GRID CONNECTED SOLAR MICRO-INVERTER FOR ROOFTOP SYSTEM

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***Abstract*— Presently, decentralized inverters are being developed at the PV panel power level, which are known as AC–Photovoltaic (PV) Modules. The AC-Module PV system consists of an inverter attached to one PV panel. This integration requires that both devices have the same life-span. Although, the available commercial inverters have a relatively short life-span (10 years) compared to the 25–year PV. This paper presents three-port micro-inverter with power decoupling capability for AC-Module PV system applications. The topology is basically a flyback converter with an extra switch and diode. This arrangement allows the use of a low capacitance film capacitor, with long lifespan. The main aim of the grid tied PV micro inverter is to convert the raw solar energy from the PV panels and feed it to the grid efficiently with reasonable power quality.**

Keywords—AC module, Flyback converter, Three port micro-inverter, photovoltaic, power decoupling.

I. INTRODUCTION

During the recent decade PV inverter technologies have developed a lot. Inverter costs have dropped and efficiency have expanded during last two decades. The inverter for PV system can be categorized into three types: centralized inverter, string inverter, and AC module. In which module integrated micro-inverter is preferred for the future application due to low cost and high reliability. The micro inverter is a single compact unit that converts the DC power from the solar module to AC power for supply to the electricity grid without the need for string or central inverter.These systems are becoming more and more popular as they reduce overall installation costs, improve safety and better maximize the solar energy harvest. It removes mismatch losses between PV modules since there is one PV module.

Based on the PV inverter topologies can be classified into transformer-less topologies and transformer isolated topologies. For the isolated transformer inverter there are two approaches. The first approach uses the single stage flyback inverter or isolated buck-boost inverter, which has the capacity to replace the electrolytic capacitor with high voltage low capacitance film capacitor for the energy storage. The second approach is two-stage approach with a transformer isolated dc-dc converter as the first stage and a full-bridge inverter as the second stage [1,2]. In this topology single stage flyback inverter is consider. A three-port micro-inverter inverter is based on flyback topology which can perform both dc- ac transformation and power decoupling. It is simple topology, and the other benefits are less power loss and decent efficiency. The micro-inverter can be utilized as a plug and play device, which can be used by persons without information of electrical installation. The reliability (life-span), weight, and volume of the inverter become more important and have a vital role on the system. The life-span of the inverter should be comparable to that of the PV panel; which is more than 20 years. The available (commercial) inverters used in AC-Module PV-system have a life-span less than the PV panel; about 3-6 years. The most vulnerable parts in the inverter are the power switches and the power decoupling capacitor; which have a strong impact on its life-span. Hence to increase a life-span of inverter electrolytic capacitor is replaced by decoupling capacitor [2-4].

II. MICRO-INVERTER TOPOLOGY AND OPERATION MODES

The circuit diagram of three port micro-inverter is shown in fig.1. It is a conventional flyback inverter in which an additional switch S_2 and a diode D_2 at the primary side is connected to realize the power decoupling function. There are two windings at secondary side which are utilized to generate the ac voltage compatible with the grid, while another two switches S_3 and S_4 in series with diodes D_3 and D_4, respectively. All are switching at line frequency [4,5].

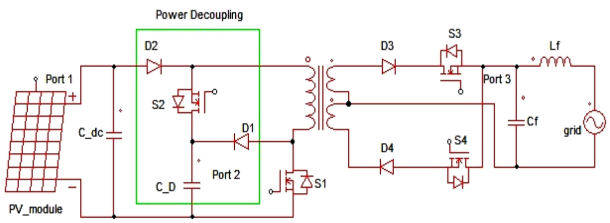

Fig.1 Three-Port Micro-Inverter

To keep the double line frequency being reflected at the PV side, the decoupling capacitor CD act as an energy buffer. At the point when the input power is greater than the output power ($P_{in} > P_o$), the surplus power ($P_{in}-P_o$) is being charged to the decoupling capacitor CD. In the other case, where the input power is less than output power ($P_{in} < P_o$), the shortfall power ($P_{in}-P_o$) is being supplied from the decoupling capacitor CD by turning ON switch S_2 [4-7].

