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Flyback-Forward Converter for Solar Based Application

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ABSTRACT: DC-DC converter is a basic element for stand-alone photovoltaic power conditioning system. Here, a new topology is developed of three-port DC-DC converter, based on flyback-forward converter where the communication problem is resolved and overall mass is decreased. Here, the battery charger and the high step-up isolated DC-DC converter can be combined in a single unit with three-port converter topology. The input to the three-port converter is given using photovoltaic system, the other two ports are for storage system and the load. Flyback-forward converter is employed for the three-port topology which has the advantages like large voltage conversion ratio, small input current-ripple, galvanic isolation and high efficiency. PWM and Phase-shifted Control strategy is employed to transfer the energy to the high voltage output or to the battery. Simulation of 1 KW flyback-forward converter and photovoltaic system is done in MATLAB.

KEYWORDS: Pulse Width Modulation, Photo-Voltaic, Maximum Power Point Tracking, Zero Voltage Switching, Pulse Width Modulation plus Phase Angle Shift.

I. INTRODUCTION

The increase in solar photovoltaic system, as an alternative source to the fossil fuels, is increasing day by day. With this increasing interest the need for an efficient and cost effective solar conversion system is greater than ever.

The solar photovoltaic exhibits non-linear characteristic and maximum power point varies with solar radiation and temperature. An intermediate DC-DC converter can be used to increase the efficiency of the system by providing impedance matching between the photovoltaic system and the load and operating the PV cell arrays at their maximum power point using MPPT techniques.

The DC-DC converters used for solar photovoltaic can be categorized into two-port and three-port DC-DC converters. Two-port DC-DC converters were used traditionally. The two port topology is shown in Fig. 1 which consists of two separate DC-DC converters. One converter is used to achieve the photovoltaic conversion and the other one is only to charge and discharge the battery. Since two separate converter controls and communication between the two, are required therefore this configuration is complex which increases the system volume and cost [1].

These two-port converters are now being replaced by the three-port DC-DC converters as it provides a single unit solution by interfacing multiple inputs and common loads.

The three-port DC-DC, as shown in Fig. 2, converters consists of three ports, i.e. one port for source (here PV), the other for the load and the third bidirectional for the battery storage.

These three-port converters have several advantages like reduced conversion stages, less component count, lower cost, improved reliability, and increased dynamic performance. Hence, the system will have high performance, lower overall mass and less compact design [2].

The isolated topologies are derived by transformers, and two kinds of isolated three-port converter topologies are there. Fully isolated TPCs can accommodate different port voltage levels, and provide electrical isolation for each port. But because of the adoption of full bridge architecture the converter uses a lot of power devices and also the control methods for the fully isolated TPCs are really complex. Therefore, three-port half-bridge converters (TPHBC) with partial electrical isolation can be used to reduce the component count and simplify the control method. To simplify the control of TPHBC pulse width modulation technique is employed. The pulse width modulation control plus the phase shift control method can also adopted to achieve zero voltage switching.

On the other hand, by combining two converters some new non-isolated topologies are developed but the component count still remains high [16]. Some isolated three-port converters are also developed, like flyback-forward

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converter, to combine two converters and reduce the component count, and the converter also offers a bidirectional port for battery usage which was not possible with the non-isolated converters. Thus, the topology formed by combining two non-isolated converter is not suitable for stand-alone renewable power system applications. Hence we go for an isolated topology having a combination of flyback and forward converter.

Nowadays, isolated converters are user's choice due to their advantages like safety in case of faults, reliable system, and output voltage can be varied by varying the turn's ratio [3].

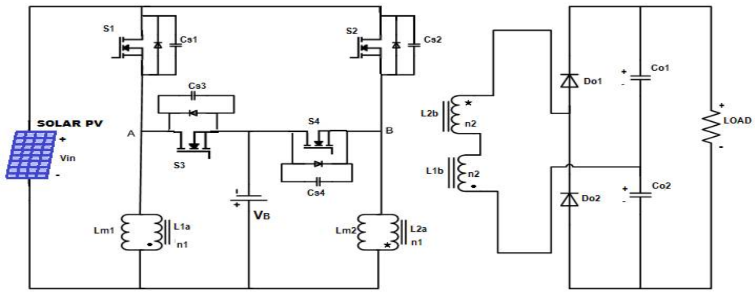

Figure 1: Three-port Flyback-Forward Converter

Therefore, Flyback-Forward converter, shown in Fig. 1, is employed here in the three-port configuration which consists of two coupled inductors to obtain large conversion ratio where each coupled inductor can work in the flyback mode when the corresponding switches are ON and in forward mode when the switches are OFF. Here, magnetic core is fully utilized and power density is enhanced [4],[5],[6].

