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TWO STAGE THREE PHASE GRID CONNECTED PHOTOVOLTAIC SYSTEM

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Abstract:- The new age of electricity generation is renewable energy. There is no other room, but to use renewable resources in energy generation to make the planet safer, and sustainable for the future. Renewable resources come in a variety of ways, but solar energy is by far the most practical. These days, solar panels are widely used due to their ease of use, accessibility, and efficiency in producing power. This Project mainly represents the simulation of compact design of a grid-tied solar system for energy production. Several fundamental characteristics, including temperature, irradiance, voltage, and current, affect the efficiency of a solar panel. Hence sudden change in any of these parameters leads drop in power and voltage. The precept aim is to improve the output voltage of PV array and boost converter there by reducing the harmonic content in grid current. The main points discussed here are the MPP tracking algorithm, the synchronization of the inverter and the connection to the grid. Tracking the dc voltage and current allows MPP calculation which gives the inverter to function efficiently.

Key Words:- Grid Connected PV Systems, DC-DC Boost Converter, Inverter, Harmonic Filter, MPPT and Phase Locked Loop(PLL).

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1. INTRODUCTION:-

1.1. Objective:-

The increase of world energy demand due to the modern industrial society and population growth is motivating a lot of investments in alternative energy solutions in order to improve energy efficiency and power qualities issues. The use of photovoltaic (PV) energy is considered to be a primary resource because there are several countries located in tropical and temperature regions, where the direct insolation density may reach up to 1000W per sq-m.

The primary objective of this project is to efficiently integrate solar power generated by photovoltaic (PV) panels into the existing electricity grid and promote the adoption of renewable energy. This project aims to ensure that the solar panels operate at their maximum power output under varying environmental conditions. This project also to synchronize the output power of the solar inverters with utility grid, regulating voltage and frequency to meet grid requirements and minimize disruptions.

1.2. Description:-

In this project we can see the power conversion from DC (PV panels) to AC (Grid/Utility) takes place at two stages. In first stage it will feature a PV module with DC-DC boost converter which will be controlled and optimized by means of a MPPT (Maximum Power Point Tracking) algorithm which is employed to obtain a maximum power output and constant output voltage from the PV module irrespective of the solar irradiance/insolation and weather conditions. In the second stage it will feature a three phase voltage source inverter (VSI) and phase locked loop network (PLL). A control methodology consisting of PI controllers for the operation of three phase inverter and its integration with grid is also used.

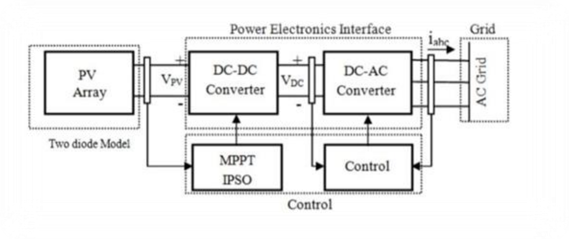

Figure-1: Two Stage Grid Connected PV Block Scheme

1.3. Focus Of The Project:-

Recently, energy generated from clean, efficient and environmentally friendly sources has become one of the major challenges for engineers and scientists. This paper discusses the detailed modeling of the whole system. PV array is connected to the utility grid by a boost converter to optimize the PV output and DC/AC inverter to convert the DC output voltage of the solar modules into the AC system. The DC input of the inverter must be constant and it is controlled by the use of a PI control circuit. An LC filter has been introduced to insure a clean current injection to the grid. The proposed model of the entire components and control system are all simulated in Matlab/Simulink Software. Two different cases are simulated; steady and transient states. All simulation results have verified the validity of models and effectiveness of control methods.

Additionally, Solar Grid places a premium on reliability and stability, employing measures to mitigate potential grid disturbances and fluctuations associated with renewable energy sources. A robust monitoring and control system forms the backbone of the project, facilitating real-time performance tracking, data analysis, and remote management to optimize system efficiency and reliability. In tandem, rigorous safety protocols and compliance with industry standards underscore Solar Grid's commitment to personnel safety, equipment integrity, and grid security.

