Photo-Voltaic Array Fed Transformer-less Inverter with Energy Storage System for Non-isolated Micro Inverter Applications

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Abstract- This paper proposes hybrid energy system which consists of renewable energy source i.e. solar powered transformer less inverter and battery powered bi-directional direct current (DC) converter. The objective of this paper is reduce common mode voltage, minimize mosfet failure from reverse diode recovery, minimize conduction loss and full magnetic utilization using transformer-less inverter which is different from normal phase-leg inverter, it has proposed phase leg with optimized inductor and diodes. Battery energy storage system is used to avoid power interruption from PV panel during dark time. Proportional-Integral (PI) controller is used to provide gate signals to the transistor switches used in the transformer-less inverter. Simulation results help to demonstrate the merits of transformer-less inverter.

Keywords- Photo-Voltaic (PV) Array, Bidirectional DC-DC Converter (BDC), Hybrid Energy storage system (HESS), Battery (Bt).

1. Introduction

Nowadays many transformer-less pv inverters are available which eliminate the conventional transformers to achieve low cost, high efficiency, and to reduce leakage current. For higher power-level application requires neutral point clamped and t-type three level inverters which requires high direct current (DC) voltage but PV source not enough to provide that voltage [1,2]. For low power applications MOSFET is used to increase the efficiency [3,4].

The switching and conduction loss in the super-junction mosfet are low. But reverse recovery from mosfet's body diode cause high change in voltage with respect to time, high change in current , and shoot through effect while false triggering of transistor switches. The highly efficient and reliable concept inverter (HERIC) using two semiconductor switches and diodes to decouple the solar panel from the grid during shoot through occur in the phase leg, which reduce the common mode voltage. Other topologies use one transistor switch and four power semiconductor diodes to do decouple action [5].

Both topologies have easy structure and conduction and switching losses are low but phase leg failure exist when mosfet is adopted [6]. Another topology consists of three

IGBTS, and two MOSFETS to disconnect solar panel from the circuit and mosfet failure risk are avoided by using two igbts, but conduction loss of this topologies is more than HERIC topology due three active devices conducting at the same time [7]. Highly efficient mosfet based transformer-less PV inverter is proposed in this paper which utilize the magnetics fully and risk of diode reverse recovery is reduced.

2. Materials and Methodology

The figure 1 represents the proposed circuit diagram consists of boost convereter, transformer leg inverter, bidirectional dc to dc converter, solar panel, battery, and Proportional Integral (PI) controller. Nine power electronic semiconductor mosfet switches used in the circuit. Solar panel producing electrical energy from sunlight using photo-voltaic effect.

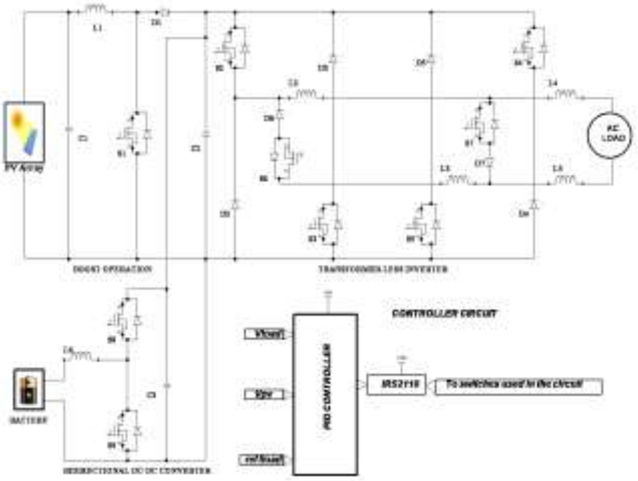

Fig. 1. Transformer-Less PV inverter with energy storage system

2.1. Modes of Operation

The modes of operation is divided into two sections a) Day time Operation b) Night Time Operation.

Day time operation: Solar power is available during this mode, and there are two modes of operation in this section. In mode1, the switch S1 in the boost converter turned ON and diode D1 is reverse biased, the solar power is storing its energy into the inductor L1. The capacitor C2 discharging its energy to the transformer-less inverter. The current loop in the transformer-less inverter is C2 positive terminal-S2-L2-L4-Load-L5-L3-S5-C2 negative terminal. The BDC acts as buck converter during this mode and battery is charging via the switch S8. The switching frequency of switches in the transformer-less inverter is double the times of switches in the boost converter and BDC. So the switches S2 and S5 are turned off during cycle 2, switch S6 turned on and stored energy in the inductors deliver to the load via S6-L2-load-L3-S6.

In mode 2, the switch S1 in the boost converter turned OFF and diode D1 is forward biased, the solar power and stored energy in the inductor L1 is fed into the transformer-less inverter and charging capacitor C2 terminal. The current loop in the transformer-less inverter is C2 positive terminal-S4-L5-Load-L4-S3-C2 negative terminal. The switches S4 and S3 are turned off during cycle 2, switch S7 turned on and stored energy in the inductors L4&L5 deliver to the load via S7-L4-load-L5-S7.

