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Modelling & Simulation of a Single Stage Flyback Micro Inverter

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ABSTRACT: In this paper a grid connected single stage flyback micro inverter with Zero Voltage Switching (ZVS) is performed. A negative current from the grid-side flows through bidirectional switches placed on the secondary side of the transformer by this the soft-switching of the primary switch is achieved. Generally, the negative current discharges the MOSFET's output capacitor and this allowing turn-on of the primary switch under zero voltage. To achieve zero voltage switching a variable frequency control scheme was implemented over the line cycle in order to optimize the amount of reactive current required. Bi-directional switches placed in the secondary side of the transformer have zero voltage switching during the turn-on time and therefore, the switching losses of the bi-directional switches are negligible.

KEYWORDS: PV- Photo voltaic, ZVS- Zero Voltage Switching, ZCS- Zero Current Switching, PWM- Pulse Width Modulation.

I. INTRODUCTION

The energy demand in the world keeps increasing day by day. For the growing energy need in the world solar energy has proven to be a very attractive solution. Solar energy has several advantages, such as its availability in abundance, inexhaustible nature, pollution-free power generation etc. With the recent advancement of the photovoltaic (PV) cell technology, it was become possible to harness solar energy in a far more efficient manner at a minimal cost. Solar energy has become one of the most important distributed generation options. More than 45percentage of energy requirement can be met by a photovoltaic module.

The centralized configuration has some limitations therefore to improve the performance of the system ac modules were introduced in the recent past. The ac module is the integration of the PV panel and a small grid-tied inverter in one electrical device to harvest the energy. The ac module performs maximum power point tracking (MPPT) of the PV panel, galvanic isolation, voltage amplification and injection of high-quality ac to the utility grid [1, 2]. To overcome the effects of partial shading and mismatch losses individual MPPT is provided for each module. Each PV module has a dc-ac inverter in this structure. A simple and efficient solution for the ac module used in the decentralized power generation systems is provided in this paper. DC-AC power conversion within the PV module could be carried out either in a single stage or multiple stages [2, 3]. A two-stage converter with an intermediate dc link is commonly used for this application. In this configuration, a dc/dc converter is the first stage and the second stage is an inverter. The first stage provides galvanic isolation and also boosts the voltage. The second stage injects high-quality current to the utility grid. The two-stage configuration is a very straightforward and simple power conversion technique. But it has some essential limitations also. Two stages of power conversion are present in this configuration so the efficiency is inherently limited, and power density of the converter is compromised by the two stages. The other limitation of the two-stage configuration is that it is very difficult to realize zero-voltage switching (ZVS) for the second stage of the converter. Therefore, to minimize the inevitable switching losses of the second stage usually, a low-switching-frequency pulse width-modulated (PWM) inverter is used. Operating with low switching frequency requires a bulky and lossy filter to remove the high-frequency component and then inject a high-quality current to the grid. A single-stage inverter topology is proposed in this paper, which offers soft-switching for the power MOSFETs, and leading to a very efficient and compact solution to interface the PV panel to the utility grid. That is in the single stage configuration

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the functions of two blocks of the multistage configuration are performed in a single stage. Figure 1 shows the multi stage and single stage configuration.

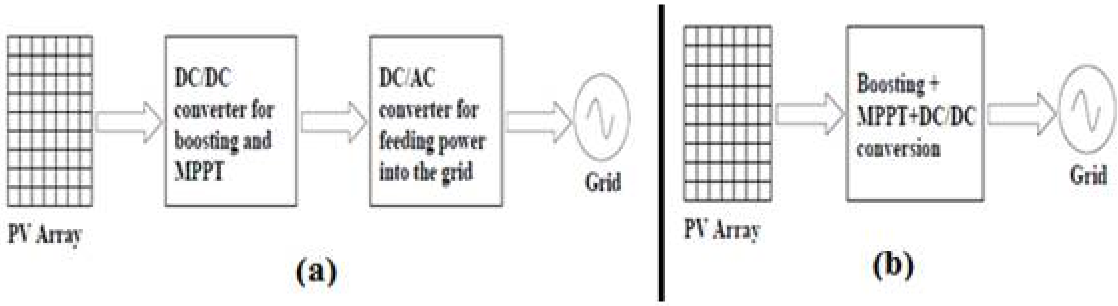

Fig 1: (a): Multi stage configuration (b): Single stage configuration

II. FLYBACK MICRO-INVERTER

Flyback topology is reliable and cost-effective which has a reduced number of semiconductor switches for PV modules [4]. By operating under ZVS condition the switching losses associated with the hard-switched flyback inverters can be drastically reduced. It is working at high frequency. In the conventional flyback inverter the secondary side consist of a combination of switch and diode. But in this case which is replaced by a bidirectional switch to permit the current to conduct from the grid side to the primary side. Therefore, ZVS is achieved for both the primary and secondary MOSFETs.