2. PV GENERATOR MODEL:-

Photovoltaic generators are neither fixed current sources nor voltage sources but can be approximated as current generators with dependent voltage sources. During darkness, the solar cell is not an active device. It produces neither a current nor a voltage. A solar panel cell essential is a p-n semiconductor junction. When exposed to the light, a current is generated (DC current).The generated current change linearly with the solar irradiance.

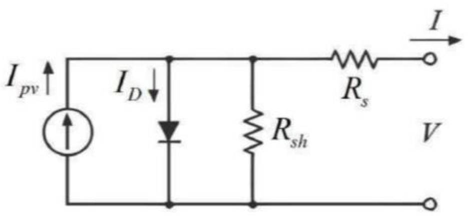

Figure-2: Equivalent Circuit of Solar Cell

The I-V characteristics of the solar cell circuit can be sets by the following equations. The current through diode is given by

$I_D = I_O$ [exp $^{(q(V + I RS)/KT)}$) – 1] (1)

While, the solar cell output current:

$I = I_L – I_D – I_{sh}$ (2)

$I = I_L – I_O$ [exp $^{(q(V + I Rs)/KT))}$ – 1] – (V + IR_s)/ R_{sh} (3)

Where:

I : Solar cell current (A)

I_L: Light generated current (A) [Short circuit value assuming no series/ shunt resistance]

I_O : Diode saturation current (A)

q : Electron charge (1.6×10-19 C)

K : Boltzman constant (1.38×10-23 J/K)

T : Cell temperature in Kelvin (K)

V : solar cell output voltage (V)

R_s : Solar cell series resistance (Ω)

R_{sh} : Solar cell shunt resistance (Ω)

2.1. P-V Characteristics

P-V Characteristics is curve plotted between Power and Voltage of a cell or module or array. The point at which maximum power is obtained is called maximum power point and the plot is approximately linearly increasing up to MPP.

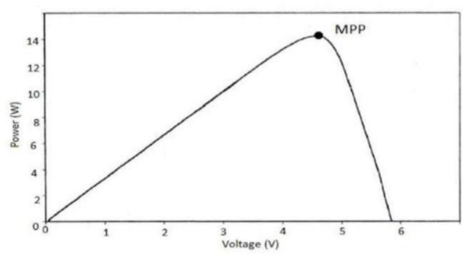

Figure-3: P-V Characteristics of PV Cell

2.2. I-V Characteristics

I-V Characteristics is curve plotted between Current and Voltage of a cell or module or array. The plot is straight line up to MPP. On x- axis the maximum value represents the open circuit voltage and the maximum value on y- axis represents the short circuit current. The conjunction with V_{oc} and I_{sc} determines the maximum power.

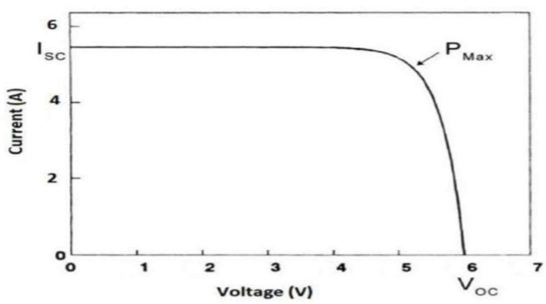

Figure-4: I-V Characteristics of PV Cell

3. DC-DC BOOST CONVERETER:-

In this work, it was selected the two-stage PV energy conversion system, because it offers an additional degree of freedom in the operation of the system when compared with the one-stage configuration, Since the output voltage of PV cell is low, the use of boost circuit will enable low-voltage PV array to be used, as a result, the total cost will be reduced. A capacitor is generally connected between PV array and the boost circuit, which is used to reduce high frequency harmonics.

