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Series-Connected Forward–Flyback Converter for High Step-Up Power Conversion

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Abstract*— *Global energy consumption tends to grow continuously. To satisfy the demand for electric power against a background of the depletion of conventional, fossil resources the renewable energy sources are becoming more popular.According to the researches despite its fluctuating nature and weather dependency the capacity of renewable resources can satisfy overall global demand for energy. High gain DC/DC converters are the key part of renewable energy systems .The designing of high gain DC/DC converters is imposed by severe demands. The power conditioning systems for the photovoltaic power sources needs high step-up voltage gain due to the low output of the generating sources. This paper presents a high step-up topology employing a Series-connected Forward-FlyBack converter, which has a series-connected output for high boosting voltage-transfer gain. Series-connected Forward-FlyBack converter is a hybrid type of forward and flyback converter. By stacking the outputs of them extremely high voltage gain can be obtained with small volume and high efficiency with a galvanic isolation. The separated secondary windings reduce the voltage stress of the secondary rectifiers and results in high efficiency.

Keywords*—*DC-DC power converters, forward converter, flybackconverter, power conditioning.

I. INTRODUCTION

The renewable energy sources such as PV modules, energy storage devices such as super capacitors or batteries deliver output voltage at the range of around 10 to 80 VDC. In order to connect them to the grid the voltage level should be adjusted according to the electrical network standards in the countries. Solar array can be installed on top of commercial buildings or residential houses in urban area.The small-scale generator has been developed under a modularizing concept because the power capacity extension of the system is quite easy by standardized photovoltaic (PV)modules [15] compared to some large-scale centralized photovoltaic power generation systemsFrom the perspective of the small scale power systems, some accommodated schemes such as “ac module” and “module-integrated converter” have emerged. AC module is a photovoltaic module including a small ac inverter with no external dc connector.Module integrated converter is more a general concept including a few series/parallel-connected dc–dc converter modules with a centralized inverter.

With the advent of extremely distributed small scale energy sources that have high-power generation efficiency even with partial shading. Occurrence, extremely high voltage boost gain is required from the power conditioners. Since the output from a typical small scale solar array is very low therefore a high step-up dc–dc converter is necessary for the grid-connected power conditioning systems.

Though there are some existing topologies applicable to such high voltage-boost power converters, such as soft-switching converters where a coupled inductor is applied or switched capacitor manner, they have poor reliability due to the absence of isolation. An isolation type converter has an advantage of the safety and system reliability, in spite of high power conversion efficiency. Therefore, many emerging applications including renewable energy conditioner demands the isolation requirement in their design specification.

For insulation, the use of a magnetic-coupled transformer [3] is essential. However, this requires a reset circuit that has disadvantages in performance and cost, resulting in the difficulty of circuit design. This reset also has loading effect by its impedance, which increases the voltage stresses of the switching devices and the turn ratio of the main transformer. Conventional research has suggested some solutions for high-power high-boost applications.

In this paper, an output-series forward–flyback (SFFB) dc–dc switching converter has been suggested, which serially connects the secondary outputs of a multiwinding forward–flyback converter in order to solve these isolation-type disadvantages. However, the conventional forward–flyback converters are confined to power factor collection circuit applications where multiple outputs or paralleled outputs are used.The dc–dc converter resolved the engineering problems of large voltage enhancement issue such as manufacturing cost and low reliability, which had been pointed out as a problem of the various conventional circuit topologies. At the same time, the proposed scheme improves the weaknesses of insulation-type converters, such as low efficiency, big volume, and high cost, by utilizing the structure of the forward–flyback converter.

The step up converter has a reduced voltage rating of rectifying diodes by separating secondary winding. The extremely high enhancement gain is also separated by the attenuated boost conversion of forward converter and flybackconverter,thus the device stress is reduced and the power efficiency is improved. Also, a utilization factor of the transformer is highly enhanced up bycontinuous power delivery from primary to secondary which contributes to the reduced volume of the forward–flyback converter.

