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Three Phase Grid Connected Photovoltaic Power System

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Abstract: A renewable energy resource can be used repeatedly because it is replaced naturally i.e., it is limitless. Example: solar energy, water, tidal. So, they represent reliable alternatives to conventional energy sources example oil and natural gas. But, the efficiency and performance of these systems are still under development. The PV systems are mostly used as they are light and easily installable. This system connection to the grid requires special conditions to obtain a high quality Electrical power system. This paper presents the interfacing of three phase grid connected PV system. DC-DC step up converter (boost converter) with maximum power point tracing (MPPT) is used to extract the maximum power obtained from the sun and transfer it to the grid. In any PV based system, the inverter is a critical component which is responsible for the control of electricity flow between the dc source, and load or grid so a voltage source inverter (VSI) is used to convert the DC power; into AC power before transferring it into the grid. A comprehensive simulation and implementation of a three-phase grid connected inverter are presented to validate the proposed controller for the grid connected PV system.

Keywords: Renewable energy, Grid, PV modules, Photovoltaic system, Boost converter, MPPT, Voltage source inverter.

I. INTRODUCTION

Due to increase in population, urbanization, and industrialization, renewable Energy demand is increasing day by day. Renewable energy resources are alternatives to our traditional energy sources which are limited and will expire. Renewable energy resources such as solar, wind and hydro became more and more popular mainly because they produce no emissions and are inexhaustible. Since the solar radiant energy is abundant and is sustainable the photovoltaic (PV) energy effect can be considered as an essential sustainable resource, thus the grid connected photovoltaic system is widely used. Even though the solar energy is present in huge amount and free of cost, the cost of photovoltaic cells is very high. The solar cell is basic element of a PV system which converts the solar irradiance into direct current. Grid interconnection of PV system requires an efficient converter to convert the low DC voltage into AC.To ensure the safety of the PV installer and reliability of the utility grid, the technical requirements from both the utility grid side and PV system side need to be satisfied to utilize the generated power effectively. An interface system must be developed to make the interconnection between the PV system and the grid. The system must be stimulated in order to ensure that the system will work as desired and to investigate its impact in different conditions.This paper is a small contribution in this area, but furthermore, researchers and projects must be done for implementation of grid-connected PV systems. So, the main objective in developing a power electronics interface for a three-phase grid connected PV, capable of extracting maximum power from the PV arrays at all insolation levels and implementation of the inverter to convert the DC output to a voltage compatible with the utility grid and house appliances.

II. GRID CONNECTED PV SYSTEM

A.Elements Included in a System of Photovoltaic Conversion
The basic schematic diagram of a grid connected PV system with voltage source inverter is shown below.

The main elements that can be included in a system ofPhotovoltaic conversions are Photovoltaic modules, A converter, utility grid, loads DC and AC, and Inverters [2].

It is an arrangement used in PV standby power supply units, it is called grid connected system without a battery backup.Although systems with battery backup confront the issue ofreliability of the grid supply but it is more complicated andmore expensive.

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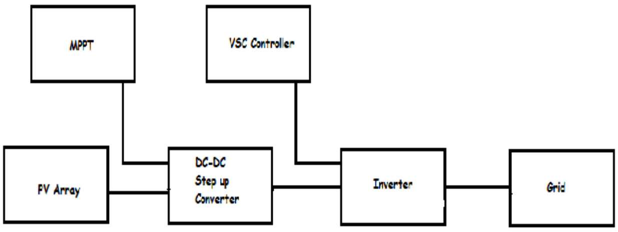

Fig.1. Grid connected PV system block Diagram

i) PV module

The solar panel is the power source of all photovoltaicinstallation. It is the result of a set of photovoltaic cells inseries and parallel. PV cell directly converters the solarirradiance into electricity in the form of dc when sunlightinteracts with semiconductor materials in the PV cells.

Figure (2) shows the equivalent circuit of a PV, from whichnonlinear I-V characteristic can be deduced. Hence, the cellsare connected in series and in parallel combinations in orderto form an array with desired voltage and power levels, solarcells are combined to form 'modules' to obtain the voltageand current (and therefore power) desired.

