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Grid Interactive Solar Inverters and Their Impact on Power System

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ABSTRACT- The inverter in a grid interactive structure can transform solar generate DC power into AC power that is then fed directly to the grid. As a building receive this AC energy, it is circulated to instruments and lighting and other devices where required. Any energy that over shoot the regular building usage goes back to a grid. Some instants, the utility issues a credit to the next bill. Grid interactive system are established on their grid tied or off grid counterparts. Nevertheless in grid interactive system, the inverter has numerous additional purposes to the accomplish. Grid connected photovoltaic system supplies good outcome or show that the control system is efficient. Photovoltaic systems are mostly used as they are light, clean or easily installable. This systems connection to the grid requires special conditions to obtain the high-quality electric power system. Under normal conditions, the inverter preserves the battery in a state of full charge in preparation for use during power outages, when the grid goes down the grid interactive inverter seamlessly steps in to inverter DC power from both a solar and battery sources into feasible AC power to run specific loads. The system will charge those batteries throughout the day from the panels or as needed from a generator or both. The grid interactive inverter can automatically control the generator to run only when needed to recharge the batteries, appreciably minimize the generator's run time, noise output and fuel use. PV panels are very costly pieces of a PV structure, the grid tied or interactive inverters are the most knowledgeable components which dominated the bearing of the PV structure. The productivity, consistency and security features of these solar inverters are important for the successful outcome of a PV structure.

KEYWORDS- Solar Inverters, Power System, Interactive Grid, Photovoltaic Module

I. INTRODUCTION

The objectives of grid interactive inverter is that 60% of energy consumption is from fossil fuel resulting an emission of 6.5 billion tons of CO2 into atmosphere environment pollution, global warming. Fossil fuel sources like coal, oil etc. are getting exhausted day by day. Distributed generation with renewable sources (solar cells, wind power etc.) may be a solution to these problems. Since power content of these sources are varying and to make voltage, frequency etc., acceptance to the present transmission system Grid interactive inverters are crucial. Recent government incentive programs such as rebates and tax credits have made electricity generation from PV arrays cost-effective and feasible. Implementation of measures like Net Metering, Feed in Tariffs (FITs), and Renewable Portfolio Standards (RPSs) could further revolutionize the solar industry. The utility interactive inverters are at the heart of this revolution. Though solar panels are the most expensive component of a PV system, these grid interactive inverters are the most sophisticated equipment's which dictate the behavior of the PV system. The efficiency, reliability and safety aspects of these inverters are crucial for the success of a PV system. These inverters should extract the maximum available power from the PV arrays and efficiently export the power to the utility grid without compromising the safety and integrity of the grid. In order to guarantee these grid interactive qualities, all grid interactive inverters must meet IEEE 1547 requirements. This lecture covers the design aspect of a solar inverter to meet IEEE 1547 requirements. Key control features such as handling abnormal grid conditions (over/under voltage/frequency conditions), anti-islanding control, ground fault detection/interruption, and current harmonics control will be covered in some details. This lecture will also touch/ponder on the future potential uses of these inverters in improving the grid security and stability.

II. MATHEMATICAL MODELING OF A PHOTOVOLTAIC MODULE

Modeling is the fundamental for computer simulation of a real system. Normally it is based on a theoretical analysis of the different physical processes happening in the system and of all factors affecting these processes. Mathematical models narrates the system characteristics are developed and translated into computer codes to be used in the simulation process. Photovoltaic cell models have long been a source for the explanation of photovoltaic cell behavior for researchers and professionals. The most usual model used to predict energy production in photovoltaic cell modeling is the single diode circuit model that represents the electrical behavior of the pn-junction. Figure 1.1 shows how photovoltaic system works.

