Design and Development of Solar PV Based Grid Interactive Inverter

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***Abstract*—Due to depleting global fossil fuel based energy resources power grids all over the world are exploring new avenues for power generation. Clean and renewable energy resources are the main focus of attention, with solar and wind being two prime renewable energy sources. Solar energy as a source is available intermittently, but in plenty in tropical areas. Therefore, its best use as a reliable power source is by connecting it to the grid. If it has to be used as a standalone power source, some provision has to be made to tackle its dispatchability issues (due to its intermittent availability), so that it supplies sufficient power to its connected loads without interruption. This paper gives a brief idea about the design considerations that go into developing a grid interactive inverter. The term interactive means that the proposed system is capable of operating in grid connected as well as islanded modes. Also, provision of load management is made in low irradiance conditions, while in island mode. The paper describes a two stage solar PV system, the first stage comprising a boost converter used as a voltage booster and for extracting maximum power. In the second stage is a three leg inverter that pumps the available energy into the grid.**

I. Introduction

THERE'S a tremendous pressure on today's grids due to the ever increasing power demand supply ratio. Also emphasis is on clean and renewable energy sources in order to reduce carbon emissions. Of all the major renewable energy sources in consideration today, solar PV is perhaps the most sought after option. Tropical countries have high solar insolation and this can be exploited extensively for power generation. For effective use of solar energy, power converters are an indispensible part of solar power generation systems. This is because, the power from solar PV is dc and has to be converted to ac to be used for standard appliances designed for ac power as input. Hence an inverter comes into picture. Also in most cases, the dc output voltage of the solar PV does not match to that of inverters dc link voltage. Hence a dc-dc converter is also required. This dc-dc converter can also serve the purpose of maximum power point tracker, which results in high overall system efficiency. Power from solar PV can be utilized in either a grid connected mode or off grid (standalone) mode. Power from standalone solar PV systems has a wide range of applications in developing tropical countries, especially in the rural areas, the typical applications being water pumping and lighting. The drawback of grid connected inverters is that, in case of a grid failure, the inverter is unable to supply power despite the solar power being available. This problem can be mitigated by the use of a grid interactive inverter. A grid interactive inverter has some load connected to it and at the same time the inverter is connected to the grid. The inverter supplies surplus power to the grid and absorbs the deficit power from the grid. In case of grid failure event, the inverter islands itself and its load, and manages to sustain the island by either using energy storage systems or by active load management.

II. Overview of Techniques Used For Grid Connected Solar PV Systems

A. *Inverters*

Various types of inverters are used for dc to ac conversion of solar power. Some are listed below.

1) Single Phase Half Bridge Inverter: This is the most basic configuration of inverter and consists of two switches and a split power supply [1]. Due to split power supply, it is not much suitable for grid connected operations as the dc link voltage would have to be boosted to double value as compared to a single phase inverter.

2) Single Phase Full Bridge Inverter: This is the most widely used configuration of single phase inverter and consists of four switches. It is used for low to medium power requirements. It can be used for single phase grid connected applications. There are also algorithms in which maximum power point (MPP) is extracted making single stage implementation possible [2].

3) Three Phase Three Leg Inverter: This is the most common configuration of inverter in any three phase application [3]. The three phase inverters are used in three phase three wire systems and are used widely used in grid connected systems with or without a transformer. They can be operated for high power operation as well.

4) Current Source Inverters: These inverters are preferred in single stage implementation of solar PV systems where the power conversion is from a low voltage dc input to a comparatively high voltage ac output. This kind of power topology is seen in [4] and [5].

B. Types of MPPT (Maximum power point tracking) converter topologies.

Various types of topologies for mppt are used by various researchers. Some are listed below.

1) Inverters with inbuilt MPPT function: In this case, there is no dedicated dc-dc converter for MPP tracking. These are single stage systems in which MPP tracking and inversion are done within the same stage, i.e. the inverter. Such systems are listed in [2], [4] and [5].

2) Boost converter for MPPT: This is a popular technique in two stage systems where a separate dc-dc converter is used to extract maximum power from solar PV because along with MPP extraction, voltage boosting is done to make the voltage suitable to the inverters dc link voltage. Such technique is used in [3]. This paper also proposes a similar technique.

3) Two inductor boost converter for MPPT: This is another popular technique used for solar PV systems because along with boosting the solar PV voltage and extracting maximum power, this topology also provides isolation [6].

4) Resonant dc-dc converter for MPPT: Researchers are also exploring the possibilities of the use of soft switching converters in MPPT. The use of a full bridge zero voltage switching resonant step up dc-dc converter is given in [7].

C. Types of Filters for Inverters [8], [9].

The most common types of filters for grid connected inverters are L filter, LC filter and LCL filter. They are briefly discussed below.