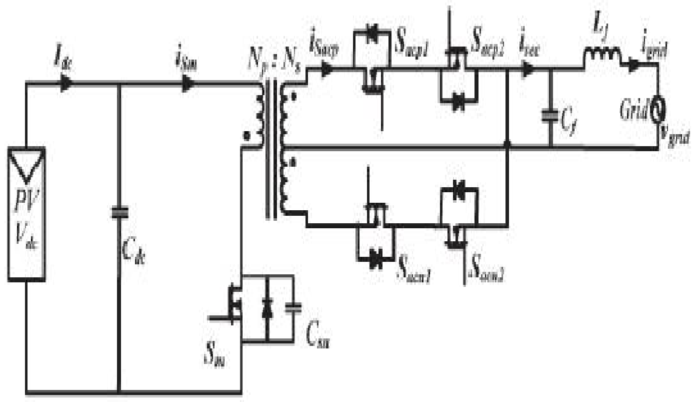

Fig 8: Flyback inverter scheme

Fig 8 shows the circuit diagram of the flyback inverter scheme for soft-switching of the primary switch [1]. This circuit consists of a center-tapped flyback transformer, primary switch, input decoupling capacitor, bidirectional switches on the secondary side, and output filter. By triggering the primary switch *Sm* the magnetizing inductance is charged up to the required reference current. As the inverter is connected to the utility grid, the peak of the primary current varies according to a sinusoidal waveform at the grid frequency. The energy stored in the magnetizing winding of the transformer is injected to the grid by turning ON either the secondary switch *S*acp1 or *S*acn1 during the positive or negative half-cycle, respectively. The polarity of the flyback transformer allows the switching of these MOSFETs at the line frequency, thus having negligible switching losses. As the secondary current tends to zero within each switching cycle, the bidirectional switch is turned ON, then allowing the current to reverse its direction. Thus, the magnetic inductance of the transformer becomes charged in the reverse direction. This duration of charging is controlled by comparison of the negative peak of the inductor current to a sinusoidal reference current with grid frequency.

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III. SWITCHING CYCLE

The detailed modes of operation of the circuit in one switching cycle are shown in the fig 9. To optimize the amount of reactive current required for ZVS, a variable switching frequency is employed. The switching cycle is divided into six modes. Since the switching frequency of the inverter is significantly higher than the grid frequency, the quantities varying with respect to the grid frequency such as the grid voltage, grid current, duty cycle, and reference currents are almost constant during one switching cycle.