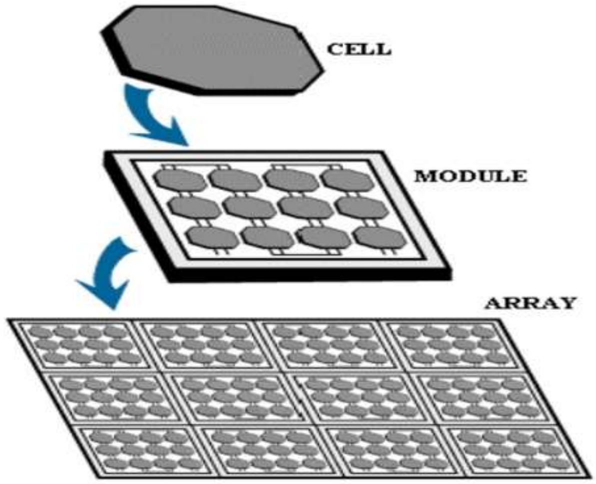

Figure 1: Solar PV Cell, Module and Array

The PV panel can be represented as a system for energy modification. Fig. 1 shows the block diagram of the model, it consists of inputs (Sun radiation intensity G, load current I and temperature T) and outputs (output voltage U of PV panel).

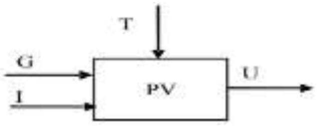

Figure 2: Block diagram of PV panel

The PV model can be expressed by equation 1.

F (I, U, G, T) = 0(1)

Where the current is restricted by[1] the short-circuit current Ik, the voltage is restricted by the open-circuit voltage U0, and G represents the conductivity of the PV panels. The conductivity and temperature parameters are nonlinear and accordingly the output voltage of the PV model is nonlinear too. According to the above relations for the PV module, the approximation to PV voltage and current can be expressed by equations 2 and 3, where parameter q is the value ofthe sun radiation intensity G. Voltage UP provides a linear approximation to the output characteristics with coefficients p0 and p1, where po = 18.6 and p1 = 2.35 for aa range of values of q and constant temperature 20°C.

U= U(I,q)= p0+ p1.q+ q/(1-q)= Up q/(1-q)(2)

I =q. (1+1/U-Up) (3)

Likewise, the open-circuit voltage U0 and short-circuit current Ik can be developed and approximated as

U0 =UP -1= p1 . q + p0 -1 = 2.35. q +18.6 (4)

Ik = q.(1-1/Up) = q.(1-1/po + p1.q) = 0.96.q – 0.003 (5)

Fig. 1.3represents the relationship between photovoltaic voltage and current represented by the effect of the solar radiation intensity q.

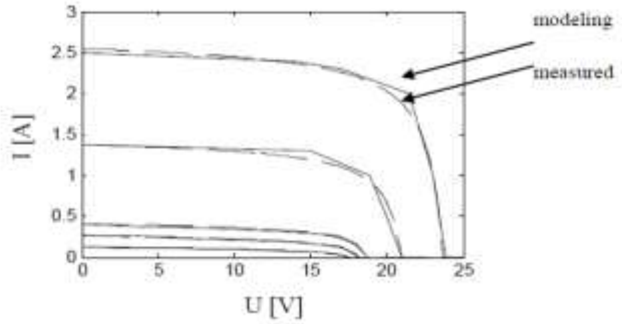

Figure 3: I-V characteristics of PV (mathematical modeling and

Experimental verification)

Likewise, the above PV curve acquired by measurement (Fig. 2) and the outcome of modeling the I-VPV characteristics with the formulae given above are shown in Fig. 3. The outcome of modeling are given by a full line and the results of testing by a discontinuous line. It can be seen that modeling gives acceptable results and the PV model can be expressed by the equations 2 or 3.Secondly, a mathematical model of the PV, which is more accurate, is shown below. The model was extended with parameter r, which represents the conductivity [Ω-1]. Therefore

I = I (U,q) = q.(1+1/U-Us) + r.U = q.(1+1/ U-so –s1 .q) + r.U (6)

U = Us + k.q/.1- k.q – r. U (7)

Where Us is a linear approximation.

