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# Maximum Power Point Tracking Based Efficient Multi-Stage Grid-Connected Photovoltaic System

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**Abstract – This project introduces a new converter called reconfigurable solar converter (RSC) for photovoltaic (PV)-battery application, particularly utility-scale PV-battery application. The main concept of the new converter is to use a single-stage three phase grid-tie solar PV converter to perform dc/ac and dc/dc operations. This converter solution is appealing for PV-battery application, because it minimizes the number of conversion stages, thereby improving efficiency and reducing cost, weight, and volume. In this paper, a combination of analysis and experimental tests is used to demonstrate the attractive performance characteristics of the proposed RSC. The proposed micro-inverter has a quadratic boost converter in the DC-DC stage and multistage universal-bridge inverter in the DC-AC stage. The boost operates in continuous conduction mode (CCM) along its overall operational range, while the full bridge inverter uses bipolar commutation. The quadratic boost is controlled to regulate a DC voltage bus with a level higher than the peak voltage of the utility in order to guarantee the adequate direction on the power flow. Meanwhile, the full-bridge inverter shapes the output current using the grid voltage waveform as reference and defining the amplitude with a control signal given by the MPPT.**

**Index Terms – MPPT (maximum power point tracking), continuous conduction mode (CCM), high-speed, pulse-width modulation (PWM).**

## 1. INTRODUCTION

Solar photovoltaic (PV) electricity generation is not available and sometimes less available depending on the time of the day and the weather conditions. Solar PV electricity output is also highly sensitive to shading. When even a small portion of a cell, module, or array is shaded, while the remainder is in sunlight, the output falls dramatically. Therefore, solar PV electricity output significantly varies. From an energy source standpoint, a stable energy source and an energy source that can be dispatched at the request are desired. As a result, energy storage such as batteries and fuel cells for solar PV systems has drawn significant attention and the demand of energy storage for solar PV systems has been dramatically increased, since, with energy storage, a solar PV system becomes a stable energy source and it can be dispatched at the request, which results in improving the performance and the value of solar PV systems.

There are different options for integrating energy storage into a utility-scale solar PV system. Specifically, energy storage can be integrated into the either ac or dc side of the solar PV power conversion systems which may consist of multiple conversion stages. Every integration solution has its advantages and disadvantages. Different integration solutions can be compared with regard to the number of power stages, efficiency, storage system flexibility, control complexity, etc.

GCPVS are implemented sensing DC (PV array) and AC (inverter output or grid) voltage and/or current in monitoring and control process for the functions, synchronization and load sharing with the grid, etc. This project presents a component saved, hence size and cost minimized GCPVS without sensing DC quantities from PV array side and only sensing AC quantities from grid side as depicted power conditioning unit (PCU) is responsible for load sharing function.

A multi-stage GCPVS only monitoring AC quantities is proposed. Power sharing with the grid and MPPT function of the PV array based on the adjustment of inverter output voltage with respect to grid voltage. Details on system and operation technique are presented. A MPPT based algorithm, for automatic load sharing and MPPT function, is also presented.

Due to the low voltage generated in a PV cell (around 0.5V), several PV cells are connected in series (for high voltage) and in parallel (for high current) to form a PV module for desired output. Separate diodes may be needed to avoid reverse currents, in case of partial or total shading, and at night. The p-n junctions of mono-crystalline silicon cells may have adequate reverse current characteristics and these are not necessary. Reverse currents waste power and can also lead to overheating of shaded cells. Solar cells become less efficient at higher temperatures and installers try to provide good ventilation behind solar panels.

Frameless modules are sometimes used in facades for aesthetic reasons. This typical construction is used because the PV module has to "survive" outdoors for at least 20-25 years under different weather conditions, sometimes extreme. This construction assures at least the lifetime of the PV modules.

In fact, PV panel manufacturers provide a guarantee of at least 20 years, for example BP Solar assures 85 % of minimum warranted power output after 25 years of service, 93 % of the minimum warranted power output at 12 years and a five-year warranty of materials and workmanship. Such a long guarantee is extremely long compared to most products and is due to the exceptional construction of PV modules.

## 2. PROPOSED DRIVE METHOD

### A.Multistage power supplying system with GCPVS

PV power penetration to the utility grid increases day-by day and a number of topologies of GCPVS are reported in recent literatures. Multistage GCPVS usually employs two stages: the first stage comprises of a boost type DC/DC converter and the second stage comprises a DC/AC inverter. In recent years, a large number of topologies suitable for multi-stage GCPVS have been proposed.