II. SYSTEM STRUCTURE AND OPERATION

2.1 Circuit configuration and description

In the converter given in Fig. 3, the main switches S1 and S2 work in interleaved or synchronous mode and are responsible for transfer of energy from PV to battery or load. The switches S3 and S4 work in interleaved mode to transfer energy from source to load. Here, L1 and L2 are the two coupled inductors with n1 and n2 as primary and secondary windings respectively. The secondary windings of both the transformer are connected in series to achieve high output voltage gain. Cs1, Cs2, Cs3, Cs4 are the parasitic capacitors of the switches S1, S2, S3, S4, respectively and N is the turns ratio n2/n1.

2.2 Working of the Converter

From [t_o-t_1]: Switches S_1 and S_2 are ON and the generated power from PV source gets stored in two coupled inductors, working in the flyback mode. Due to the polarity D_{o1} and $_{Do2}$ are reversed biased and the load is supplied by the secondary output capacitors C_{o1} and C_{o2}.

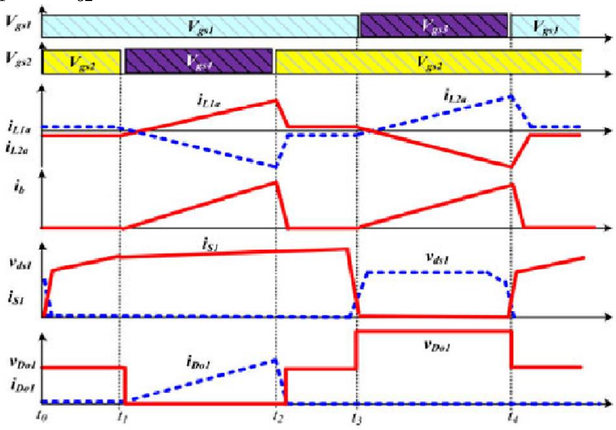

Figure 2: Waveforms of the Three-port Converter

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From [t_1-t_2]: S_2 is turned OFF and S_4 turns ON and hence the diode D_{o1} gets forward biased. Hence, L_1 works in flyback mode and L_2 in forward mode. The battery is charged from energy stored in L_2.Here, $L_1 = V_{pv}$ and $L_2 = -V_B$.
From [t_2-t_3]: This stage is same as that of the first one. Here, again S_2 is turned ON, coupled inductor stores the energy and load is supplied from C_{o1} and C_{o2}. Diode D_{o1} turns off at t_3 as leakage inductance falls to zero.
From [t_3-t_4]: Now, S_1 is turned OFF and S_3 is turned ON. D_{o2} turns ON and L_1 charges the battery from S_3. Here, L_2 works in forward mode and L_1 works in flyback mode.
There are three modes of operation of this converter, as shown in Fig. 5(a), (b), (c), below:

Mode-1: When power flows from PV array to the load only

This mode comes in role when the power generated by the PV array is sufficient enough todrive the load. No extra power is generated by the PV array. In other words, the amount of generated power is equal to the power demand at the load end.

The Figure 5(a) shows the flow of power from solar PV array to the load and since no extra power is generated therefore battery does not comes into play during this mode. For this mode of operation the switches S1 and S2 will be ON and S3 and S4 will remain OFF. Both the switches have same duty cycle but have a phase shift of 180 degree. When S1 and S2 are ON then the energy gets stored in the coupled inductors and due to the polarity the diodes D_{o1} and D_{o2} are reverse biased. The load is then supplied by the output capacitors. This time the converter works in the Flyback mode.

Mode-2: When power flows from PV array to the load and to the battery

During this mode the solar PV array supplies to both load and the battery. This mode shows that the power generated by the PV array is not completely utilized by the load or in other words the demand is less than the generation, then the remaining power is used to charge the battery. This mode, shown in Fig. 5(b), is obtained when the switches S1 and S4 are ON and switch S2 is OFF and S3 remains OFF. The energy stored in the coupled inductor corresponding to switch S2 (in mode-1) is released, when the switch is turned OFF, to charge the battery. As the polarity of the inductor reverses therefore, the diode D_{o1} gets forward biased and the load is continued to supply.

Mode-3: When power flows from battery to the load

This mode comes into play when there is no power generation from solar PV array but it is necessary to fulfil the load demand. In this case battery plays a crucial role. In order to fulfil the load side demand battery supplies the power to the load. This indicated the night time operation of the Stand-alone PV system. Here, S3 and S4 becomes the main switches.