Us = s0 + s1. q (8)

Then the open-circuit voltage U0 and short-circuit Current Ik are given by:

Uo = Us – k.q/k . q + r.Us = s0 + s1q – k.q/k.q + r.(s0+s1q) (9)

Ik(q) = I(0,q) = k.q.(1-1/Us) = k.q . (1- 1/s0 + s1. q) (10)

The linear approximation (Eq. 8) to the output characteristics has coefficients s0 = 18.8, s1 = 2.3 and r = -0.003. The results of I-V PV characteristics by mathematical modeling with the previous equations are shown in Fig. 1.4. It can be seen that this approximation gives better results and higher accuracy in comparison with the previous approximation. On the other hand, the first method can be more effective in simplifying the hardware implementation of upmost power point tracking MPPT. The outcome of the experimental verification correspond well to the mathematical modeling.

Figure3 I-V characteristics of PV

Components involved in a System of Photovoltaic Conversion

The principle schematic diagram of a grid connected PV system with voltage source inverter is shown below in Fig. 4.

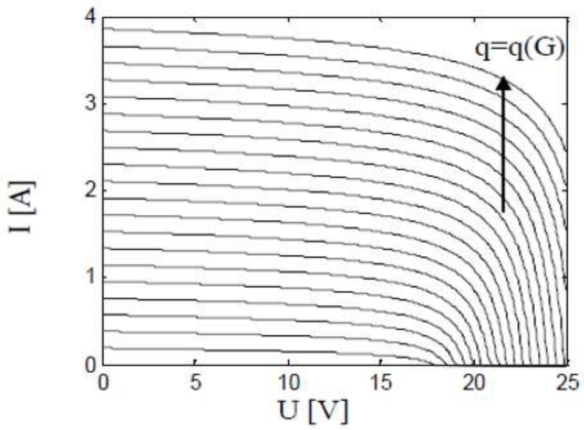

Figure 4: Grid connected PV system block Diagram

The main components that can be involved in a system of photovoltaic conversion are Photovoltaic modules, converters, utility grid, loads DC and AC, and Inverters as shown in Fig [2]. Although [2] systems with battery backup oppose the issue of reliability of the grid supply but it is more tricky and more expensive.

A. Grid Modeling

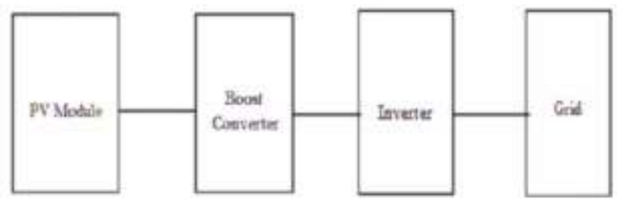

Figure 5: is grid modelling diagram.

Fig 5: Grid equivalent circuit
PV SOLAR

B. Why Pv Solar

PV solar is used because it is abundantly available and Benign in Nature as explained below
Abundantly Available.
Sunlight striking the earth for 40 minutes equivalent to global energy consumption for a year. The US has 250,000 square miles of land in southwest alone that receives 4,500 quadrillion BTU of solar radiation/year. Only some 30,000 square miles of photovoltaic arrays would have to be erected to generate 3000 GW of power. Land required to produce each GW of power from solar less than that needed for a coal-powered plant when factoring in land for coal mining.
Benign in Nature.
In pv solar there is negligible CO2footprint. As there are no moving parts which means there will not be any kind of noise. No water consumption is required for PV solar because we are generating electricity from sun. In PV solar there is no emissions, less geographical restrictions and it is also Pollution free.