The operation of this topology is divided into two main modes: 1) Charging mode; 2) Discharging mode. The two operation modes are depend upon the value of the output power, $P_o(t)$, where P_{PV} is the produced power from the PV panel, u_{ac} and i_{ac} are the grid voltage and current, respectively, I_{Lm} is the magnetizing current at the primary side, and i_2 is the present at the secondary side. At the point when the input power from PV, P_{PV}, is greater than the output power, the inverter operates in Mode I. At the point when $P_o(t) > P_{PV}$, the circuit will be operate in mode II. The decoupling capacitor will support the PV panel by releasing energy into the transformer, and give the required power to the utility grid.

A. Mode I

In this mode, the operation is divided into four circuit stages in each switching cycle, as shown in Fig.2 [4,5].

1) Storing energy into the transformer's magnetizing Inductance;
2) Charging the decoupling capacitor;
3) Transferring the power to the output;
4) Waiting for a new switching cycle.

Stage 1[t_0 –t_1]: During this stage, shown in fig.2(a), S_1 is turned ON, and the magnetizing inductance starts storing energy from the PV panel. The magnetizing current keeps ramping up until it reaches the peak value i_{Lm_peak1}. Once the magnetizing current reaches this peak value (i_{Lm_peak1}), S_1 is turned OFF, and the next stage starts.

Stage 2[t_1 –t_2]: All switches are OFF during this mode as shown in fig.2(b). The transformer magnetizing energy will discharge into the decoupling capacitor. The current will keep discharging until it reaches the current, i_{Lm_peak2}, whose value can be calculated based on the assumption that the energy stored in the magnetizing inductance.

Stage 3 [t_2 –t_3]: This stage starts when switch S_3 (S_4) turns ON. During this stage, the current i_2 is released through one of the secondary windings, and the corresponding ac switch, either S_3 or S_4, as shown in Fig.2(c). The grid voltage during one switching period u_{ac} can be assumed to be constant.

Stage 4 [t_3 –t_4]: This stage starts when the current i_2 reaches zero. During this stage, all the switches are turned OFF, as shown in fig.2(d). The capacitor Cr and inductor L_r keep pumping energy to the grid, while the flux in the flyback transformer is reset.