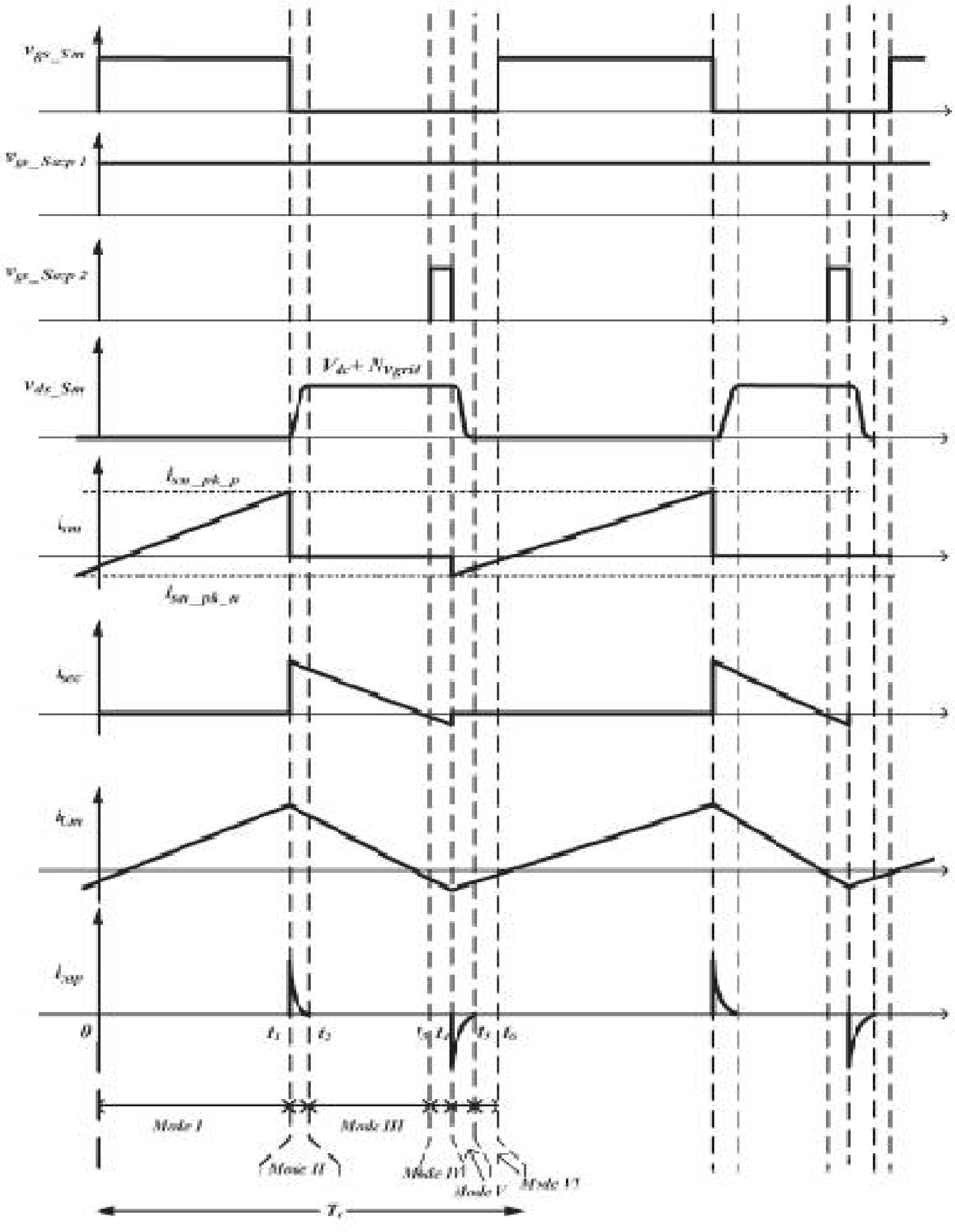

Fig 9: Detailed operation of inverter scheme

Mode I (Interval 0 < t < t1): Primary switch *Sm* is turned ON at the start of a switching cycle. Secondary switch *S*acp1 remains ON during the entire positive half of the ac cycle, whereas *S*acn1 remains ON during the entire negative half of the ac cycle. Fig 10 shows the circuit components that are active during this interval.

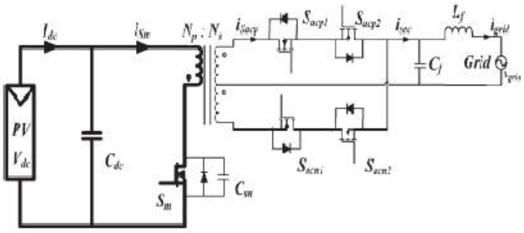

Fig 10: Mode I

During this mode, the input PV voltage is applied across the magnetizing inductance *Lm* of the transformer at the primary side. Hence, the primary current increases. When the current reaches the peak value *i*sm_pk_p at *t* = *t*1, the primary switch is turned OFF. The peak of the primary current *i*sm_pk_p is dependent on the instantaneous value of the ac output power as the amount of energy transfer to output is governed by the magnetizing inductor current.

Mode II (Interval t*1 *< t <* t2*): Switch *Sm* is turned OFF at the beginning of the interval, whereas the secondary switches remain ON, as shown in Fig 11. Due to the presence of output capacitor across the primary MOSFET, the drain–source voltage cannot increase instantly to a high voltage. The rise of the drain–source voltage across the switch *Sm* is slowed down because of charging of capacitor *C*sn. This mode comes to an end when the capacitor has charged to its maximum value of *V*dc + *N*vac. This transition from the ON state to the OFF state of switch *Sm* occurs within a very short interval of time.

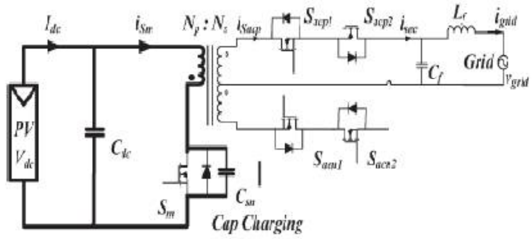

Fig 11: Mode II

Mode III (Interval t*2 *< t <* t3*): Once the capacitor *C*sn is completely charged to its maximum value, the energy stored in the magnetizing inductor of the transformer is transferred to the grid. This is made possible by either the secondary switch *S*acp1 or *S*acn1 depending on the positive or negative half-cycle of the grid voltage being ON. Fig 12 highlights the active switch *S*acp1 and the anti-parallel diode of switch *S*acp2 during this interval for the positive half of line cycle.

