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High Performance Single-Phase Inverter for Grid-Connected Photovoltaic Systems

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Abstract— **This paper presents a high performance single-phase inverter for grid connection of photovoltaic applications. The proposed inverter utilizes two split ac-coupled inductors that operate separately for positive and negative half grid cycles. The proposed inverter has high performance and operates at higher switching frequencies. The high efficiency and operating at higher operating frequencies enables reduced cooling requirements and results in system cost savings by shrinking passive components. The photovoltaic array can be decoupled from the grid with two additional ac-side switches. The operation principle, common-mode characteristic and design considerations of the proposed transformerless inverter are illustrated. The proposed topology gives higher efficiency than topologies with transformers. In this proposed system PI controller is used in control to reduce Harmonics.**

Index Terms—**About four key words or phrases in alphabetical order, separated by commas.**

I. INTRODUCTION

Photovoltaic (PV) systems have been used for many decades. Today, with the focus on greener sources of power, PV has become an important source of power for a wide range of applications. Improvements in converting light energy into electrical energy as well as the cost reductions have helped create this growth. In the middle of the 1980's the market for PV grid connected systems developed with central inverters of several kilowatts in size being the most common. Even with higher efficiency and lower cost,[1-4] the goal remains to maximize the power from the PV system under various lighting conditions. The elimination of the output transformer from grid connected photovoltaic (PV) systems not only reduces the cost but also size[5].

Photovoltaic (PV) power supplied to the utility grid is gaining more and more visibility, while the world's power demand is increasing[6]. Today the contribution from photovoltaic (PV) energy compared to the other renewable energy sources is very low, but due to decreasing system prices the market for PV systems is one of the most stable and fastest growing in the world[7]. Photovoltaic (PV) ac modules may become a trend for future PV systems because of their greater flexibility in distributed system expansion. Photo voltaic(PV) inverters become more and more widespread within both private and commercial circles[8].

Not many PV systems have so far been placed into the grid due to the relatively high cost, compared with more traditional energy sources such as oil, gas, coal, nuclear, hydro, and wind. Solid-state inverters have been shown to be the enabling technology for putting PV systems into the grid. The continuing decrease of the cost of the PV's, the advancement of power electronic and semiconductor technology and favourable incentives in a number of industrial countries in general had a profound impact on the commercial acceptance of grid connected PV systems in the recent years. When sun rays diving into PV cell it converts solar energy into electricity.

There exists two layer in a PV array, N-type layer and P-type layer, the two layers work together and generate electricity when photon exceeds band gap of solar cell. The equivalent circuit of a solar cell can be described as a current source is parallel with a diode and shown in Fig.1

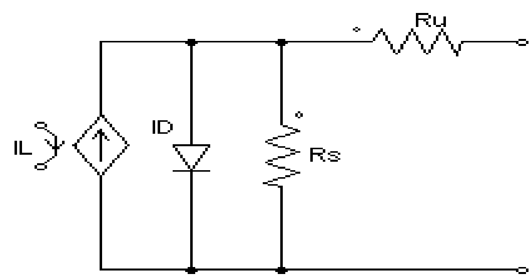

Fig.1 equivalent circuit of solar cell

Solar photovoltaic (PV) systems are becoming a more common sight, especially in regions of the country where sunlight is the strongest. The most basic part of a PV system is the cell. Groups of cells are assembled in a series to form a module, which is enclosed between sheets of tempered glass or plastic to protect the cells. A photovoltaic system, also photovoltaic power system, solar PV system, PV system or casually solar array, is a power system designed to supply usable solar power by means of photo voltaics. It consists of an arrangement of several components, including solar panels to absorb and directly convert sunlight into electricity, a solar inverter to change the electrical current from DC to AC, as well as mounting, cabling and other electrical accessories to set-up a working system. To avoid the common-mode leakage current, the conventional solution employs the half-bridge inverter or the full-bridge inverter with bipolar sinusoidal pulse width modulation (SPWM)[9].

A grid connected system is connected to a larger independent grid (typically the public electricity grid) and feeds energy directly into the grid. This energy may be shared by a residential or commercial building before or after the revenue measurement point. The difference being whether the credited energy production is calculated independently of the

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customer's energy consumption (feed-in tariff) or only on the difference of energy (net metering). Grid connected systems vary in size from residential (2-10kWp) to solar power stations (up to 10s of MWp). This is a form of decentralized electricity generation. The feeding of electricity into the grid requires the transformation of DC into AC by a special, synchronising grid-tie inverter. In kW sized installations the DC side system voltage is as high as permitted (typically 1000V except US residential 600V) to limit ohmic losses. Most modules (72 crystalline silicon cells) generate 160W to 300W at 36 volts. It is sometimes necessary or desirable to connect the modules partially in parallel rather than all in series. One set of modules connected in series is known as a 'string'[10].