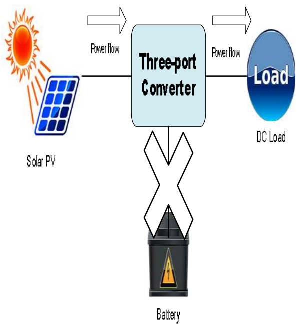

Figure 3: Mode-1 of three-port converter

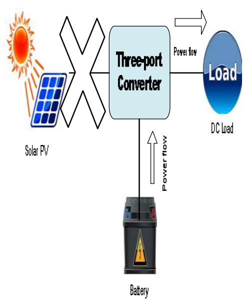

Figure 4: Mode-2 of three-port converter

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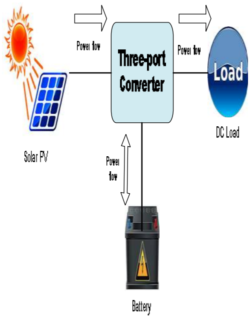

Figure 5: Mode-3 of three-port converter

The control strategy implemented for the three-port Flyback-Forward DC-DC converter will be the PPAS control strategy to realize a flexible energy flow control. This method improves the device sharing ratio among different ports, realizes soft switching operation, and achieves decoupled control. Both the strategies have different role in the converter control. The Pulse Width Modulation control strategy is employed to realize MPPT performance and control the battery state of charge (SOC) while the Phase-angle shift control is employed to regulate the output voltage [8],[9],[10].

III. DESIGN CONSIDERATION

A 1-KW solar power generation system is adopted. The output power, Po, requirement is 1 KW and output voltage, Vo is 230 V and based on these requirement the Flyback-Forward converter is modelled and designed.

$$\text{Voltage gain, } M_{ideal} = \frac{V_o}{V_{in}} = \frac{2*N}{(1-D)}$$

Now, value of magnetizing inductor can be calculated as:

$$L_m = \frac{D * V_{in}}{f*0.2*I_{Lm}}$$

∴ Voltage across output capacitors,

$$V_{co1} = V_{co2} = \frac{N* V_{in}}{(1-D)}$$

Table: 1 Converter Ratings

Parameters	Ratings
Pout	1000W
Vout	230V
Io	4.327A
Ro	52.9 Ω
Vin	51V

Table: 2 Solar Panel Rating

Parameters(4 in series)	Ratings
V_{oc}	60.9V
V_m	51.25V
I_{sc}	21.72A
I_m	22.8A
R_p	515.05*4 Ω
R_s	0.173*4 Ω

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Above mentioned table consists of the rating of solar photovoltaic used here. Since the power requirement is 1KW therefore, 4 panels are connected in parallel.

IV. SIMULATION OF CONVERTER AND SOLAR PHOTOVOLTAIC SYSTEM

The simulation of PV model is carried out as shown below:-

$$I_{ph} = \frac{G}{G_{ref}}(I_{ph,ref} + \mu_{se} * \Delta T)$$

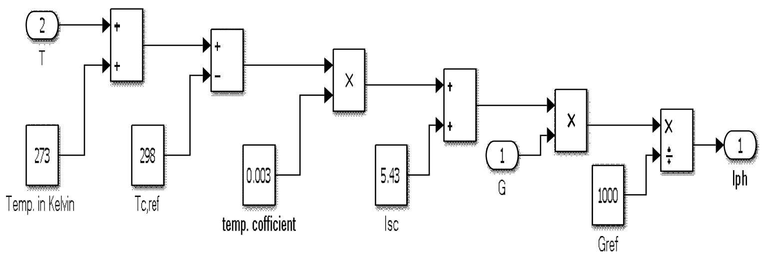

Figure 6: Iph implementation in detail

$$I_{o,ref} = I_{sc,ref} / \exp\left(\frac{-V_{ocref}}{a}\right)$$

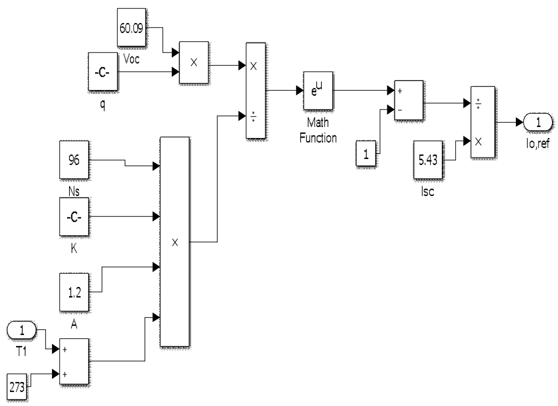

Figure 7: Implementation of Io,ref in detail

$$I_o = I_{o,ref}\left(\frac{Tc}{T_{cref}}\right)^3 \exp\left[\left(\frac{-q\varepsilon_G}{A*k}\right)\left(\frac{1}{T_{cref}} - \frac{1}{T_c}\right)\right.$$