1) L filter: This is the most basic filter and is not as efficient as LC or LCL filter. It is a first order filter and has attenuation of 20db/decade over the entire frequency range [8]. Hence L filter is suited for converters with high switching frequency where the attenuation proves to be sufficient.

2) LC filter: LC filter is a second order filter and has better filtering characteristics than an L filter. LC filters are easy to design and have an advantage of stopping specific harmonics. LC filters are suitable for converters that have switching frequencies of hundreds of hertz, and thus produce PWM harmonics at frequencies too low to tune an LCL filter [9].

3) *LCL filter:* LCL filters have the attenuation of 60db/decade after the resonant frequency and can therefore be used for converters with lower switching frequencies. But if the resonant frequency is too far from the switching frequency, it might challenge the control loop [9]. LCL filters have good current ripple attenuation even while they have small inductance values [8].

III. PROPOSED SOLAR PV SYSTEM

As discussed above, a grid tied connected inverter cannot deliver power in the case of grid failure. Therefore, the grid interactive inverter can be a solution to this problem as it islands itself when grid failure occurs. The proposed solar PV system has three modes of operation, they are grid connected mode, island mode and load management mode. This makes it more energy efficient as whatever energy is being generated is continuously being utilized as long as the load is connected. Fig. 1 gives the diagrammatic representation of the proposed solar PV system. The control in this system is implemented using Texas Instruments TMS320F28069 Digital Signal Processor.

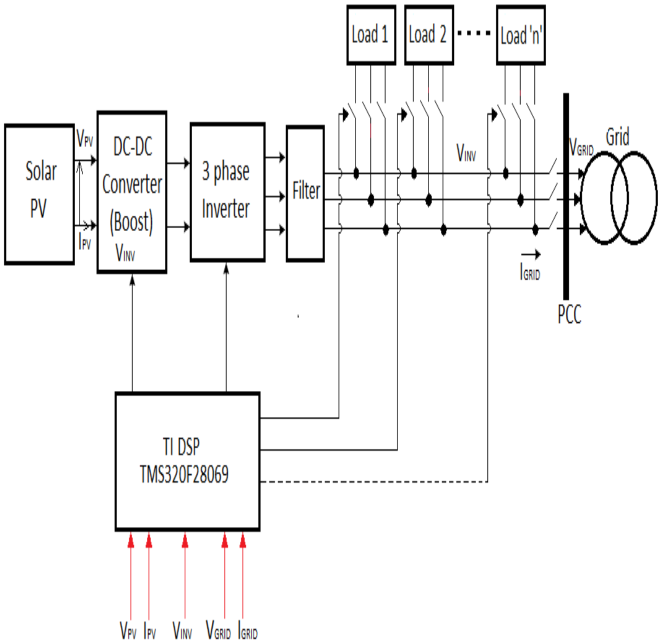

Fig. 1 Block diagram of the proposed solar PV system

The proposed system is designed to be connected to an array of solar panels of 1000W. The boost converter is used for extracting maximum power from the solar panel array and to boost it in order to provide a sufficiently high dc link voltage to the inverter . The three phase three leg inverter feeds the voltage to the grid in current mode control through an LC filter, apart from maintaining the dc link voltage. The system does not have an isolation transformer to make it light and compact. Hence the system has an excellent power to weight ratio. The proposed system is a two stage system and the operation of the two stages is given below.

A. Stage 1.

The stage 1 is a boost converter that is being used to boost the available solar pv voltage while simultaneously tracking the maximum power point. The input voltage to the boost converter from the solar PV array is approximately around 400V with a range being from 350V to 500V or above. The transfer function of a boost converter is given below in equation (1). The boost converter will raise the voltage level at the output of the solar panels to somewhat around 700V because that is approximatedc link voltage for a transformerless grid connected solar pv system, when the grid voltage is 230 volts. But the dc link voltage is maintained by the inverter.

$$\frac{V_c}{d} = \frac{(1-D)V_c - LI_L s}{LCs^2 + \frac{L}{R}s + (1-D)^2} \qquad (1)$$

It follows the simple and time tested perturb and observe algorithm. The boost converter as a system needs significant compensation to make it a highly stable system. The amount of compensation by a typical PI compensator is not always sufficient to stabilise a boost converter system. Hence the type III compensator is used so as to satisfy the stability requirement of the boost converter. A precisely tuned type III compensator will stabilise the boost converter system by providing the necessary compensation.

B. Stage 2.

The second stage is a three leg inverter for converting the dc output of the boost converter to ac so as to make the available power compatible to be fed to the grid. It is given in Fig. 2.