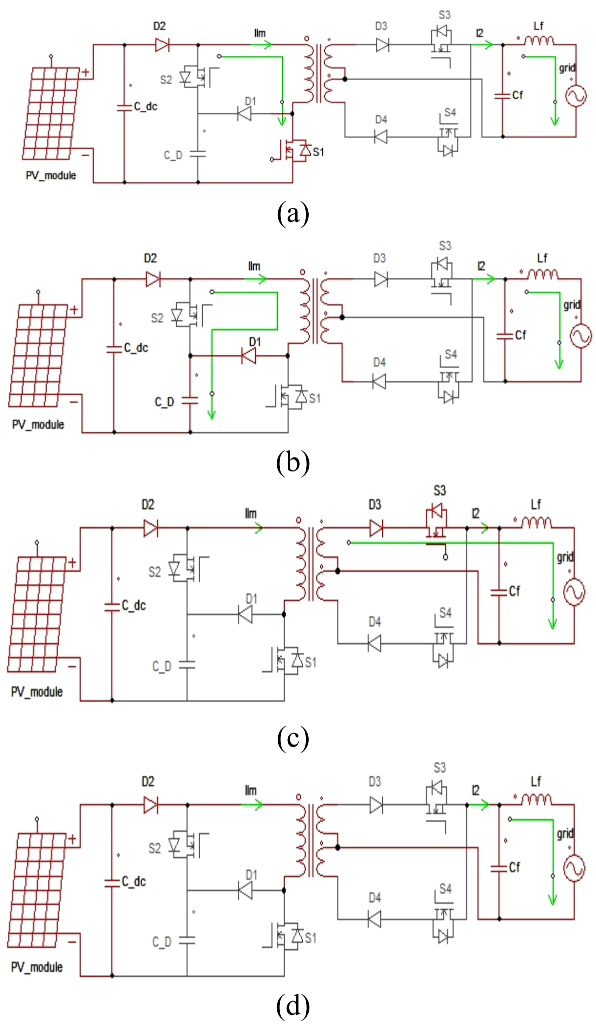

Fig.2 Operation stages of mode I

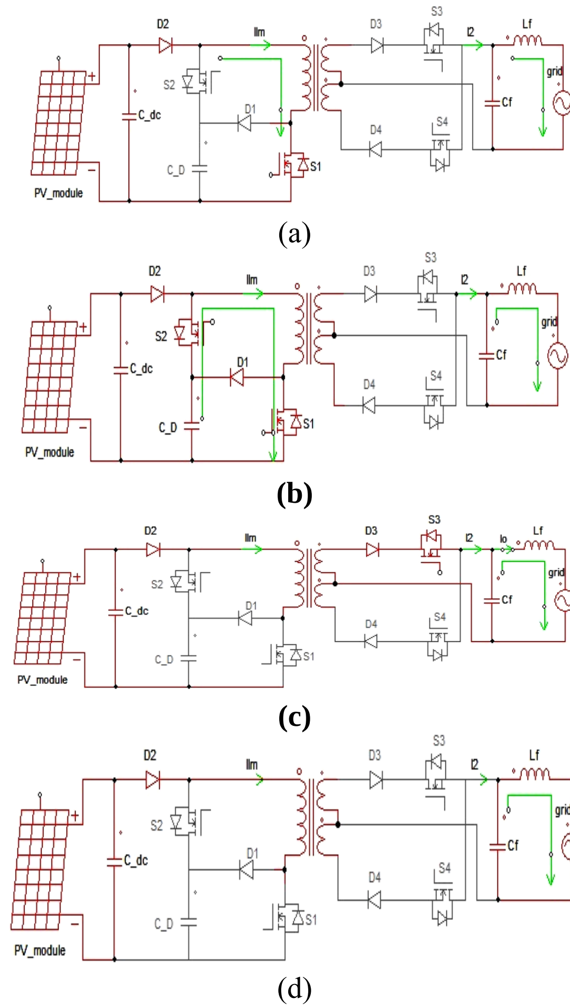

Fig.3 Operation stages of mode II

B. Mode II

This mode is also divided into four circuit stages as shown in Fig.3. In this mode the corresponding secondary-side switch, either S_3 (or S_4 according to its polarity), is always ON [4,5].

Stage 1[t_5 -t_6] and Stage 3[t_7 – t_8]: The first and the third stages are similar to those in mode I. The only difference is that, the peak current i_{Lm_peak1} is kept at the same level in mode II, and thus, the input power (P_{PV}) remains constant.

Stage 2[t_6 –t_7]: The decoupling capacitor will be discharging its energy into the transformer's magnetizing inductance, through switch S_2.

Stage 4[t_3 -t_4]: This stage starts when the current i_2 reaches zero. During this stage, all the switches are turned OFF, as shown in fig.3(d). The capacitor Cr and inductor L_r keep pumping energy to the grid, while the flux in the flyback transformer is reset.

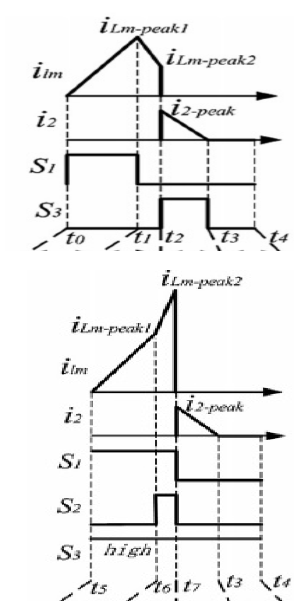

Fig.4 The current and driver signals in mode I and mode II.

The Current and driver signals in mode I and mode II are shown in fig.4. In which I_{Lm} is

Inductance magnetizing current, I_2 is current at secondary side, and S_1, S_2, S_3 are gate signals for switch S_1, S_2 and S_3 respectively.

III. PHOTOVOLTAIC SYSTEM MODELLING

Three PV modules are connected in series and this PV array is connected to the single stage single phase micro-inverter**.** The MATLAB Simulink diagram of PV array is given in Fig.5 [8-10].