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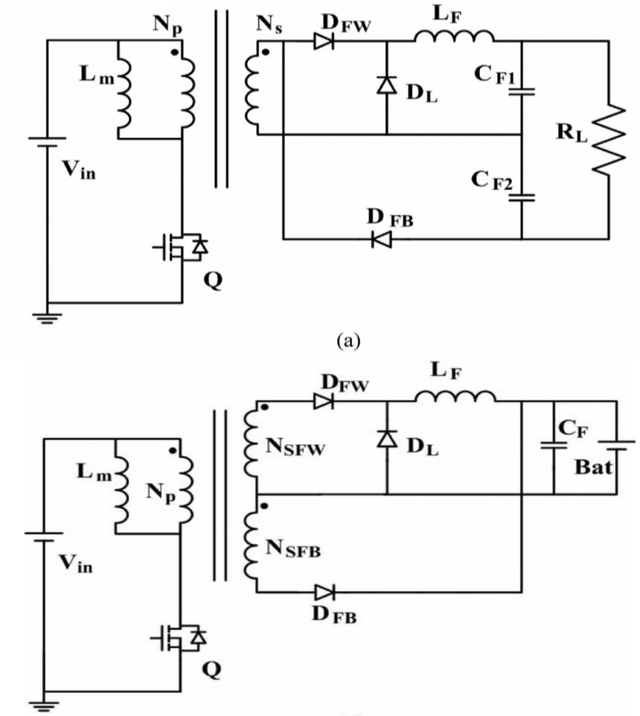


(a)

(b)

Fig.1Conventional forward–flyback power converters. (a) Double winding forward–flyback converter. (b) Triple-winding parallel-output forward–flyback converter.

Though there are some existing topologies applicable to such high voltage-boost power converters, such as soft-switching converters where a coupled inductor is applied or switched capacitor manner, they have poor reliability due to the absence of isolation. On the other hand, an isolation type converter has an advantage of the safety and system reliability, in spite of the high power conversion efficiency. Therefore, many emerging applications including renewable energy conditioner demands the isolation requirement in their design specification. For insulation, the use of a magnetic-coupled transformer is essential.However,this requires a reset circuit that has disadvantages in performance and cost, resulting in the difficulty of circuit design. This reset also has loading effect by its impedance, which increases the voltage stresses of the switching devices and the turn ratio of the main transformer. Conventional research has suggested some solutions for high-power high-boost applications; however, still there are material cost and design

II. SERIES CONNECTED FORWARD FLY BACK CONVERTER

In this paper, an output-series forward–flyback (SFFB) dc–dc switching converter has been suggested, which serially connects the secondary outputs of a multiwinding forward–flyback converter in order to solve these isolation-type disadvantages. Forward–flyback converters deliver the required energy to the load through a transformer no matter when the main switch turns ON or OFF, holding an advantage in terms of supplying more power to the load than any other single-ended isolation schemes does at the same volume.

However, the conventional forward–flyback converters are confined to power factor collection circuit applications where multiple outputs or paralleled outputs are used [14]. The dc–dc converter resolved the engineering problems of large voltage enhancement issue such as manufacturing cost and low reliability, which had been pointed out as a problem of the various conventional circuit topologies. At the same time, the proposed scheme improves the weaknesses of insulation-type converters, such as low efficiency, big volume, and high cost, by utilizing the structure of the forward–flyback converter. Technically, the suggested high step-up converter has a reduced voltage rating of rectifying diodes by separating secondary winding. The extremely high enhancement gain is also separated by the attenuated boost conversion of forward converter and flyback converter thus,the device stress is reduced and the power efficiency is improved. Also, a utilization factor of the transformer is highly enhanced up by continuous power delivery from primary to secondary which contributes to the reduced volume of the forward–flyback converter.

A. Structure of a SFFB Converter

The structure of the proposed dc–dc converter is shown in Fig.6.The primary has a pulse width modulation (PWM) switching voltages occurred by a single main switch. The secondary is a structure where the forward converter and the flyback converter are separated by transformer winding. However, the outputs are serially connected for the output voltage boost. Since the single-ended structure of the proposed converter is suitable for small power capacity compared to other bridge type topologies, it mostly has a low current level over high output voltage, allowing a discontinuous conduction mode (DCM) to be easily implemented. In addition, the elimination of reverse recovery current of diodes in DCM has advantages in terms of power efficiency.