- **Solar Inverter Design.**

The design of solar inverter is shown in figure 6. In designing solar[3] inverter there are few requirements as mentioned below:

i) Electrical Requirements
ii) Thermal Requirements
iii) PV Specific Control and Protection Functions
iv) Testing

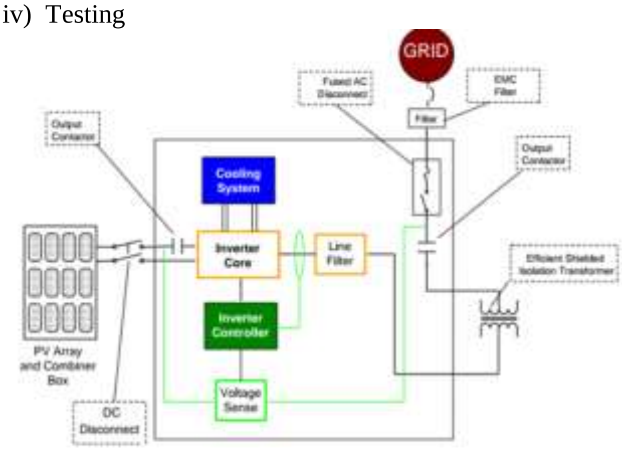

Figure 6: Solar inverter design

Electrical Requirements.
The design of solar inverter starts with specifying the electrical demands.
DC input voltage range (e.g. 250V to 600V),AC output voltage (e.g. 120V, 208V, or 480V)
Number of phases (1 ph, split ph or 3 ph),Frequency (50Hz or 60Hz)
Output Power (e.g. 100kW) Output current (e.g. 95 A),Voltage Total Harmonic Distortion (e.g. < 2%),Current Total Demand Distortion (e.g. < 5%),Overall efficiency (e.g. > 95%)

C. Auto Wake Up

The PV inverter shall [4]be able to wake up when the available power is more than the total loss of the inverter system.
Reverse Dc Bus Protection
Inverter shall be able to[5] identify the reverse polarity of the DC connection and warn the installer and remain in sleep state. Reverse voltage can potentially damage the capacitors and can also cause excessive current in the DC circuit.

D. Ground Fault

Current flows through the ground to the negative terminal first then goes to the positive through the PV cells.. Inverter shall shutdown and disconnect itself from the grid as well as the PV array as soon as the ground fault is detected. The ground fault current shall be interrupted.

E. Remote Monitoring

The PV inverters are generally installed in not-so-convenient places. It is therefore desirable to have a capability to find out the status of the unit remotely. Monitoring power, power factor, energy, currents, and voltages over days, weeks, months and years help us extract useful economic information. Remote monitoring also help diagnose the problem by furnishing the information around the event.

III. MATLAB/SIMULINK MODEL OF GRID INTERATIVE SOLAR INVERTER

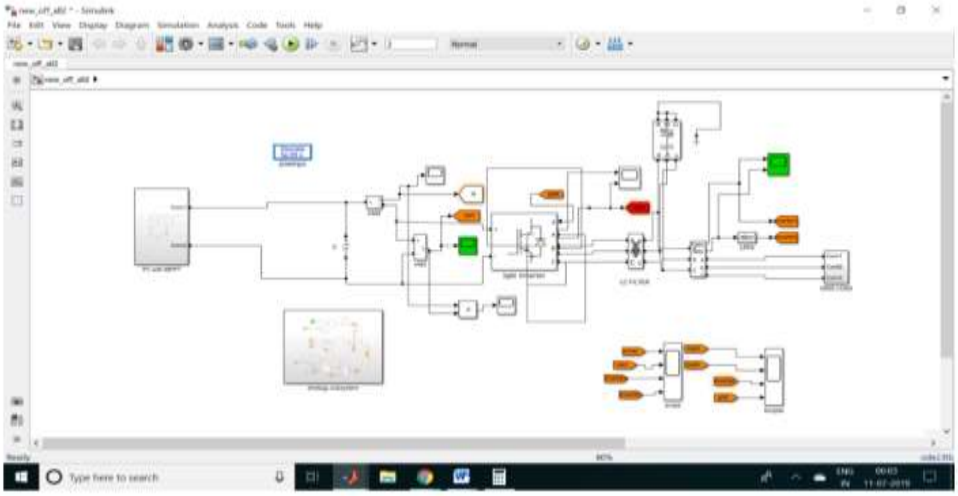

Figure 7: Final PV with Grid integration model

Figure 7 shows the Photovoltaic Module based Grid integration MATLAB simulation model which consists of PV subsystem, PV MPPT subsystem, inverter subsystem and Load subsystem. The total capacity of the proposed [6] PV plant is 8KW. System is designed in such a way that the load requirement till 8KW will be catered by PV plant and if the demand increases the rest of the required power will be delivered by the grid.