Night time operation: Solar power is not available during this section, battery provide energy during this mode via BDC. The Bidirectional dc to dc converter is connected in dc link. It acts as boost converter during this mode, because battery voltage is low compared with dc link voltage. The operation of transformer less inverter is same as previous section. In mode 1 switch S9 is turned ON and the current loop for this mode is C3 positive terminal-S2-L2-L4-Load-L5-L3-S5-C3 negative terminal. The switches S2 and S5 are turned off during cycle 2, switch S6 turned on and stored energy in the inductors deliver to the load via S6-L2-load-L3-S6. In mode 2 switch S9 turned OFF and battery energy and stored energy in the inductor is fed into the dc link. The current loop in the transformer-less inverter is C3 positive terminal-S4-L5-Load-L4-S3-C3 negative terminal. The switches S4 and S3 are turned off during cycle 2, switch S7 turned on and stored energy in the inductors L4&L5 deliver to the load via S7-L4-load-L5-S7.

3. Simulation Results and Discussion

The figure 2 is the simulink diagram which is designed using Matlab/simulink. Simulink and Simpower system components are used to design this circuit. Transistor (Mosfet) switches are used here, the switching frequencies used in the circuit is 10KHz.The solar panel is designed using single diode model. Powergui block is used to run simpower system elements. Scope is used to show the output in graphical view. Pulse generator and pwm generator block is used to provide gate pulses to the transistor switches.

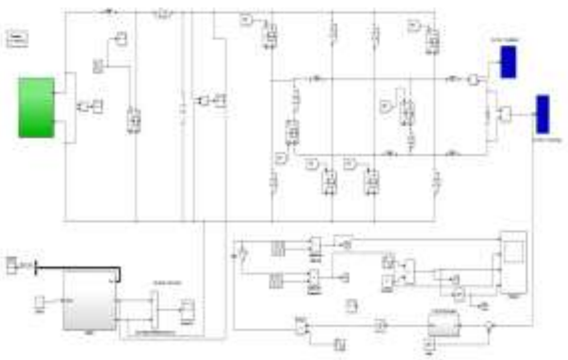

Fig. 2. Simulink Circuit of Transformer-Less PV inverter with energy storage system

The figure 3 represents output voltage of solar panel. The magnitude of this voltage is **113V**. İn all the graphs x-axis represents time period in seconds.

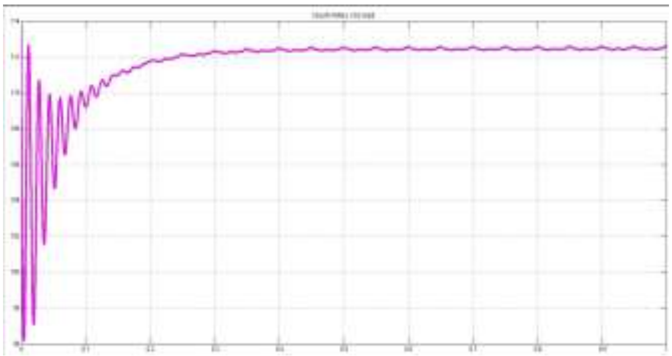

Fig. 3. Output Voltage of Solar Panel

The figure 4 represents four different gate pulses which is given to power semiconductor switches in the transformer-less inverter. The reference voltage and output voltage of the transformer-less inverter is compared, and then the output is given to the PI controller thereby Kp and Ki values are tuned to reduce the error. This controller produce reference signal which in turn compared with carrier signal to produce gate pulses. The carrier signals are operating in 10kHz frequency. The first gate pulses given to switches S2 and S5. The second row of this figure represents the pulse signal of the switches S3 and S4. These four switches are operated in high frequency (10kHz). Gate signal for switches S6 and S7 are produced by comparing sinusoidal wave which is operating at 50Hz with zero. The third row of this figure represents the pulse signal of the switches S6 .The last row of this figure represents the pulse signal of the switches S7. Switches S6 & S7 are operated in fundamental frequency (50Hz).

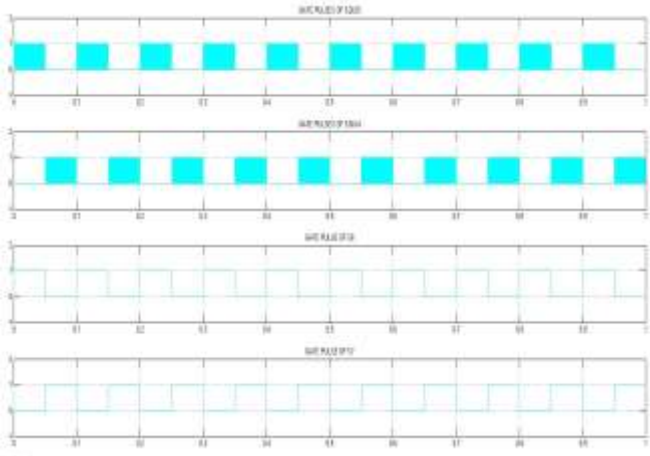

Fig. 4. Pulse signal given to switches in the transformer-less inverter

The figure 5 represents the DC Link voltage. The DC link is the common point for boost converter output, transformer-less inverter input, and output of the BDC. The magnitude of dc link voltage is **230V DC**.