Uncertainties in revenue over time relate mostly to the evaluation of the solar resource and to the performance of the system itself. In the best of cases, uncertainties are typically 4% for year-to-year climate variability, 5% for solar resource estimation (in a horizontal plane), 3% for estimation of irradiation in the plane of the array, 3% for power rating of modules, 2% for losses due to dirt and soiling, 1.5% for losses due to snow, and 5% for other sources of error. Identifying and reacting to manageable losses is critical for revenue and O&M efficiency. Monitoring of array performance may be part of contractual agreements between the array owner, the builder, and the utility purchasing the energy produced.[citation needed] Recently, a method to create "synthetic days" using readily available weather data and verification using the Open Solar Outdoors Test Field make it possible to predict photovoltaic systems performance with high degrees of accuracy. This method can be used to then determine loss mechanisms on a local scale - such as those from snow or the effects of surface coatings (e.g. hydrophobic or hydrophilic) on soiling or snow losses. Access to the Internet has allowed a further improvement in energy monitoring and communication. Dedicated systems are available from a number of vendors. For solar PV system that use micro inverters (panel-level DC to AC conversion) [11][12], module power data is automatically provided. Some systems allow setting performance alerts that trigger phone/email/text warnings when limits are reached. These solutions provide data for the system owner and the installer. Installers are able to remotely monitor multiple installations, and see at-a-glance the status of their entire installed base.

A grid-connected photovoltaic power system will reduce the power bill as it is possible to sell surplus electricity produced to the local electricity supplier. Grid-connected PV systems are comparatively easier to install as they do not require a battery system. Grid interconnection of photovoltaic (PV) power generation systems has the advantage of effective utilization of generated power because there are no storage losses involved.

A photovoltaic power system is carbon negative over its lifespan, as any energy produced over and above that to build the panel initially offsets the need for burning fossil fuels. Even though the sun doesn't always shine, any installation gives a reasonably predictable average reduction in carbon consumption.

The grid connected inverter topologies [13] requires only six Metal Oxide Field Effect Transistors (MOSFETs), six diodes and two coupled inductors. In this paper, a high-performance inverter, using MOSFETs for all the active switches, is proposed for PV, non isolated, ac-module applications. Detailed power stage operating principles, PWM scheme for the proposed inverter are described clearly. The smallest possible grid connected **PV** system unit is a **PV** module with a module-integrated inverter. In this case, mismatching losses are minimised,[14] since load matching for the individual **PV** module is achieved through its inverter. A centralised inverter[15] topology is one of the system configuration around four systems.

II. PV INVERTER AND OPERATION ANALYSIS

The below fig 2 shows the circuit diagram of the PV inverter consisting of six MOSFETs switches (S1–S6), six diodes (D1–D6), and two split ac-coupled inductors named *L*1 and *L*2 . In this four diodes D1,D2,D3,D4 perform voltage clamping functions for the active switches S1,S2,S3,S4 . The Secondary side(ac-side) switch pairs are composed of S5, D5 and S6, D6 , respectively, which provide unidirectional current flow branches during the freewheeling phases decoupling the grid from the PV array and minimizing the CM leakage current. Here the inverter topology divides the ac side into two independent units for positive and negative half cycles.

It consists of four operation stages of the inverter within one grid cycle. During positive cycle S1 and S3 are turned ON While S5 remains turned ON. If S1 and S3 are in ON condition the diode D5 is in reverse biased condition .Both the inductors i_{L01} and i_{L03} are charged equally. The energy is delivered from DC source to the Grid. Whenever S1 and S3 are in off condition the S5 and D5 facilitates inductor current i_{L01} and i_{L03} and freewheeling path occurs when the panel is decoupled from the grid. In this condition coupled inductor L1 is active and L2 is inactive.

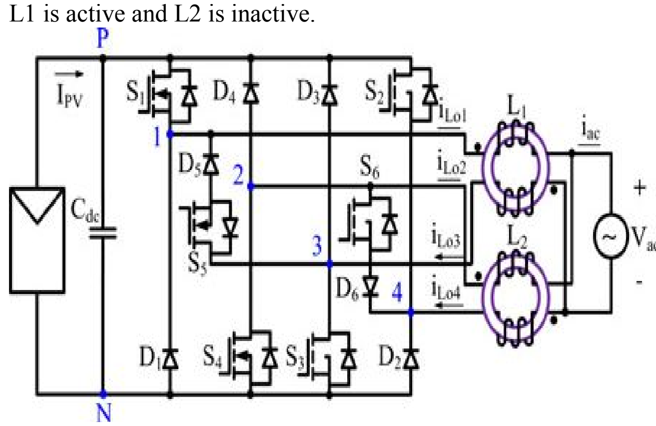

Fig 2 PV inverter circuit diagram

Where as in the case of negative half cycle Switch S2 and switch S4 are turned on while S6 remains turned ON. If S2 and S4 are in ON condition the diode D6 is in reverse biased condition .Both the inductors i_{L02} and i_{L04} are charged equally. And the freewheeling path occurs only through Switch S6 and D6.