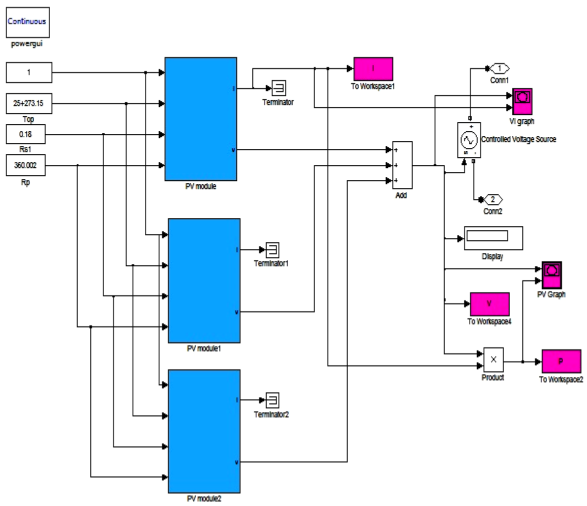

Fig.5 Simulink block diagram of PV array

The simulated I-V and P-V characteristic of a PV array at different irradiation are, shown in fig.6 and fig.7, and the different irradiation values are 400, 600, 800 and 1000 W/m^2.

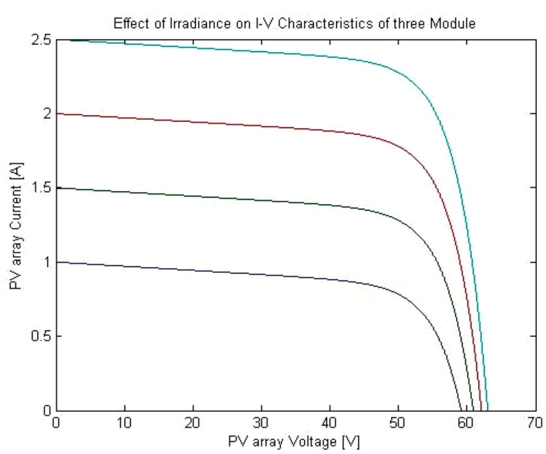

Fig. 6 I-V Characteristic of three modules at different irradiation.

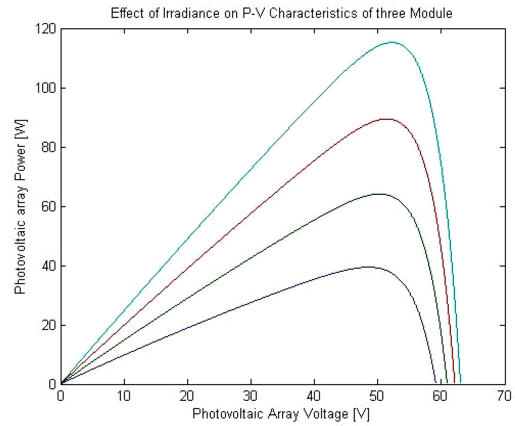

Fig.7 P-V Characteristic of three modules at different irradiation.

The simulated I-V and P-V characteristic of a PV array at different temperature are, shown in fig.8 and fig.9, and the different temperature values are 273, 293, 303 and 313K.

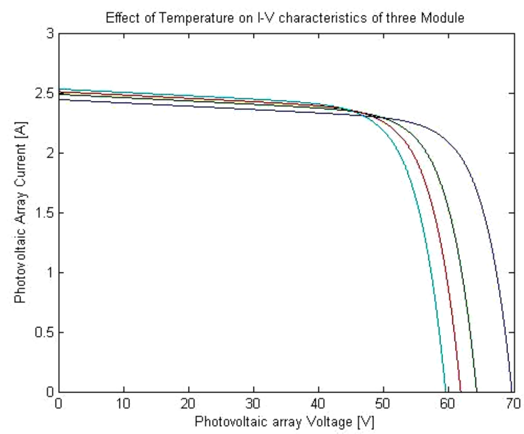

Fig.8 I-V Characteristic of three modules at different temperature.

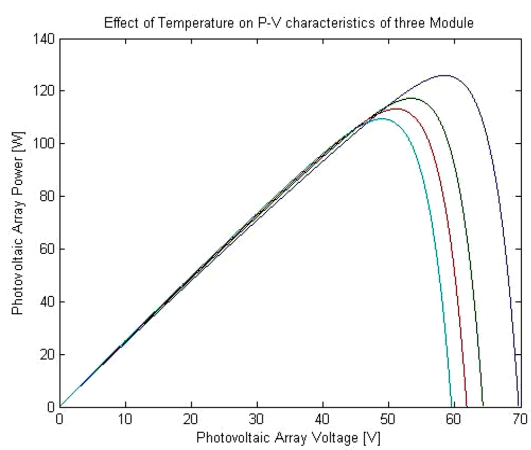

Fig.9 P-V Characteristic of three modules at different temperature.