Main advantages of the multi-stage system are compact, deduced weight and low cost, etc. Single-stage system has to be configured for high PV array voltage using a string of series connected modules to make output voltage compatible for grid interfacing. Such systems involve issues of hot-spots during partial shading of the array, reduced safety due to high leakage through the parasitic capacitance between the panel and the system ground. To extract maximum available power depending on ambient conditions from PV array, MPPT is one of the key functions in PV system. Hill climbing, perturb and observe (P&O), incremental conductance algorithms are well implemented MPPT method. In the proposed system, the adjustment of inverter output voltage phasor to transfer power from inverter output through grid connecting reactance is responsible for MPPT function of PV array. All existing approaches on GCPVS are implemented sensing DC (PV array) and AC (inverter output or grid) voltage and/or current in monitoring and control process for the functions such as MPPT, synchronization and load sharing with the grid, etc. This paper presents a component saved, hence size and cost minimized GCPVS without sensing DC quantities from PV array side and only sensing AC quantities from grid side.

A photovoltaic system is a system which uses one or more solar panels to convert solar energy into electricity. It consists of multiple components, including the photovoltaic modules, mechanical and electrical connections and mountings and means of regulating and/or modifying the electrical output.

### B. Proposed Drive Method

PV cells are made of semiconductor materials, such as silicon. For solar cells, a thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current that is, electricity. This electricity can then be used to power a load. A PV cell can either be circular or square in construction.

An ideal is modeled by a current source in parallel with a diode. However no solar cell is ideal and thereby shunt and series resistances are added to the model as shown in the PV cell diagram above. The intrinsic series resistance whose value is very small. The equivalent shunt resistance which has a very high value.

Applying Kirchhoff's law to the node where IIC, diode, π and. α meet, we get

$$IIC=ID+I\pi+CC \qquad (2.1)$$

We get the following equation for the photovoltaic current

$$CC=IIC-ID-I\pi \quad (2.2)$$

$$CC=IIC-IR\{\exp[(V+I\alpha)/VT]-1\}-\{[(V+I\alpha)/\pi]\} \quad (2.3)$$

Where, IIC is the Isolation current, CC is the Cell current, IR is the Reverse saturation current, is the Cell voltage, α is the Series resistance, π is the Parallel resistance, VT is the Thermal voltage kt/q is the Boltzmann constant, is the Temperature in Kelvin, is the Charge of an electron.

The efficiency of a PV cell is defined as the ratio of peak power to input solar power.

$$\lambda = (VPP*IPP)/(I\ (kw/m2)*A\ (m2)) \quad (2.4)$$

Where VPP the voltage at peak power is, IPP is the current at peak power, I is the solar intensity per square meter, A is the area on which solar radiation fall. The efficiency will be maximum if we track the maximum power from the PV system at different environmental condition such as solar irradiance and temperature by using different methods for maximum power point tracking The building block of PV arrays is the solar cell, which is basically a p-n junction that directly converts light energy into electricity: it has a equivalent circuit as shown below in Figure 2.5. In the ideal PV Cell model, and are related to cells temperature and radiation intensity, and are not easy to be determined. This makes the engineering application very difficult. Manufacturers of PV arrays provide only a few experimental technical parameters such as open-circuit voltage, short-circuit current, the maximum power point voltage, the maximum power point current, and the maximum power point power

Solar cell I-V curves where a line intersects the knee of the curves where the maximum power point is located. Photovoltaic have a complex relationship between their operating environment and the maximum power they can produce. The fill factor, abbreviated FF, is a parameter which characterizes the non-linear electrical behavior of the solar cell. Fill factor is defined as the ratio of the maximum power from the solar cell to the product of Open Circuit Voltage Voc and Short-Circuit Current Isc. In tabulated data it is often used to estimate the maximum power that a cell can provide with an optimal load under given conditions, P=FF*Voc*Isc. For most purposes, FF, Voc, and Isc are enough information to give a useful approximate model of the electrical behavior of a photovoltaic cell under typical conditions.

For any given set of operational conditions, cells have a single operating point where the values of the current (I) and Voltage (V) of the cell result in a maximum power output. These values correspond to a particular load resistance, which is equal to V / I as specified by Ohm's Law. The power P is given by P=V*I. A photovoltaic cell, for the majority of its useful curve, acts as a constant current source. However, at a photovoltaic cell's MPP region, its curve has an approximately inverse exponential relationship between current and voltage. From basic circuit theory, the power delivered from or to a device is optimized where the derivative (graphically, the slope) dI/dV of the I-V curve is equal and opposite the I/Vratio (where dP/dV=0). This is known as the maximum power point (MPP) and corresponds to the "knee" of the curve.

A load with resistance R=V/I equal to the reciprocal of this value draws the maximum power from the device. This is sometimes called the characteristic resistance of the cell. This is a dynamic quantity which changes depending on the level of illumination, as well as other factors such as temperature and the age of the cell. If the resistance is lower or higher than this value, the power drawn will be less than the maximum available, and thus the cell will not be used as efficiently as it could be. Maximum power point trackers utilize different types of control circuit or logic to search for this point and thus to allow the converter circuit to extract the maximum power available from a cell.