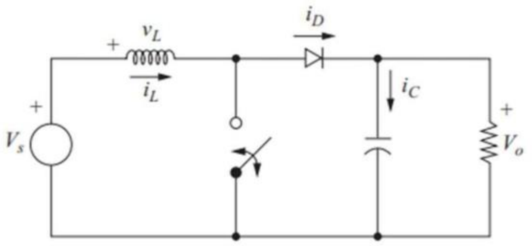

Figure-5: Boost Converter Circuit

DC-DC converters boost step-up the PV voltage to the level of the allowable maximum line voltage and to the stable required dc level without storage elements as battery. DC to DC converter is controlled to track maximum power point of the PV array.

4. INVERTER:-

Alternating Current (AC) power supply is used for almost all the residential, commercial and industrial needs. But the biggest issue with AC is that it cannot be stored for future use. So, AC is converted into DC and then DC is stored in batteries. And now whenever AC is needed, DC is again converted into AC to run the AC based appliances. So, the device which converts DC into AC is called Inverter. The inverter is used to convert DC to variable AC. This variation can be in the magnitude of voltage, number of phases, frequency or phase difference:

Power inverters produce one of three different types of wave output

- Square Wave
- Modified Square Wave (Modified Sine Wave)
- Pure Sine Wave (True Sine Wave)

The three different wave signals represent three different qualities of power output. Square wave inverters result in uneven power delivery that is not efficient for running most devices. Square wave inverters were the first types of inverters made and are obsolete. Modified square wave (modified sine wave) inverters deliver power that is consistent and efficient enough to run most devices fine. Some sensitive equipment requires a sine wave, like certain medical equipment and variable speed or rechargeable tools

The two main function of the dc-ac converter is:

- Efficiently generate AC output current in phase with the AC grid voltage
- Balance the average power delivery from the PV array to the grid

4.1 Self commutated inverters:-

Such inverters are more complicated and use switching devices (IGBT and MOSFET) that can control the switch-on and switch-off time and adjust the output signal to that of the grid. The self-commutated inverters are the predominant technology in PV power sources because of their ability to control the voltage and current output signal (AC side), regulate the power factor and reduce the harmonic current distortion.

4.2 Voltage source inverter (VSI):-

A voltage source inverter or VSI is a device that converts unidirectional voltage waveform into a bidirectional voltage waveform, in other words, it is a converter that converts its voltage from DC form to AC form. An ideal voltage source inverter keeps the voltage constant through-out the process.

A VSI usually consists of a DC voltage source, a transistor for switching purposes, and one large DC link capacitor. A DC voltage source can be a battery or a dynamo, or a solar cell, a transistor used maybe an IGBT, BJT, MOSFET, GTO. VSI can be represented in 2 topologies, are single-phase and a 3-phase inverter, where each phase can be further classified into a Half-bridge inverter and full-bridge inverter.

4.3 Current source inverter (CSI):

Respectively, CSI the DC source appears as a constant current input and the voltage is changing with the load. The protection filter is normally a capacitance in parallel with the DC source.

Also self-commutated inverters produce very good sine wave outputs when PWM technique and low pass filters are used.

Solar panels absorb energy from the sun's rays, and the energy is transferred to the semiconductor, creating an electric field that generates voltage and current. The voltage remains relatively constant, but the current can vary based on the amount of light. To increase solar power capacity, multiple solar panels can be connected in series, raising the system's voltage. Series connections are used when a grid-connected inverter or charge controller requires 24 volts or more. To wire panels in series, connect the positive terminal of one panel to the negative terminal of the next panel. In conclusion, using solar energy for homes is a sustainable and efficient way to harness the sun's power and increase our reliance on renewable energy sources.

5. MPPT (Maximum Power Point Tracking):

The efficiency of a solar cell is low. With a specific end goal to expand the efficiency, various routines are to be undertaken to match the source and load appropriately. One such strategy is the Maximum Power Point Tracking (MPPT). This procedure is utilized to acquire the most extreme conceivable power from a fluctuating source. In photovoltaic frameworks the I-V bend is non-direct, along these lines making it hard to be utilized to power a certain heap. This is finished by using a help of converter whose duty cycle is differed by utilizing a mppt algorithm.