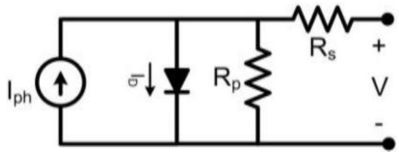

Fig. 2. Equivalent circuit of photovoltaic cell

2) DC-DC Boost Converter

The positioning of the boost converter will improve thewhole photovoltaic installation, allowing different controlsfrom the system. Depending on the applied regulation, thepanels will contribute to the maximum energy given to thesystem or the optimal energy for their operation. The boostconverter is a medium of power transmission to performenergy absorption and injection from solar panel to grid-tiedinverter. The process of energy absorption and injection isperformed by a combination of four components which arean inductor, electronic switch, and diode and outputcapacitor [3]. The connection of a boost converter is shownin figure.

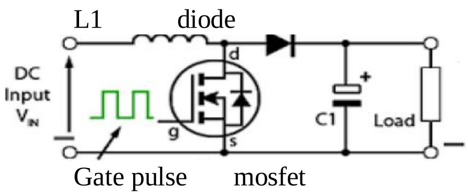

Fig.3. Boost Converter Circuit

When switch is closed for time t l, the inductor currentrises and energy is stored in inductor L. If the switch is openfor time t2, the energy stored in the inductor is translatethrough diode D and inductor current falls, the switchingduty cycle a is defined as the ratio of the on duration to theswitching time period so the output voltage is greater thanthe input voltage and is expressed as in eq. (1)

$$Vout/Vin=1/\ (1-a)\quad (1)$$

5-kHz DC-DC boostconverter increasing voltage from PV natural voltage (273 V DC at maximum power) to 500 V DC. Switching duty cycle is optimized by a MPPT controller that uses the 'Incremental Conductance + Integral Regulator' technique. This MPPT system automatically varies the duty cycle in order to generate the required voltage to extract maximum power.

3) Inverter

It is the main part of the system which is consists ofsemiconductor switches with a controller that provides theright switching pulses to control the inverter. It converts the DC power produced by the PV array into AC powerconsistent with the voltage and power quality required by theutility grid.

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The inverter topology selected for this design is thevoltage source inverter (VSI). Figure (4) shows a schematicdiagram of a 3 phase VSI. It is composed of six switches SIthrough S6 with each phase output connected to the middleof each "inverter leg". Two switches in each phase are usedto construct one leg. The AC output voltage from the inverteris obtained by controlling the semiconductor switches ONand OFF to generate the desired output [4].

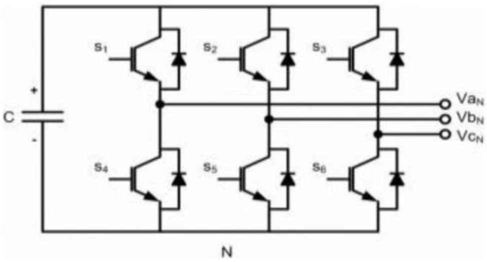

Fig. 4. Topology of Three Phase Inverter

The AC output waveforms shape and quality are directlyrelated to how the conduction intervals of the switches arecontrolled. The method chosen for this application wassinusoidal pulse width modulation (SPWM), it allows thecontrol of the phase, magnitude, and frequency of thegenerated AC waveform. It requires three referencesinusoidal waveforms (for three phase operation) of the same frequency as the desired output waveform and one high frequency triangle waveform known as the carrier signal.
The process is done by comparing the magnitudes of thesinusoidal and triangle waveforms. When the amplitude ofthe modulating signal is greater than that of the carriersignal, the upper switch in the corresponding phase leg infigure (4) is activated. This leads to the output voltagehaving the same magnitude of the DC link voltage and thevice versa. The magnitude of the output phase voltage(RMS) can be determined using eq. (2). Where ma is themodulation index and calculated as in eq. (3).

$V\ rms = m_a(Vdc/2.828)$ (2)

$m_a = Vm/Vcarrier$ (3)

4) Other Devices
Filter can also be used for a better performance, ameter could be used to account for the energy being drawn from or fed into the local supply network.

5) Load
It is the component responsible for absorbing this energy and transforming it into work.

6) Grid
An electrical grid is an interconnected network for delivering electricity from supply to consumer. Utility grid (25-kV distribution feeder + 120 kV equivalent transmission system).

B. METHODOLOGY
The system is composed mainly as following:
Photovoltaic array converts the sun irradiance and generates dc voltage and current, the DC-DC boost converter controlled by maximum power point tracking technique to track the maximum power point of the array then the three phase Inverter converts the dc voltage to AC for grid interfacing or supply to the local load. The band pass filter removes harmonic components from the inverter output, the transformer to step up the output voltage and to circulate zero sequences before connecting to the Utility grid and Control circuits to achieve the MPPT control, Synchronization, and Switching.