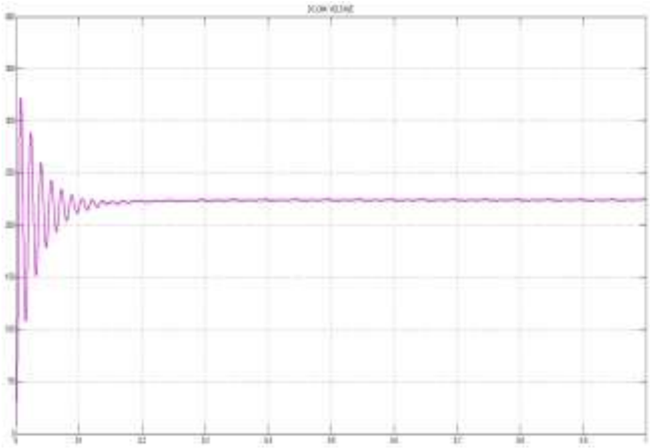

Fig. 5. DC Link Voltage

The AC output voltage of the Transformer-less inverter is shown in the figure 6. X-Axis and Y-axis represents time period and amplitude of voltage respectively. The Magnitude of the output voltage is **230V AC.**

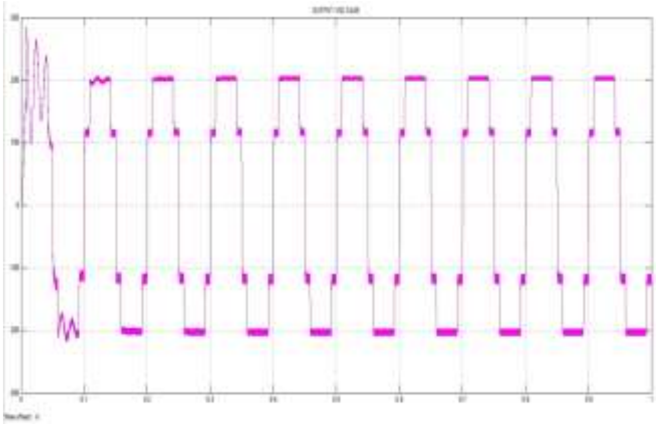

Fig. 6. AC Output Voltage

The AC output current of the Transformer-less inverter is shown in the figure 7 X-Axis and Y-axis represents time period and amplitude of current respectively. The magnitude of the output current is **0.2A AC.**

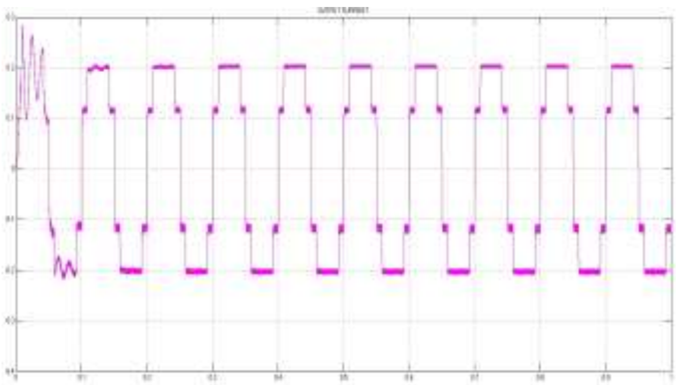

Fig. 7. AC Output Current

The figure 8. represents the Proportional-Integral controller used in the circuit diagram. The values of proportional and integral gain used in the circuit are 1 and 10 respectively**.**

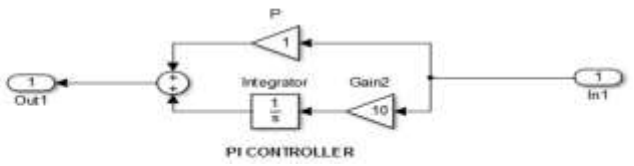

Fig. 8. Proportional-Integral Controller.

4. Conclusion

This paper proposed a novel transformer-less PV inverter with energy storage system which helped to improve the system efficiency, low cost, reduced risk of diode reverse recovery. The magnetics of the optimized inductor are fully utilized. The proposed phase leg of the inverter prevent solar panel from shoot through effect which caused due to false triggering of switches. The proportional-Integral controller helped to generate gate pulses to the transformer-less inverter switches, reduce noise in the waveforms. The battery energy storage system provided energy to the load while solar power was not available. The simulation results demonstrated advantages of proposed transformer-less PV inverter.

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