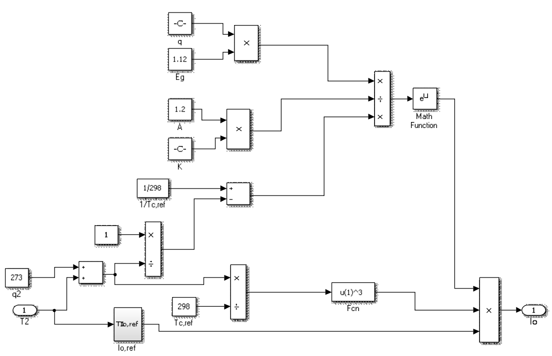

Figure 8: Implementation of Io in detail

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Now, at the end the total current through the PV array is designed which completes the simulation of PV array using the below equation

$$I = I_{ph} - I_o * [\exp\left(\frac{V+I*R_S}{a}\right) - 1] - \left(\frac{V+I*R_S}{R_P}\right)$$

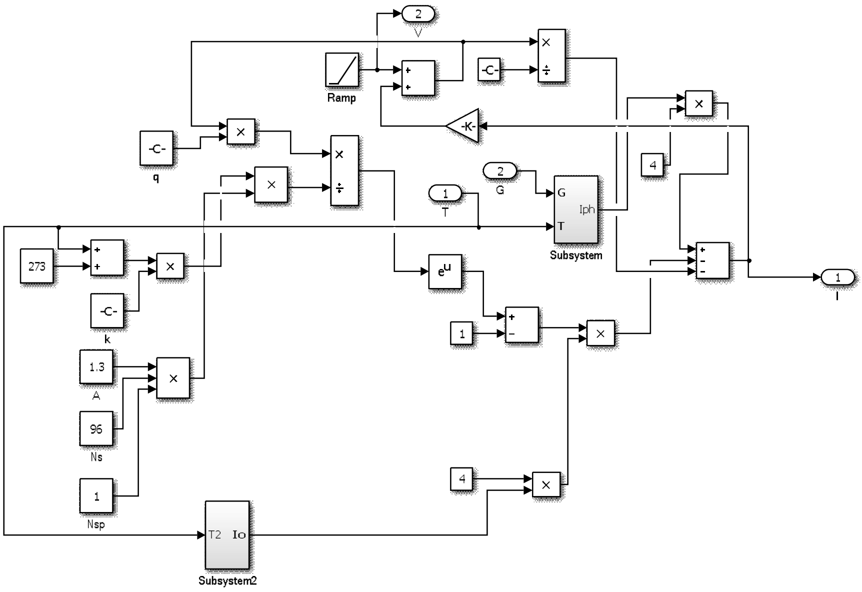

Figure 9: Implementation of I in detail

Therefore the P-I and I-V curves are generated as shown in the below figure 10 and figure 11 using the above models.

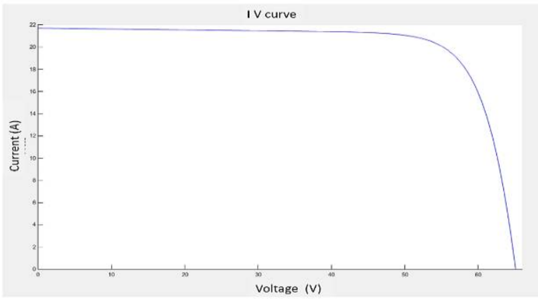

Figure 10: IV curve of the solar PV array

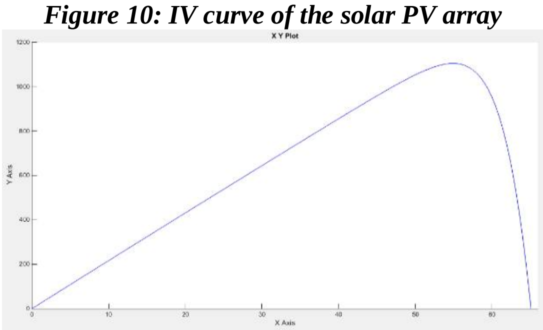

Figure 11: IV curve of the solar PV array

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The flyback-forward DC-DC converter is simulated below in the figure 12.