1) Solar Array :
It depends on the load requirements, solar irradiation, and geographical location.PV array delivering a maximum of 100 kW at 1000 W/m^2 sun irradiance.
The 100-kW PV array uses 330 SunPower modules (SPR-305E-WHT-D). The array consists of 66 strings of 5 series-connected modules connected in parallel (66*5*305.2 W= 100.7 kW).
The 'Module' parameter of the PV Array block allows you to choose among various array types of the NREL System Advisor Model (https://sam.nrel.gov/).

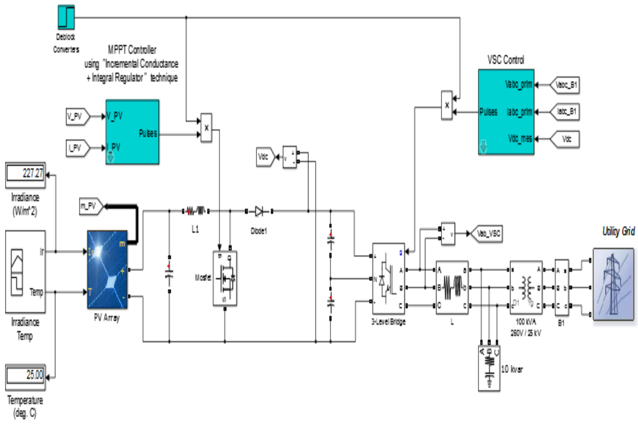

Fig. 5. MA TLAB model of grid-connected PV system

The manufacturer specifications for one module are:

- Number of series-connected cells : 96
- Open-circuit voltage: Voc= 64.2 V
- Short-circuit current: Isc = 5.96 A
- Voltage and current at maximum power : Vmp =54.7 V, Imp= 5.58 A

2) Band bass filter and Transformer

They are connected between the inverter and the grid.The filter type is a band pass filter centered at 50 Hz withvery low band width. To meet IEEE 519 standard aboutharmonic injected in system. The delta star transformer wasmainly introduced for voltage step-up and to trap the tripleorder harmonics.

3) MPPT control

There are several MPPT algorithms. Here incremental conductance algorithm is used. This algorithm flow chart is shown in figure (6)

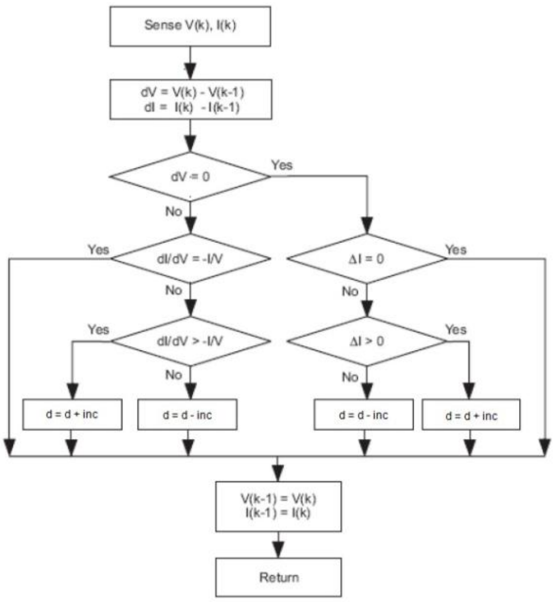

Fig.7. Flow chart incremental conductance algorithm

4) Control circuit

It takes grid parameter (voltage and current) and dc ofboost converter for synchronization between grid and PVvoltage. The aim of a control circuit to produced PWMsignal for an inverter. The control circuit is shown in figure

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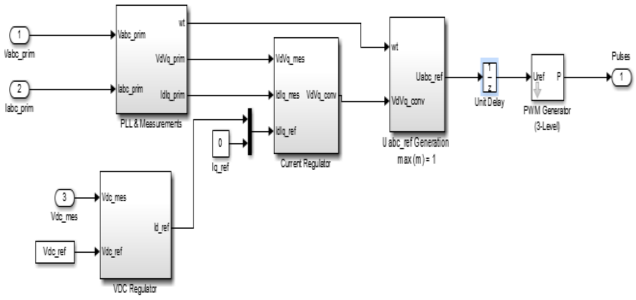