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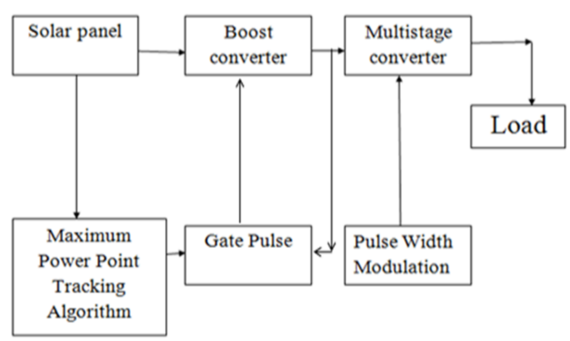
## 3. BLOCK DIAGRAM OF PROPOSED SYSTEM

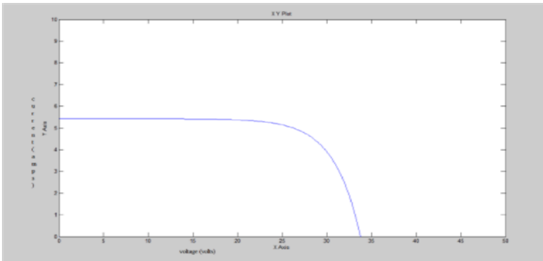



Block diagram of MPPT with Multistage converter and PWM control

### 3.1. Block Diagram Description

Due to the low voltage generated in a PV cell (around 0.5V), several PV cells are connected in series (for high voltage) and in parallel (for high current) to form a PV module for desired output. Separate diodes may be needed to avoid reverse currents, in case of partial or total shading, and at night. The p-n junctions of mono-crystalline silicon cells may have adequate reverse current characteristics and these are not necessary.

Reverse currents waste power and can also lead to overheating of shaded cells. Solar cells become less efficient at higher temperatures and installers try to provide good ventilation behind solar panels.



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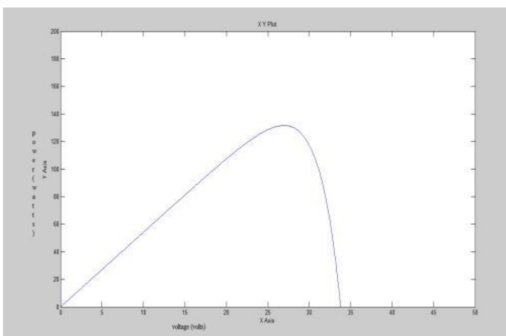


In fact, PV panel manufacturers provide a guarantee of at least 20 years, for example BP Solar assures 85 % of minimum warranted power output after 25 years of service, 93 % of the minimum warranted power output at 12 years and a five-year warranty of materials and workmanship. Such a long guarantee is extremely long compared to most products and is due to the exceptional construction of PV modules.

PV Array Characteristic Curves:

The current to voltage characteristic of a solar array is non-linear, which makes it difficult to determine the MPP. The Figure below gives the characteristic I-V and P-V curve for fixed level of solar irradiation and temperature. The key principle that drives the boost converter is the tendency of an inductor to resist changes in current. When being charged it acts as a load and absorbs energy (somewhat like a resistor), when being discharged, it acts as an energy source (somewhat like a battery). The voltage it produces during the discharge phase is related to the rate of change of current, and not to the original charging voltage, thus allowing different input and output voltages.

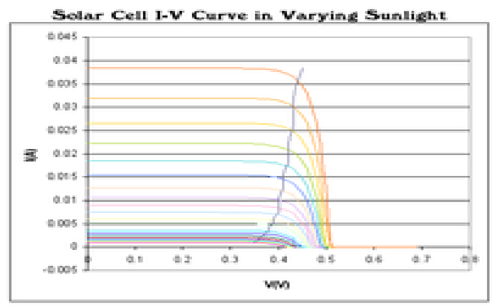
The basic principle of a Boost converter consists of 2 distinct states (see figure 2):

•In the On-state, the switch S (see figure 1) is closed, resulting in an increase in the inductor current;

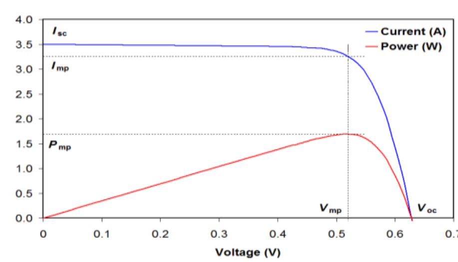
•In the Off-state, the switch is open and the only path offered to inductor current is through the flyback diode D, the capacitor C and the load R.