III. SIMULATION VERIFICATIONS

This section explains the details of the converter power stage designed in this paper. The converter topology is then implemented using MATLAB (R2010a) to test the validity of system. The output of the converter power stage is obtained for both filtered and unfiltered waveforms. Inverter voltage and current is compared to that of the grid. Fig 3 shows the simulation diagram for proposed high performance converter circuit in MATLAB (R2010a).

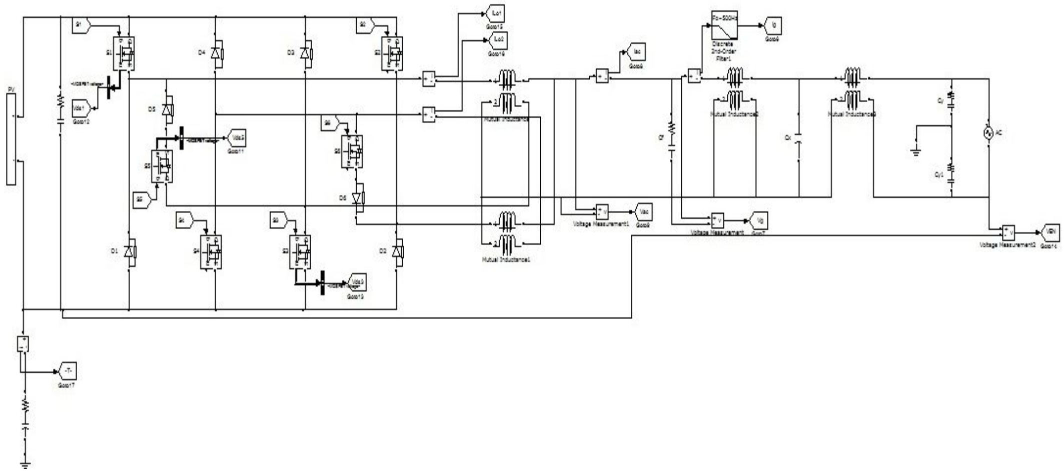

Fig 3 Simulation diagram of proposed converter

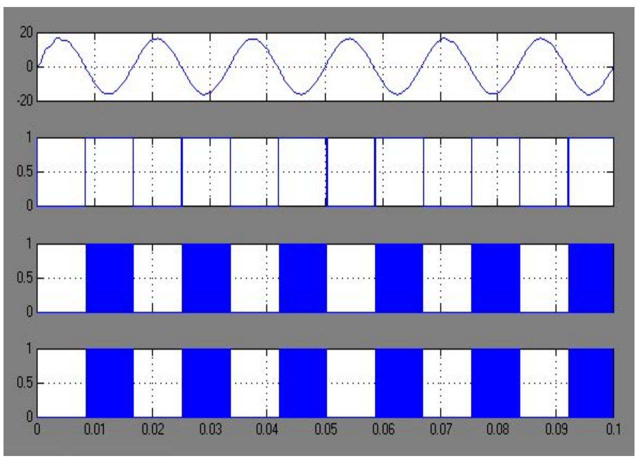

Fig 4 Switch gating signals

Fig 4 shows the Ig (Grid current) in 4(a), gating signal given to S_5 in 4(b), gating signal to S_1 voltage at switch1 in 4(c) and gating signal to S_3 voltage in 4(d).

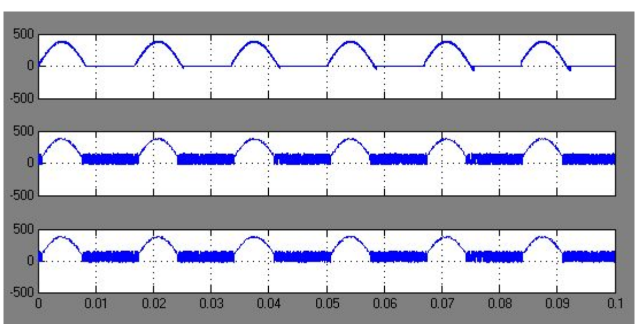

Fig 5 Voltages accross the switches S_5, S_1 and S_3

Fig 5 shows the drain to source voltages of the switches during grid connected mode operation where the S_1 and S_3 are in on condition and S_5 will take care of free wheeling action.