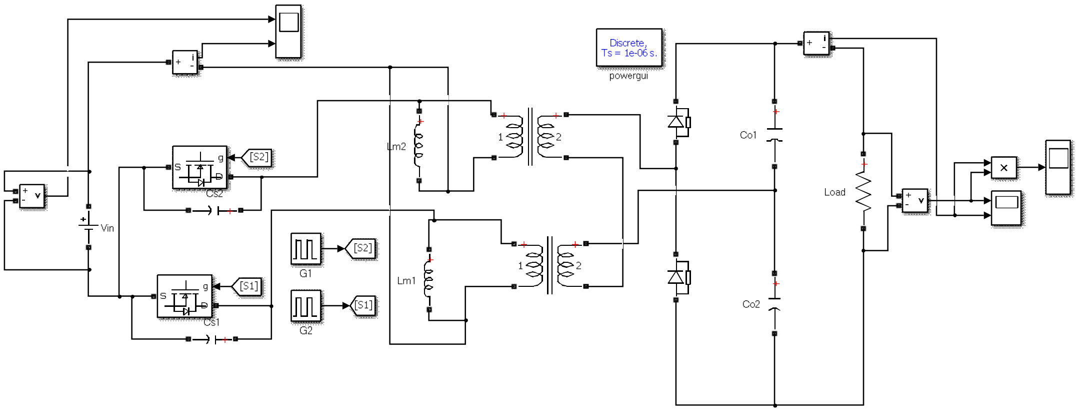

Figure 12: Simulation of Open loop Flyback-Forward converter

The input voltage and current waveforms are shown in figure 13 and the gate pulses, in figure 14, according to which the inductance stores and releases the energy.

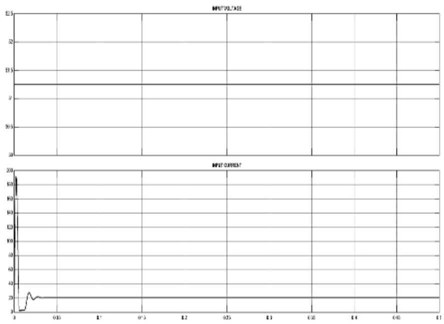

Figure 13: Input voltage and current waveform

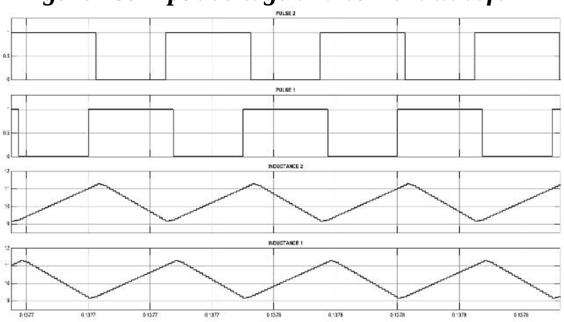

Figure 14: Gate pulses and magnetizing inductance current waveform

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Therefore, the output voltage is stepped up from 51V to 230V as shown in the figure 15 and the waveforms of current and power are also shown.

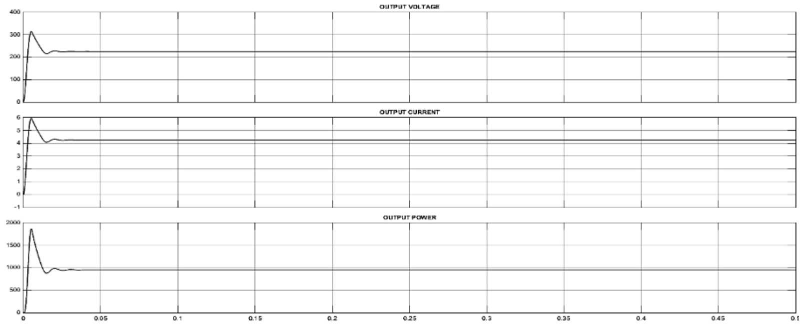

Figure 15: Output Voltage, Current & Power waveform

V. CONCLUSION

This paper has presented the Three-port isolated Flyback-Forward DC-DC converter for stand-alone photovoltaic system. It can be concluded that the Flyback-Forward converter is a high step-up DC-DC isolated converter. The converter, with duty ratio of 0.55, provides a large conversion ratio where voltage is converted from 51V DC to 225V DC.

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