Fig. 8. Control Circuit

The VSC converts the 500 V DC link voltage to 260 V AC and keeps unity power factor. The VSC control system uses two control loops: an external control loop which regulates DC link voltage to +/- 250 V and an internal control loop which regulates Id and Iq grid currents (active and reactive current components). Id current reference is the output of the DC voltage external controller. Iq current reference is set to zero in order to maintain unity power factor. Vd and Vq voltage outputs of the current controller are converted to three modulating signals Uabc_ref used by the PWM Generator. The control system uses a sample time of 100 microseconds for voltage and current controllers as well as for the PLL synchronization unit. Pulse generators of Boost and VSC converters use a fast sample time of 1 microsecond in order to get an appropriate resolution of PWM waveforms.

III. RESULTS

A) Grid voltage and current:

Figure (8) shows the current and voltage waveform of the grid

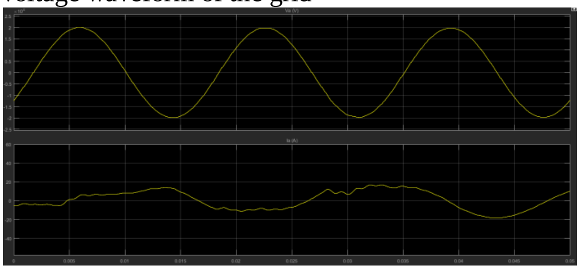
Fig.8. Grid voltage and current

B) Grid power:

Figure (9) shows the power across the grid

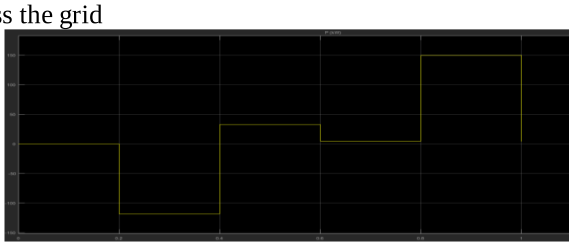
Fig.9. Grid power

C) Output of MPPT:

Figure (10) shows the output of MPPT which is given to the gate of mosfet.

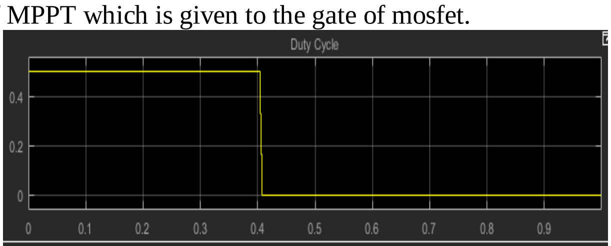

Fig.10. Output of MPPT

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D) Temperature and irradiance:
All simulation results, obtained under MATLAB Simulink environment, show the control performance and dynamic behavior of grid connected photovoltaic system provides good results and show that the control system is efficient. provide protection to the utility workers in fault conditions, was implemented successfully. All simulation results, obtained under MATLAB Simulink environment, show thecontrol performance and dynamic behavior of grid connected photovoltaic system provide good results and show that the control system is efficient.

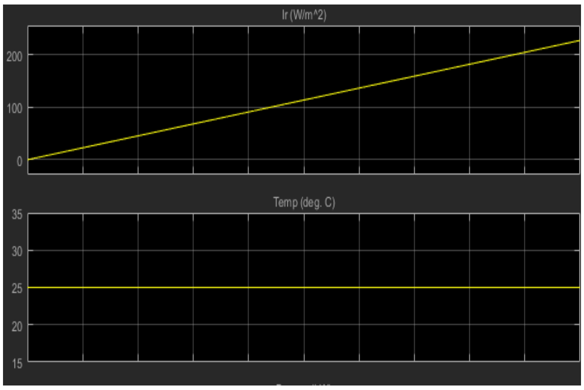

Fig.11. Temperature and irradiance

IV. CONCLUSION

This paper presents interfacing of grid-connected PV system, identify its components, and describe how it works. The MPPT with incremental and conductance algorithm has extracted the maximum amount of power from the PV array with high efficiency in a dynamic response time. The three phase inverter was implemented successfully and its output was fed to a band pass filter and gave a clear sinusoidal alternative current, its power quality output meets the grid standard. The sinusoidal pulse width modulation technique used in the VSI was implemented properly and reduced the filtering requirements.The switching technique has used the PV system as abackup supply to the house when the grid is of line and provide protection to the utility workers in fault conditions, was implemented successfully.

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