•This results in transferring the energy accumulated during the On-state into the capacitor.

•The input current is the same as the inductor current as can be seen in figure 2. So it is not discontinuous as in the buck converter and the requirements on the input filter are relaxed compared to a buck converter.

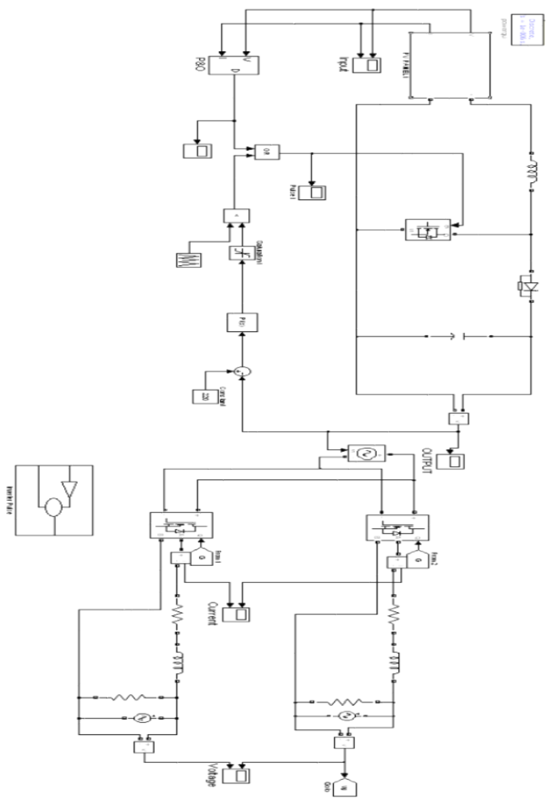



Maximum power point tracking (MPPT) is a technique that grid connected inverters, solar battery chargers and similar devices use to get the maximum possible power from one or more photovoltaic devices, typically solar panels, though optical power transmission systems can benefit from similar technology.Solar cells have a complex relationship between solar irradiation, temperature and total resistance that produces a non-linear output efficiency which can be analyzed based on the I-V curve.

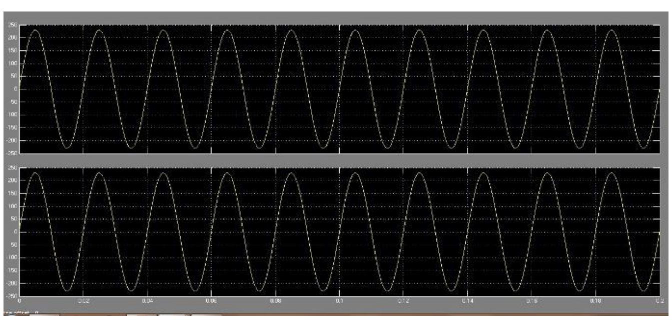



It is the purpose of the MPPT system to sample the output of the cells and apply the proper resistance (load) to obtain maximum power for any given environmental conditions. MPPT devices are typically integrated into an electric system that provides voltage or current conversion, filtering, and regulation for driving various loads, including power grids, batteries, or motors.

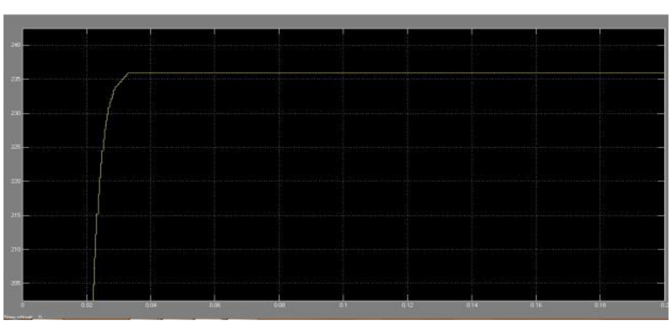
## 4. SIMULATION DIAGRAM MPPT BASED MULTI STAGE GCPVS



Simulation Output of Boost Converter



Simulation Output of Multistage System



## 5. CONCLUSION

A Multi-stage grid-connected photovoltaic system only monitoring AC quantities is proposed. Power sharing with the grid and maximum power point tracking MPPT function of the PV array based on the adjustment of inverter output voltage with respect to grid voltage. Details on system and operation technique are presented.

A MPPT based algorithm, for automatic load sharing and MPPT function, is also presented. Simulation results on load sharing of the inverter with the grid are presented. Future scope of this is the bidirectional current flow control naturally has smoothly mode transition because of the unified power stage model and the adopted unified controller, but for all the other mode transitions a certain control scheme is needed to develop and further investigated.

The other mode transitions include transition between current mode battery charging and voltage mode battery charging control, transition between voltage mode battery charging and bus system voltage mode discharging, and transition between current mode battery discharging and voltage mode discharging.

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