The maximum power that can be delivered by a PV panel depends greatly on the insulation level and the operating temperature. Therefore, it is necessary to track the maximum power point all the time. The weather and load changes cause the operation of a PV system to vary almost all the times. A dynamic tracking technique is important to ensure maximum power is obtained from the photovoltaic arrays. The Perturb and observe (P&O) technique are used. This algorithm uses simple feedback arrangement and little measured parameters. In this approach, the module voltage is periodically given a perturbation and the corresponding output power is compared with that at the previous perturbing cycle. In this algorithm a slight perturbation is introduced to the system. This perturbation causes the power of the solar module varies. If the power increases due to the perturbation then the perturbation is continued in the same direction. After the peak power is reached the power at the MPP is zero and next instant decreases and hence after that the perturbation reverses. When the stable condition is arrived the algorithm oscillates around the peak power point. In order to maintain the power variation small the perturbation size is remain very small. The technique is advanced in such a style that it sets a reference voltage of the module corresponding to the peak voltage of the module. A PI controller then acts to transfer the operating point of the module to that particular voltage level.

6. PHASE LOCKED LOOP (PLL):-

A Phase-Locked Loop (PLL) system in a three-phase grid-connected solar inverter is a control mechanism used to synchronize the inverter's output with grid's voltage and frequency. The PLL system continuously monitors the grid voltage to detect its phase angle. This is typically done by comparing the phase of the grid voltage with a reference signal generated internally. Along with phase detection the PLL system also measures the frequency of the grid voltage.

If there is any phase difference between the grid voltage and the reference signal, the PLL system generates an error signal based on this difference. This error signal is then used to adjust the phase angle of the inverter's output voltage to match the grid. Similarly, if there is any frequency difference between the grid and the reference signal, the PLL system generates an error signal to adjust the frequency of the inverter's output accordingly.

The PLL system maintains synchronization of inverter's active and reactive current with grid voltage.

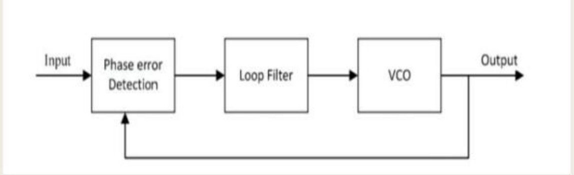

Figure-6 Conventional Phase Locked Loop System

PLL techniques have been applied recently to synchronize grid-tied photovoltaic systems. With a high degree of immunity and in sensitivity to disturbances, harmonics, unbalances, sags/swells, notches, and other sorts of distortions in the input signal, an ideal PLL can offer rapid and accurate synchronization information.

A conventional phase locked loop as shown in Fig.6 consists of three primary units namely phase (error) detection unit (PD), a loop filter and a voltage controlled oscillator (VCO).The phase detector measures the phase difference between the input and the output signal. The obtained phase error then passes through the loop filter which extracts the DC component from the phase error. This obtained DC component is then amplified and passed onto the VCO which consists of a PI controller which generates the frequency of the output signal, which is onwards passed through the integrator resulting in the phase angle of the output signal, this phase angle is afterwards extracted from the PLL loop and is used for the generation of the grid current reference signal.

7. MATLAB-SIMULINK ENVIRONMENT:-

The system model shown in Figure, demonstrates PV solar cell array connected to a 50 HZ, 400 V grid through a DC/DC boost converter and DC/AC inverter. The 600 V obtained from DC/DC converter is applied to a signal dc to ac inverter. The task of the boost DC/DC converter drains the power from the PV solar cell array and supplies the DC link capacitor with a maximum power point tracker obtained from the MPPT controller. An LC filter is inserted after the dc-ac inverter in order to eliminate the harmonics contained in both the voltage and current of the inverter output.

In Figure the model of PV panel as a constant dc source created using the subsystem block from Simulink library browser, which included all functions of PV panel. The model has three inputs irradiance, temperature and voltage input that is coming as a feedback from the system and the output of the block gives the current, table 1 show parameters of the PV model.