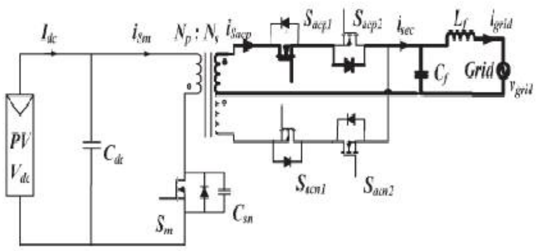

Fig 12: Mode III

Mode IV (Interval t*3 *< t <* t4*): At the beginning of this mode of operation, the anti-parallel diode of the switches *S*acp2 or *S*acn2 is conducting depending on the polarity of grid voltage. When the secondary current tends to zero, either *S*acp2 or *S*acn2 is turned ON under ZVS depending on the polarity of grid voltage.

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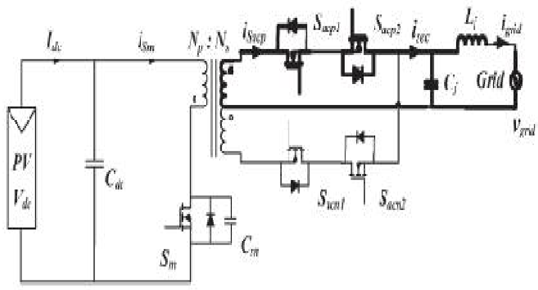

Fig 13: Mode IV

Since the bidirectional switches are ON, the current in the secondary side changes direction and starts charging the magnetizing inductance in the opposite direction. At the instant when *i*sec equals the reference value, the bidirectional switch (*S*acp2 or *S*acn2) is turned OFF. Fig 13 shows that both the switches *S*acp1 and *S*acp2 are ON during this interval for positive half-cycle, allowing the secondary current to reverse its direction. The voltage observed across the magnetizing inductance of the transformer remains identical during the modes III and IV.

Mode V (Interval t*4 *< t < t*5*): This mode begins when the bidirectional switches on the secondary side are turned OFF, as shown in Fig 14. Thus, all the switches are in the OFF state during the interval. Since the magnetizing inductance *Lm* was charged in the reverse direction in the previous interval, the inductor current flows in the direction to transfer the energy stored in *Lm* to the input capacitor. As a result, the primary current *iSm* is negative during this interval. The voltage across switch *Sm* starts to decrease slowly as the capacitor across the switch starts to discharge. This mode comes to an end with the complete discharge of the capacitor across the switch.

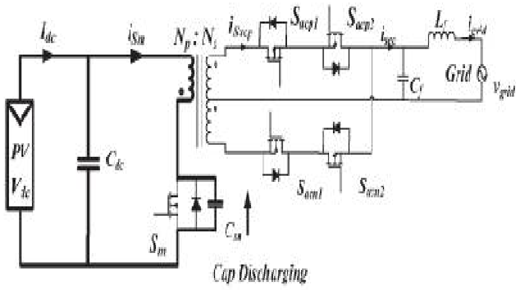

Fig 14: Mode V

Mode VI (Interval t*5 *< t < t*6*): Since the capacitor is completely discharged, the drain–source voltage of the primary switch *Sm* nearly equals zero. It causes the anti-parallel diode of the switch to conduct, as shown in Fig 15. Hence, the magnetizing current continues to increase from its negative value. Since the drain–source voltage has been forced to zero, the primary switch can be turned on with ZVS during this interval.

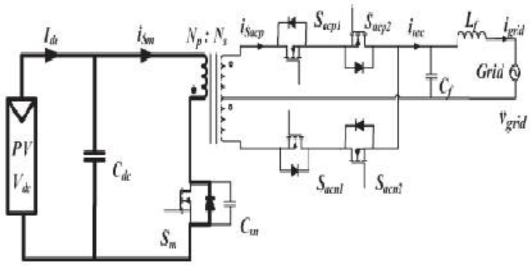

Fig 15: Mode VI

It can be observed that *Modes II*, *V*, and *VI* occur during the switching transitions. As a result, the time intervals of these modes are quite small as compared with the *Modes I*, *III*, and *IV*.

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VI. CONCLUSION

For a grid connected micro-inverters the single stage flyback topology is most suitable for better operation. The ZVS is achieved by using bidirectional switches was introduced for the grid-connected micro inverters. The soft-switching of the primary MOSFET is made possible by allowing a current flow from the grid side to the transformer, which provided the negative current required for ZVS. This is achieved by replacing the power MOSFET and the diode on the secondary side of conventional flyback inverters with bidirectional switches. Also the bidirectional switches were turned ON under ZVS, and thereby providing increased efficiency.

Advantages

- Higher maximum power tracking efficiency.
- Easier installation.
- Longer life-time.
- Incorporating converters into the solar panel modules reduces installation costs.
- Replacing hard-switching techniques with the soft switching it improves efficiency and reduces heat dissipation.
- Micro inverters tend to be lower powered which tends to lower internal temperatures and improve reliability.
- Improves system reliability.

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