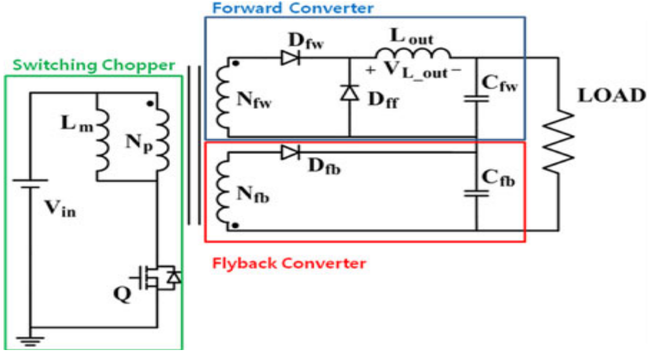


Fig. 6 Circuit diagram of the proposed SFFB converter.

B. Operating Principles

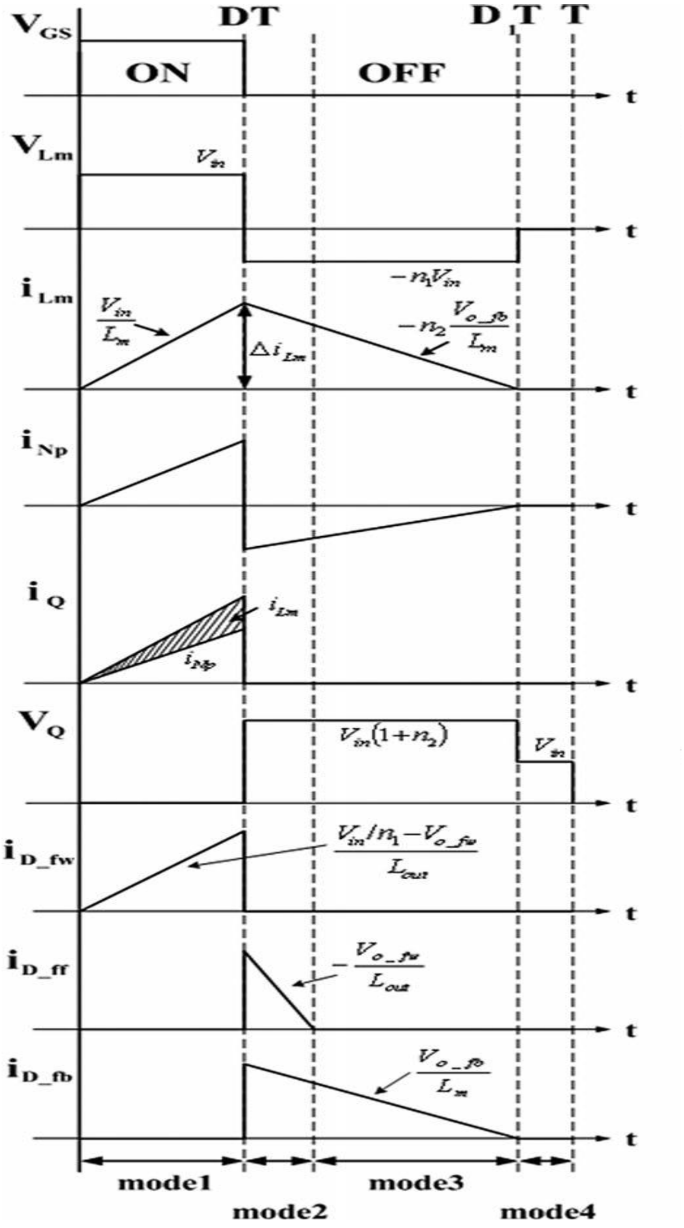
The proposed converter has four operating modes as shown in Fig. 7, according to the switching state of switching circuits.

Mode 1: Current flows to the magnetizing inductance and the primary winding Np as a result of turning ON switch Q. The primary current is transferred to the secondary Nfw coil of the forward converter via the magnetic linkage. Then, the ac power is rectified into dc which load requires through a forward diode Dfw and a low-pass filter Lout and Cfw .Since a flyback diode Dfb is reverse biased,the capacitor C0 provides the load current during this mode.

Mode 2: When switch Q is turned OFF, a forward diode Dfw is reverse biased and the energy stored in Lout is transferred to the load by the freewheeling current via Dff , and at the same time, the energy magnetically stored at Lm is also supplied to load through Dfb of the flyback converter. Thus, all the freewheeling current in magnetic devices decreases linearly.

Mode 3: The forward converter starts to operate in DCM when all the energy in Lout is discharged, and then a freewheeling diode Dff is reverse biased. The energy only stored in Lm is supplied to load through the flyback converter.