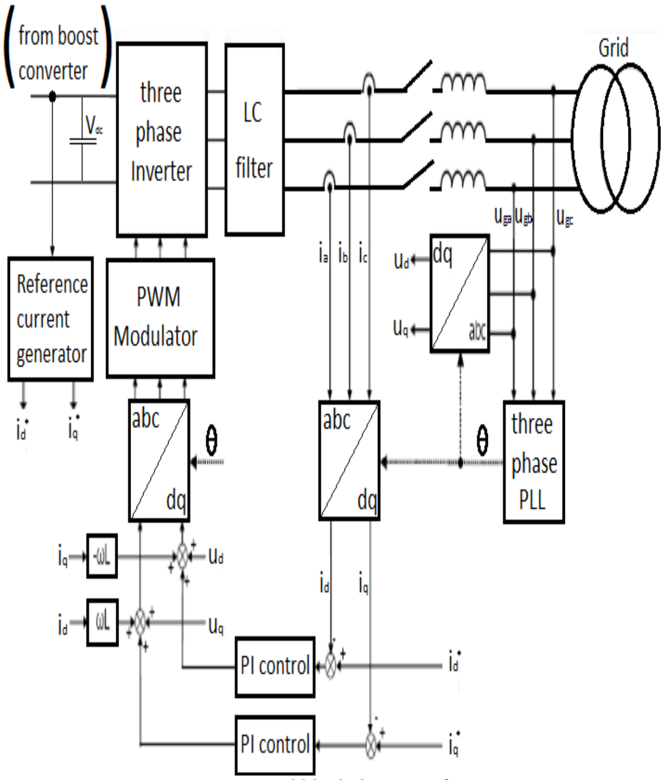

Fig. 2 Functional block diagram of stage 2.

For grid synchronisation the, dq reference frame has been used due to its advantages over other methods [9][10]. As seen in Fig. 2, the grid voltage is sensed and the grid angle (theta) is obtained by the use of a three phase PLL (Phase Locked Loop). In the grid connected mode of operation, the voltage is always determined by the grid. Once the output voltage and the phase of the stage 2 perfectly matches to that of the grid, the switch between the grid and stage 2 is closed to facilitate power flow to the grid (or from the grid in deficit condition.). Hence the amount of current to be fed into the grid remains to be regulated and varied according to the available power at the output of the boost converter, i.e. stage 1. The current flowing to the grid is also sensed and converted to the dq reference frame. Hence we get the values Id and Iq. These values are compared to the referance values Id* and Iq*. For transferring only active power to the grid, the variable Id needs to be regulated, while, by setting the reference value Iq* to zero, the reactive power is forced to zero. Hence only active power is transferred to the grid. The reference value Id* is generated using the dc link voltage. The difference between Id* and Id, is passed through a PI regulator which acts like a compensator and also eliminates error. The output of the PI regulator is again converted back to three phase, using the phase angle available from the three phase PLL. This is given to PWM modulator, which fires the switches of the three leg inverter. The transfer function of a three leg inverter is given below. The equations below represent control to d axis current in grid connected mode.

$$\frac{\hat{i}_d(s)}{\hat{d}_d(s)} = \frac{V_{dc}s}{s^2L - Z\omega} \qquad (2)$$

$$\frac{\hat{i}_d(s)}{\hat{d}_q(s)} = \frac{-V_{dc}.Z}{s^2L^2 - Z\omega L} \qquad (3)$$

IV. Modes Of Operation

The modes of operation are discussed below in brief.

A. Grid connected mode.

In this mode, the grid is available. In this mode, the load shown in Fig. 1 will get uninterruptible power even if very little solar power is available, as during cloudy weather or during the times around sunrise and sunset. In this mode, the surplus power (if available) is pumped into the grid and, in case of power deficit (when solar power available is lower than required by the connected load), the deficit power is taken from the grid.

B. Island mode.

The system will enter this mode in the event of grid failure and when the solar power available is sufficient to cater to the connected load.

C. Load management mode.

The system would enter this mode only during the event of a grid failure and when the available solar power won't be sufficient to feed the connected load. In this mode, the available power will then be utilised by managing the various connected mode by priority and the amount of power each load consumes. The frequent occurrence of this mode will be in the monsoons and the applications in places where the grid condition is poor. Immediately after the system enters this mode, there can be a sudden switching of various loads depending upon the priority of the load and the available solar insolation (power).

V. SIMULATION DETAILS

The system was simulated for island mode of operation i.e. in voltage mode control. The system worked stably and accurate signal tracking was done using standalone mode. PI compensator was used for stability and error elimination. For PI controller, Proportional gain (Kp) value was 40 and Integral gain value (Ki) was 200 for d component as well as for q component The following results were obtained. The inverter was also tested for 'sudden change in load' condition, for which it showed satisfactory performance. The change in control signal for sudden change in load can be observed at time 0.2 in Fig. 4 below.