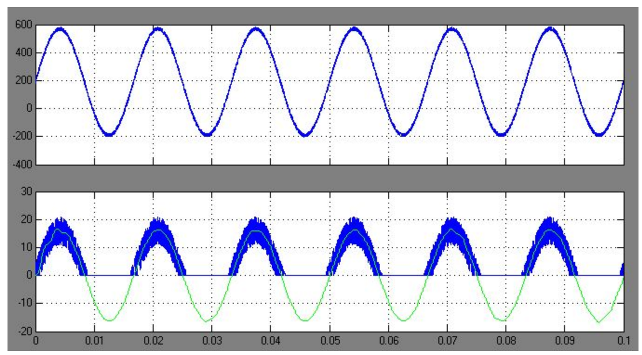

Fig 6 Ground potential, Grid current and Inductor current(i_{Lo1})

Fig.6 shows the ground potential and output current. It can be seen that the output current is sinusoidal waveform.

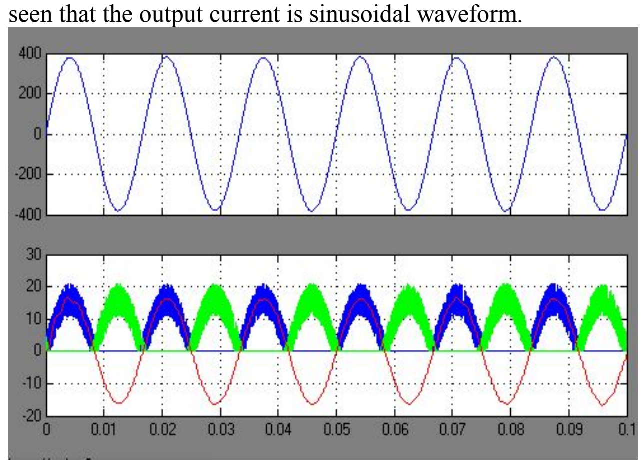

Fig 7 Inverter output waveforms

The simulated waveforms of the grid voltage and current under the operating conditions are described in Fig. 7 along with the current through the respective inductor. This figure shows that the proposed inverter presents high power factor and low harmonic distortion.

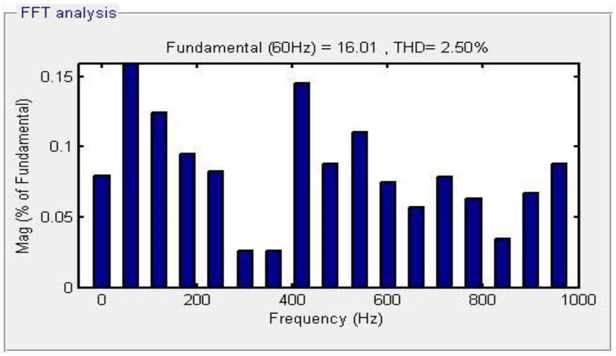

Fig 8 THD without PI Controller

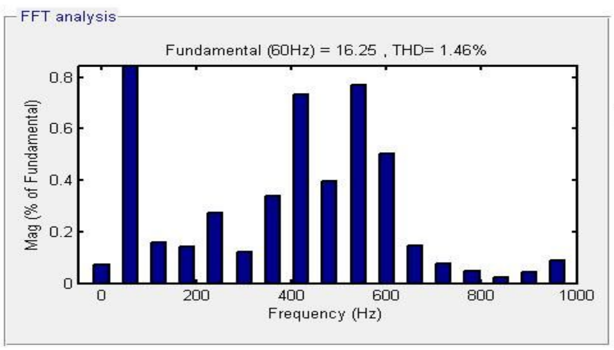

Fig 9 THD with PI Controller

Fig. 8 and Fig 9 presents the FFT analysis of inverter output current without and with PI controller respectively.

The fast Fourier transform ensures that proposed inverter output has THD of 2.50% but with PI controller output has THD of only 1.46%. After filtering the output has low level of THD because the proposed circuit is totally transformer less.

CONCLUSION

A high performance single phase inverter for grid connected photovoltaic systems are presented in this paper .Here we are using two coupled inductors ,so by using this we can step up and step down the voltages at a time as a result we can reduce the cost of the inverter. And also due to High operating frequencies, it enables reduced cooling requirements. By the use of PI controller in this topology, THD is reduced from 2.50% to 1.46%. Hence this system has high performance and economical.

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