Table-1

Parameters	Values
Solar irradiance G_{ref}	1000W/m^2
Cell temperature T_{ref}	25^{0}C
I_{mp}	356.26A
V_{mp}	303.6V
P_{mp}	108161W
I_{sc}	380.7A
V_{oc}	363V

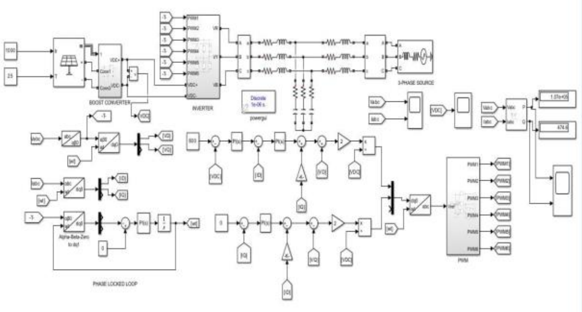

Figure-7 Simulink of the Grid Connected PV system

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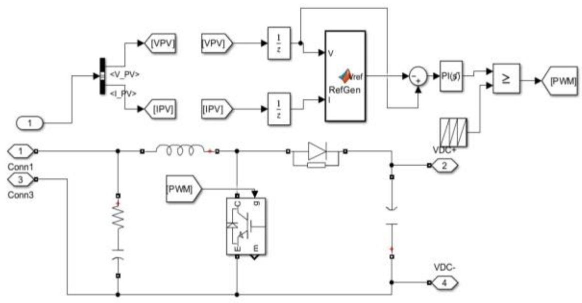

Figure-8 Simulink diagram of a boost converter and P&O MPPT algorithm

Table-2

Boost converter parameters	Values
Switch	IGBT
Input capacitor	1000µF
Inductor	1.45mH
Load capacitor	3227mH
Output voltage	600V

The table 2 shows the parameters values of inductor, capacitor that are required to design boost converter.

Based one the requirement of the output voltage the parameters values may vary and can be determined by calculating with the given specified formulas.

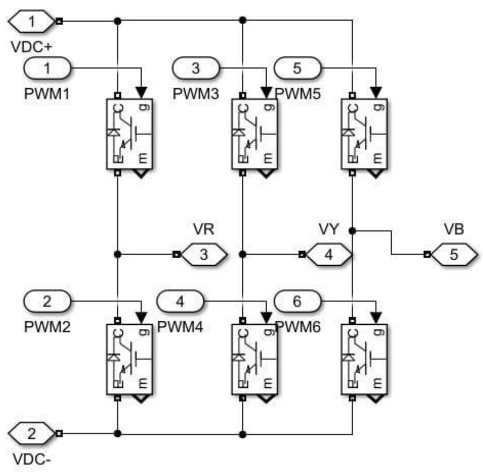

Figure-9 Simulink diagram of inverter

Table -3

Inverter Parameters	Values
Switching Frequency	10KHz
Control Technique	PWM
Input Voltage	600V

8. RESULTS AND SIMULATION :-

The simulation time was set for 5 seconds. The grid was simulated according to standards with a 400V AC RMS and a resistive load in series with an inductive load.

The MPPT algorithm, succeeded to track the maximum power point and extracting this power from photovoltaic system. Through simulation it is observed that the system completes the maximum power point tracking successfully despite of fluctuations.

The simulation results of inverter voltage, grid voltage & current, active and reactive power of grid are also plotted.