Mode 4: The transformer of the forward–flyback converter is demagnetized completely during this period and the output voltage is maintained by the discharge of the output capacitors Cfw and Cfb. All the rectifier diodes are reverse biased.



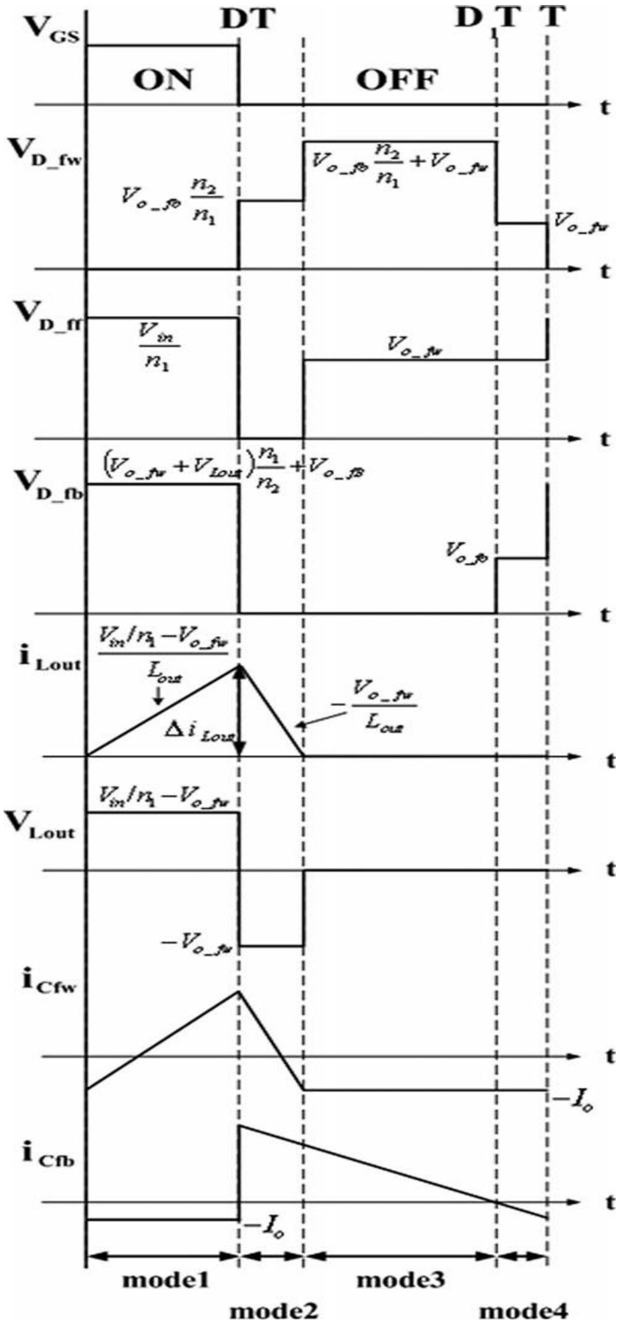


Fig 7 Working Principle

III. DESIGN GUIDELINES

Key design parameters of the proposed SFFB converter are transformer core and windings, MOSFET and diodes, forward inductor and output capacitors, etc

A. Analysis of the Optimal Transformer Turn Ratio

For high efficiency without core saturation,*Kn*= 0.4 With the selected *Kn*, the winding number is chosen as *Np*: *N*fw : *N*fb = 20 : 150 : 60. Critical magnetizing inductance for DCM is derived as

$$Lm_{(\max)} = \frac{n_2{}^2 R_{fb} \min (1 - DB\ max)^2}{2fs} = 274\mu\text{H}.$$

B. Forward's Filter Inductor

The maximum filter inductance of the forward's output is determined as

$$Lout_{max} = \frac{RL\ \min\ (1 - DB\ max)}{2fs} = 2.185\text{mH}.$$

The inductance utilized in the hardware prototype DCM is *L*out = 1.7mH.