The parameters of module being used are shown in below table.

Table 1 Simulated result of a module and array.

Parameters	Values	
	module	Array
Short Circuit Current I_{SC} [A]	2.5	2.5
Open Circuit Voltage V_{OC} [V]	21.1	63.3
Voltage, maximum power V_{mpp} [V]	17.19	51.69
Current, maximum power I_{mpp} [A]	2.297	2.294
Maximum power P_m [W] From I-V Characteristics (calculated)	39.48	118.57
Maximum Power P_m [W] From P-V characteristics	39.46	118.4

IV. MATLAB SIMULATION AND RESULTS

Three PV panels are supplying power to grid through the micro-inverter was simulated in MATLAB/SIMULINK.

Table 2 Simulation parameters

Circuit parameters	Values
Input voltage	63V
Grid voltage	230V
Switching frequency	50KHz
Decoupling capacitor C_d	46µF
Filter inductor L_f	1mH
Transformer turns ratio	1:2.5:2.5
Magnetizing inductance L_m	35µH

The Simulink diagram of single phase grid connected micro-inverter connecting with PV system is given in Fig.10.

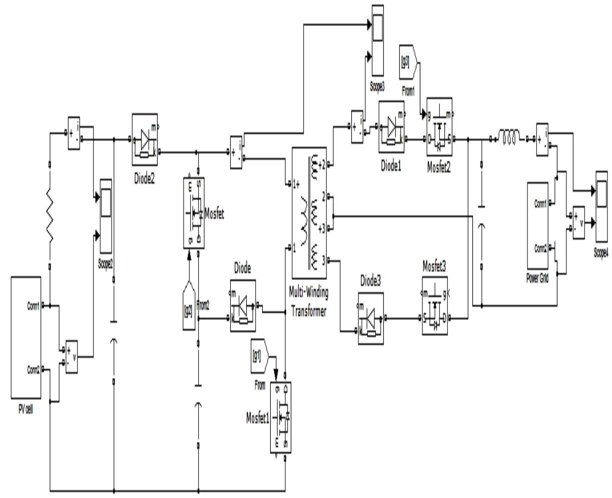

Fig.10 Simulink diagram of micro-inverter using PV system

Fig.11 and 12 shows the driver signal generated in mode I for in switch S_1 and S_3 and in mode II for switch S_1, S_2 and S_3 respectively.

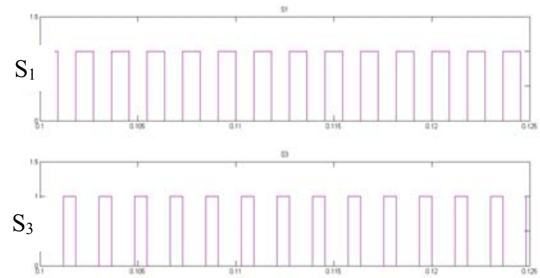

Fig.11 Gate pulses generated in switch S_1 and S_3 in mode I

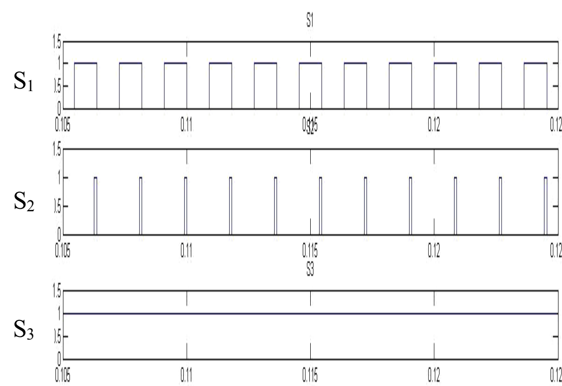

Fig.12Gate pulses generated in switch S_1, S_2 and S_3 in mode II

The fig.13 shows the waveforms of input PV voltage (V_{pv}). Fig.14 and 15 shows the expanded view of input current (I_{in}) and Inductance Magnetizing current (I_{Lm}) respectively in mode I. It is clear how the input current is following the magnetizing current during mode I. when switch S1 in on the magnetizing current starts to flow and after some time it reaches to peak value. The switch S_2 will off during mode I.