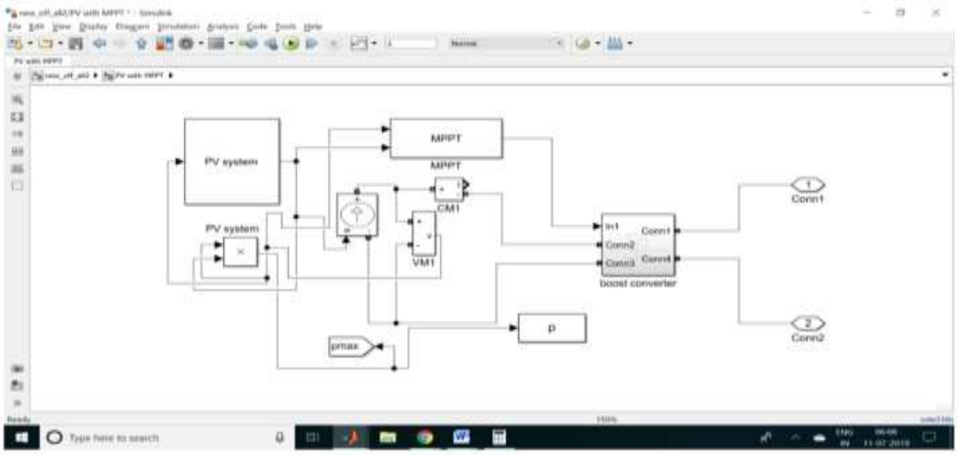

Figure 8: PV module subsystem with MPPT

Figure 8 displays the PV module subsystem with boost converter. The boost converter gating pulses is provided by the PV MPPT which is shown in figure 4.3 the P&O MPPT technique is utilized to maximize the power extraction from the PV cells.

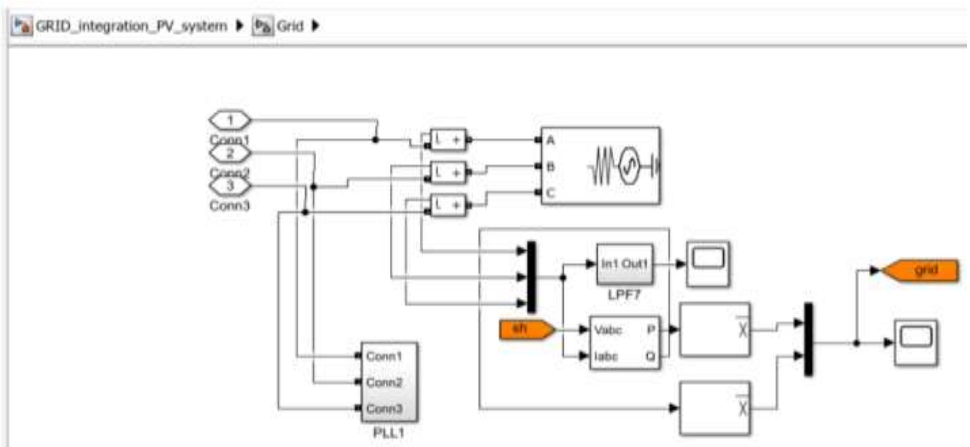

Figure 9: Load GRID Subsystem

Figure 9 shows the GRID system which is implemented as infinite source of power and this grid is being synchronized with the inverter 3-phase output so that both sources and feed the required load power as per require.