C. MOSFET and Diodes

The voltage stress is derived as
$VDS\_\ \max = Vin\_\ \max\ (1 + n2) = 77.8$ V
The secondary-diode selection should consider voltage and current stresses, reverse recovery characteristics, etc. Voltage stresses of the forward, freewheeling, and flyback diodes are, respectively, shown in

$$V_{Dfw} = V_{ofb}\left(\frac{n2}{n1}\right) + V_{ofw} = 207\ V$$

$$V_{Dff} = \frac{V_{in}}{n1} = 300V$$

$$VD_{fb} = \left(V_{ofw} + VL_{out}\right)\frac{n1}{n2} + V_{ofb} = 233V$$

IV. SIMULATION

The tools used for computer simulation is PSIM. Steps involved in simulation are

1. Simulation of forward converter.
2. Simulation of flyback converter.
3. Simulationof the series connected forward flyback converter.

Table 1 Output specifications

Input voltage	20-40 V
Output voltage	340 V
Output power	100 W
Switching frequency	20 KHz
Magnetizing inductance	246 uH
Forward's output inductance	1.7 m H

Series connected forward flyback converter is a dc– dc converter, which serially connects the secondary outputs of a multiwinding forward–flyback converter in order to solve these isolation-type disadvantages.Forward–flyback converters deliver the required energy to the load through a transformer no matter when the main switch turns ON or OFF, holding an advantage in terms of supplying more power to the load than any other single-ended isolation schemes does at the same volume.

The primary has a pulse width modulation (PWM) switching voltages occurred by a single main switch. The secondary is a structure where the forward converter and the flyback converter are separated by transformer winding. However, the outputs are serially connected for the output voltage boost. Since the single-ended structure of the proposed converter is suitable for small power capacity compared to other bridge-type topologies, it mostly has a low current level over high output voltage, allowing a discontinuous conduction mode (DCM) to be easily implemented. In addition, the elimination of reverse recovery current of diodes in DCM has advantages in terms of power efficiency.Next,the simulation of the proposed circuit to obtain an output of 340V, which is shown in the fig. 8 followed by the simulation resultsin fig. 9

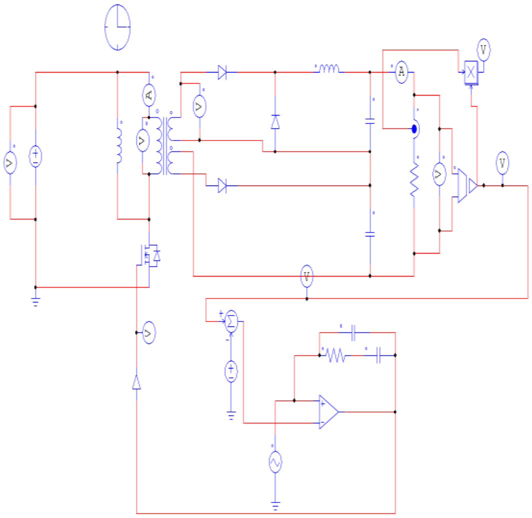


Fig 8 simulation diagram of proposed circuit

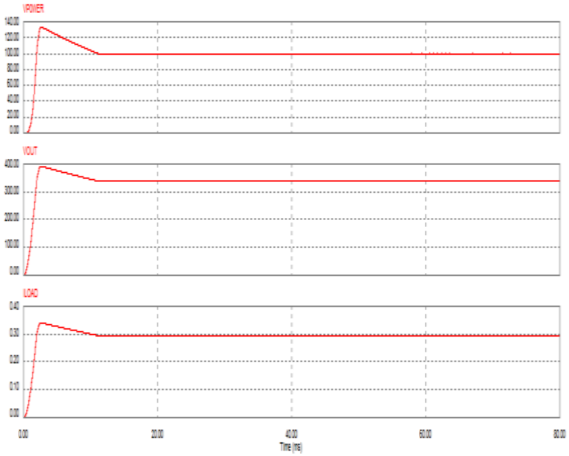


Fig 9 simulation results of the proposed circuit

V. CONCLUSION

In this paper, a preregulating dc–dc converter of an series connected forward fly back converter for multistage PV power conditioning systems has been proposed. SFFB is a hybrid type of forward and flybackconverter,sharing a transformer for increasing the utilization factor. By stacking the outputs of them,high voltage gain can be obtained with small volume and high efficiency.The separated secondary windings in low turn-ratio reduce the voltage stress of the secondary rectifiers and thus high efficiency can be achieved.The high voltage, low-current output has a filter inductor under DCM operation that contributes to better performances by eliminating reverse recovery of the rectifying diodes .As a future work, it will be worthwhile to obtain the softswitching operation in extremely step-up applications for the more various specifications such as high-frequency applications, high or low voltage or current applications.

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