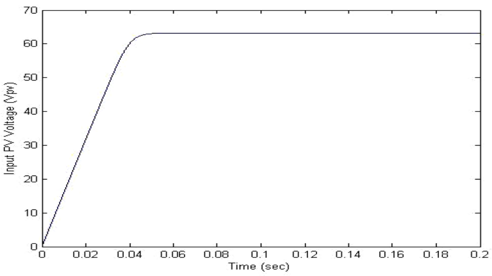

Fig.13 The input PV voltage

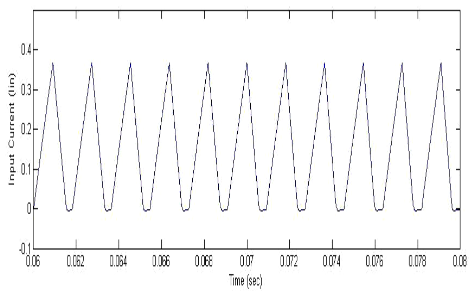

Fig.14 Input current in mode I

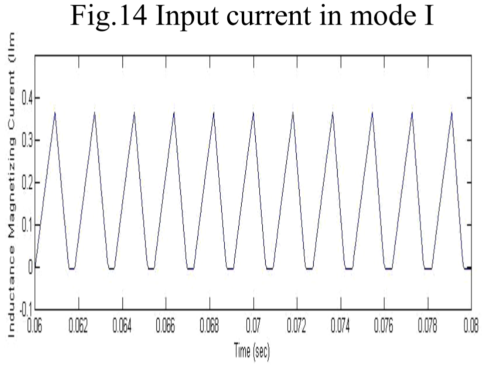

Fig.15 Inductance Magnetizing current in mode I

Fig.16 shows the Inductance Magnetizing current (I_{Lm}) in mode II. The switch S_3 is always on in this mode. When switch S_1 is on and S_2 is off the magnetizing current charged from panel. When both switch S_1 and S_2 are turned off an exact amount of energy will be transferred into the output through either switch S_3 or S_4.

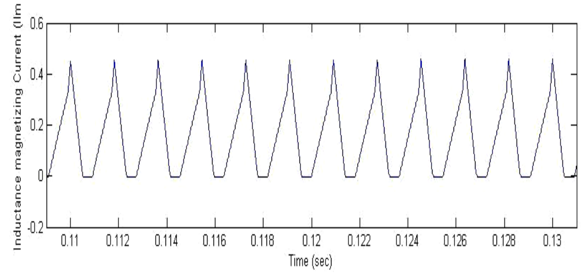

Fig.16 Inductance Magnetizing current in mode II

The fig.17 shows the Grid voltage and Grid current waveforms respectively. When the switch S_3 is on I_2 starts flowing, at that time the magnetizing current reaches zero value.

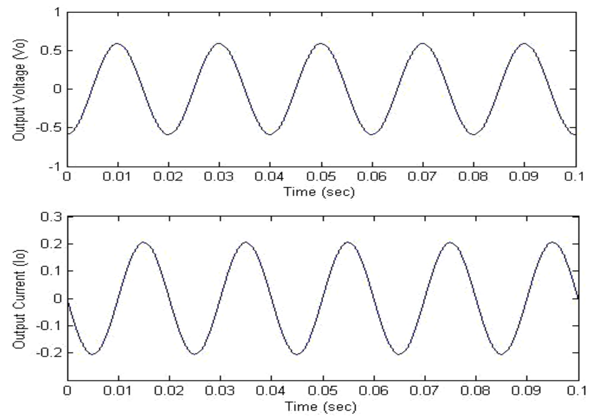

Fig.17 Grid Voltage and Grid Current

V. CONCLUSION

A new three port micro-inverter topology and complete analysis of this topology has been studied. It is primarily intended for the ac module PV systems. The topology employs a new power decoupling technique where a small film capacitor can be used instead of the bulky, low reliable electrolytic capacitor. Hence, it will have a long lifespan comparable to the PV panel. And other benefits like no double power conversion, fewer components used in decoupling circuit and the transformer leakage energy is stored in the decoupling capacitor which reduced power losses.

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