n_{31}=N_{31}/N_{11}$	1:1
Turns ratio	$n_{22}=N_{22}/N_{12}$	0.08:1
Turns ratio	$n_{21}= N_{21}/N_{11}$	0.23:1
Duty cycle	d_1	0.66

IV. SIMULATION

The simulation of the converter circuit has been carried on MATLAB / Simulink platform. The results are depicted in Figs. 4(a) through 4(d). A reference signal of 2.18 volts is employed and a PI controller is used to regulate the output of the converter. Necessary simulation waveforms are shown in the figures. The gate pulse waveforms as displayed in Fig. 4 (c), indicate that the maximum achieved duty cycle is greater than 0.5.

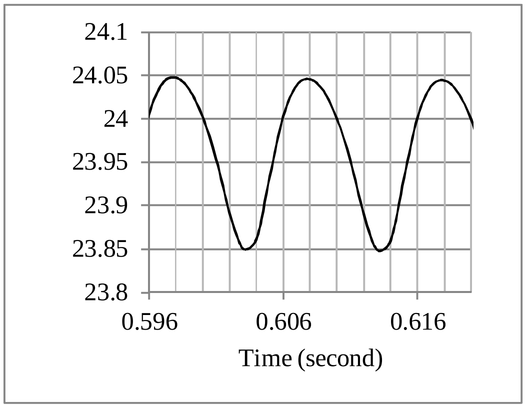


Figure 4 (a). Output voltage waveforms

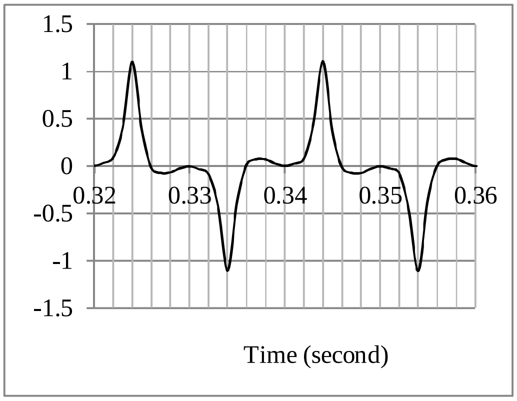


Figure 4 (b). Input current waveforms

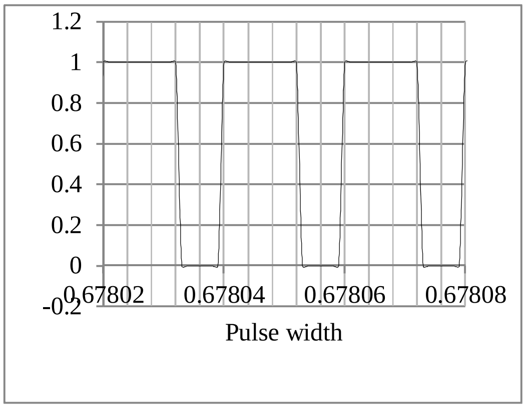


Figure 4 (c). Gate pulse waveforms

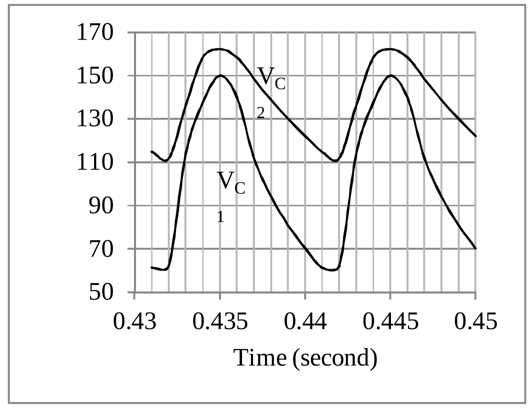


Figure 4 (d). Series capacitor voltage waveforms

V. Conclusions

Combining different modules or sub-converters with their inputs connected in series with a forward sub-converter, an enlarged switch duty cycle above 0.5 is obtained. In a two module configuration, the duty cycle is as wide as 0.66. The results obtained are satisfactory and expected ones. The voltage stress on the switches is less due to the distribution of voltages which helps improve the efficiency. Continuing with the proposal, the idea can be extended to large number of input modules combined together in series or in parallel.

References

[1] C. K. Tse, H. L. Chow and M. K. H. Cheung, "A family of pfc voltage regulator configurations with reduced redundant power processing," *IEEE Trans. Power Electron,* vol. 16, pp. 794-802, 2001.