IV. RESULTS AND DISCUSSIONS

It has been found that by using MPPT, PID controller and three-level inverter with hysterics current control technique, the efficiency of our system is increased and the dynamic stability of our system connected to the grid is also maintained. The results validate the satisfactory performance of the whole designed control and can be developed for grid interactive PV systems at remote places or to promote renewable energy usage, using MPPT technique.

A. Results and discussion for grid interactive solar inverter

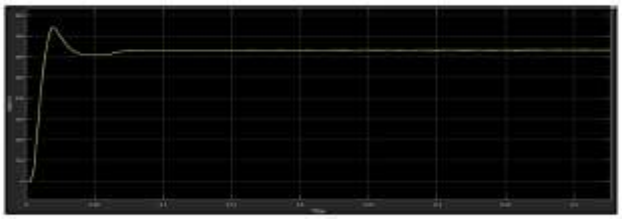

Figure 10: Tuned VDC

Figure 10 shows the tuned VDC of the PV panel which is being fed to [7]the inverter to get converted into 3-phase AC. The VDC is tuned to 800V and total power provided by the PV is 8000W.

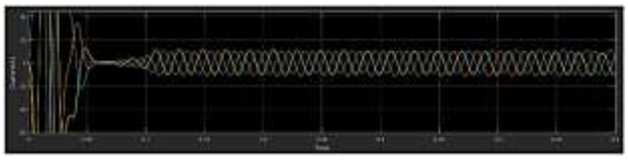

Figure 11: Three Phase Inverter Current

Figure 11 shows the inverter output current i.e. 3-phase A.C. current with magnitude around 30 amps.

Figure 12: Three Phase Load Current

Figure 12 shows the 3 phases Load current where in it can be seen that the load current decreases at 0.3 seconds. This variation exactly happens because of the dynamic change in load requirement to demonstrate the robustness of the system.

V. CONCLUSION AND FUTURE SCOPE

This project gives interfacing of grid-connected PV system, recognize its elements, and gives details how it works. The MPPT with perturb and [8] observe (P&O) algorithm has taken out the supreme amount of power from the PV array with high efficiency in a dynamic response time. Three phase inverter was implemented successfully and its output was fed to a band pass filter and gave an accessible sinusoidal alternative current, its power quality output meets the grid benchmark. The sinusoidal pulse width modulation technique used in the VSI was implemented correctly and diminish the filtering needs. All simulation outcomes, acquired under MATLAB Simulink environment, show the control production and dynamic behavior of grid connected photovoltaic system supplies good outcome and show that the control system is efficient. Photovoltaic systems are mostly used as they are light, clean and easily installable. This systems connection to the grid requires special conditions to [9] obtain a high-quality electric power system. This project presents interfacing of three phase grid connected PV system. DC-DC boost converter with maximum power point tracking (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 responsible for the control of electricity flow between the dc source, and loads or grid so a voltage source inverter (VSI) is used to convert the dc power into AC power before injecting 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. Design innovation in inverter topology is imperative to improve efficiency, cost, reliability and life. Innovation in manufacturing and testing side is also needed to improve the quality of the inverter. More research needed to develop advanced robust control techniques to improve inverter performance, to reduce the inverter downtime and to eliminate costly sensors.

Future Scope

Different algorithms for maximum power control may be developed for application on other renewable energy sources such as fuel cells and wind power. Artificial neural network algorithms can be developed to improve the performance of the solar energy conversion function of the MPPT. Intelligent devices like microprocessors, Programmable Logic Controllers (PLC) may be added to the system to keep the operating point (maximum power point) for maximum efficiency. To take care of the uncertainty in the insolation level, use of [10] fuzzy control may be done. Use of feedback path for automatic control-position control servo for changing the transformation ratio of varies can be used. The simulation of the PV with three-phase inverter and current control can be performed. Grid Connected PV system with Smart Grid functionality, there is a great need of designing the control system that would control the designed inverter power. The control would be able to integrate the inverter with other renewable energy sources available.

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