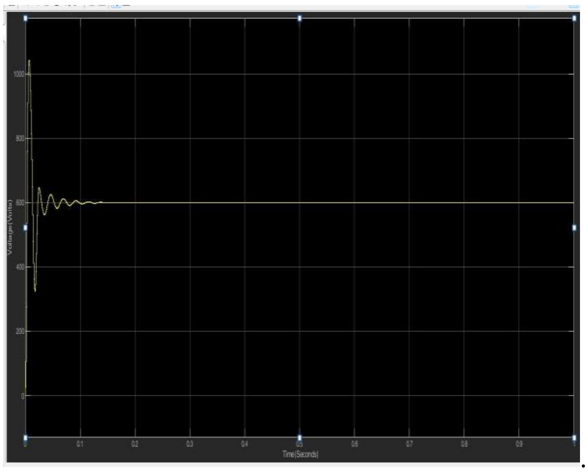

Figure-10 DC/DC converter output voltage

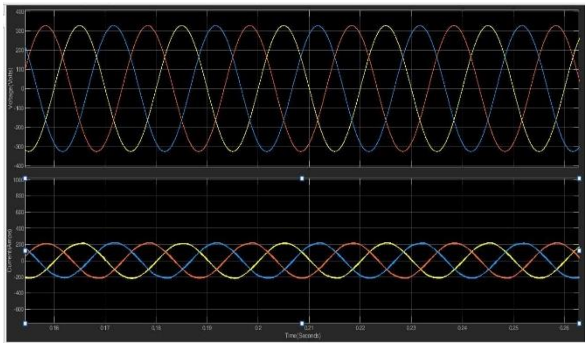

Figure-11 Grid Voltage and Current

The Grid Voltage and Grid Current are in phase So that maximum active power is injected into the grid from the PV system. The reactive power feeding to grid is set to zero using feed forward decoupling control of inverter current. The RMS value of grid voltage is 400 V and RMS value of grid current is 141.42 A.

The Grid Current is sinusoidal with RMS Value of value of 141.42 A. THD of Grid Current is within the limits of IEEE Standard 519.

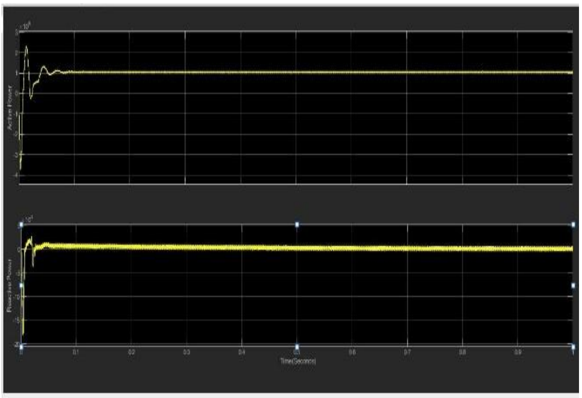

Figure-12 Active and reactive power of the grid.

The power requested by the load is 100KW and 0 KVAR. Since the PV array generate only an active power of 100KW and no reactive power. Active power value of load and inverter is greater than reactive power, but reactive power value of grid is a greater than active power.

9. FUTURE SCOPE:-

To further advance the project or to enhance the future scope of work, it is required to investigate methods to further improve the power quality delivered by the inverter, focusing on reducing harmonic distortion, minimizing voltage fluctuations and enhancing grid stability during transient conditions.

Exploring advanced control strategies such as predictive model or fuzzy logic algorithm for maximum power point tracking to optimize the performance of the inverter under varying operating conditions and grid disturbances. Develop advanced monitoring and diagnostic capabilities for the inverter system to enable real- time performance assessment, fault detection and predictive maintenance and to identify potential issues proactively.

Improvement to this project can be made by reducing the harmonics during synchronization with the grid using other PLL methods. Algorithm for PLL may be applied to obtain less harmonic oscillation during steady state and transient conditions. Hardware model for the simulation can be developed using DSPACE, IOT based real time monitoring may also be carried out by creating a robust data logging mechanism to store historical data and analyze the amount of power transferred to grid and that of stored in battery.

10. CONCLUCION:-

In order to construct a PV grid connected system, a number of parameters have to be taking into account and to be optimized in order to achieve maximum power generation. The maximum power point tracking algorithm when applied an accurate PV model has the ability to increase the efficiency of the system. In addition to that a controller has to be used in order to achieve the synchronization to the grid and to perform the power management between the system and the electrical grid. P&O MPPT method and PV grid connected with it's control are implemented with MATLAB-

SIMULINK for simulation. The MPPT method simulated in this paper is able to improve the dynamic and steady state performance of the PV system simultaneously. Through simulation, it is observed that the system completes the maximum power point tracking successfully. Moreover, this study shows that the proposed control scheme offers a simple way to study the performance for utility interface applications. It is simple to implement and capable of producing satisfactory sinusoidal current and voltage waveforms

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