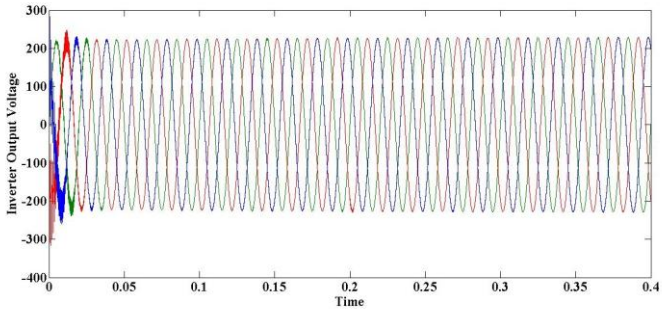

Fig. 3 Inverter Output Voltage

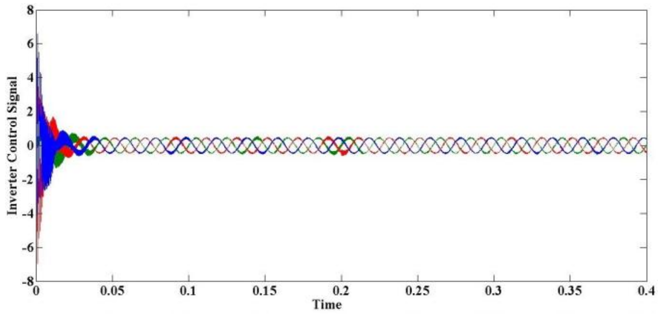

Fig. 4 Control Voltage of Inverter.

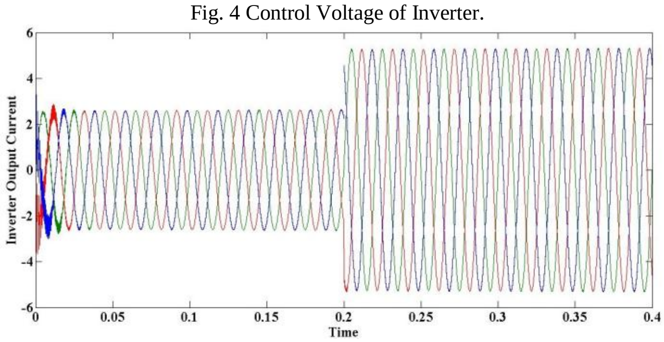

Fig. 5 Inverter Output Current

The originally connected load is 500VA and at 0.2 seconds the load is doubled i.e. 1KVA. The system response is satisfactory as there is almost zero variation in system output voltage.

VI. HARDWARE IMPLEMENTATION AND RESULTS

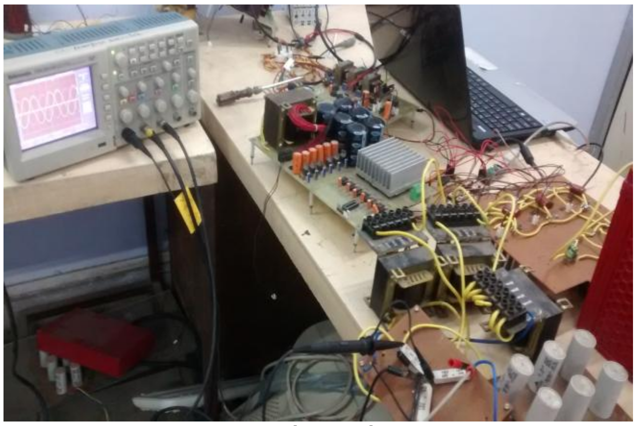

Fig. 6 Hardware Implementation.

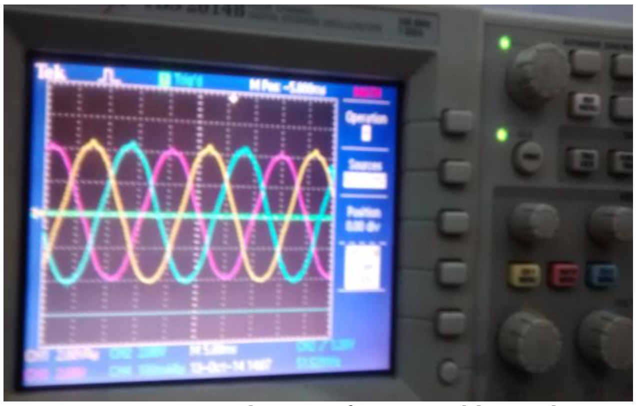

Fig. 7 Output Voltage Waveforms in standalone mode.

VII. CONCLUSION

It is seen that, in the above system, the available solar power is used efficiently as compared to a conventional grid connected system, due to the ability of the grid interactive inverter to manage load and operate in the island mode as well. Also, the system will be cheaper and lighter due to the absence of a bulky transformer. The energy efficiency can be further improved by incorporating limited energy storage element, but, at a higher cost. The proposed system is an attractive option to isolated rural communities that do not have continuous access to a power grid, due to its load management capability and cheap cost.

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