[2] E. A. M. Basaldua, J. A. M. Saldana and R. L. Palomo, "Design methodology for quadratic step-up dc-dc converters based on non-cascading structures," *IEEE 13th Power Electron. Conf.*, pp 210- 215, 2016.

[3] E. A. M. Basaldua, J. A. M. Saldana and R. L. Palomo, "Design methodology for quadratic step-down dc-dc converters based on non-cascading structures," *IEEE 13th Power Electron. Conf.*, pp 305- 310, 2016.

[4] M. K. H. Cheung, M. H. L. Chaw and C. K. Tse, "Performance considerations of pfc switching regulators based on non-cascading structures," *37th IEEE Power Electron. Spec. Conf.*, 2006, pp 1236-1242.

[5] Q. Xiaohui and S. C. Wong, "Non-cascading structure for electronic ballast design for multiple led lamps with independent brightness control," *IEEE Trans. Power Electron,*, vol. 25, pp. 331-340, 2009

[6] R. L. Palome and J. A. L. Saldana, "Analysis of quadratic step-down dc-dc converters based on non-cascading structures," *IEEE Electron., Robo. and Mech. Conf*. 2012, pp. 305-310

[7] G. Spiazzi, "Reduced redundant power processing concept: a reexamination", *IEEE Power Electron. Conf.* 2016.

[8] G. Spiazzi, "A high-quality rectifier based on the forward topology with secondary side resonant reset", *IEEE Trans. Power Electron,*, vol. 18, pp 725-732, 2003.

[9] S. Kumar, K P S. Rana, and V. Kumar, "Non-cascading structure based flyback-forward converter with large duty ratio," *IEEE Power Electron. Conf.* 2016.

[10] S. K. Changchien, T. J. Liang, K. C. Tseng, J. F. Chen and R. L. Lin, "A demagnetization circuit for single-ended forward converter," *IEEE Power Electron. Spec. Conf.* 2007.

[11] S. Luo, W. Qiu, W. Wu and I. Batarseh, "Flyboost power factor correction cell and a new family of single-stage ac/dc converters", *IEEE Trans. Power Electron,*, vol. 20, pp 25-34, 2005.

[12] S. Kumar, K P S Rana, and V. Kumar," Analysis and design of a converter based on non-cascading structure," *Turkish Journal of Elec. Engg. and Comp. Sci*., Nov., 2017

[13] S.Kumar, K P S Rana, and V. Kumar," Non-cascading converter: analysis, modeling and control," *IEEE Conf. (AEEICB 2016)*, pp 63-67, 2016.

[14] S.Kumar, K P S Rana, V. Kumar and R. K. Katare," A forward converter with load side demagnetization scheme," *Intl. Conf. Vision Towards Emerging Trends in Communication and Networking (ViTECoN),* 2019.

[15] M. A. Pagliosa, R. G. Fast, T. Brunelli and I. Barbi, "Input-series output –series connected modular single-switch flyback converter operating in discontinuous conduction mode", IET, pp 1962-1970, vol. 9, 2016.

[16] R. Giri, R. Ayyanar and E. Ledezma," Input-series and output –series connected modular DC DC converters with active input voltage and output voltage sharing", IEEE APEC, 04, 2004, pp 1751-1756.

[17] A. J .B. Bottion and I.B arbi," Input-series and output –series connected modular output capacitor full bridge PWM DC DC converter *IEEE Trans. Indl. Electron,*. pp 6213-6221, vol. 62, 2015.

[18] Mohammadpour, L. Parsa and M. H. Todonovic," Series-input parallel output modular-phase DC DC converter with soft switchingand high frequency isolation," *IEEE Trans. Power Electron*, pp 111-119, vol. 31, 2016.
[19] S. Deshang, D. Kai and L. Xialzhong, " Duty cycle exchanging control for input-series-output-series connected two PS-FB DC-DC converters", *IEEE Trans. Power Electron*,. pp 1490-1501, vol. 27, 2012.
[20] L. Qiwei, Y. Zijing and L. Shuai," Research on voltage sharing for input-series-output-series phase-shift full-bridge converters with common duty ratio", IECON 2011, IEEE Conf.. pp 1548-1553.
[21] S. Deshang, G. Zhiquang and L. Tianmei," A general control strategy for input-series-output-series modular DC DC converters", *IEEE Trans. Power Electron*, vol. 29, pp 3766-3775, 2014.