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MODIFIED SWITCHING ARCHITECTURE FOR PV PANELS UNDER SHADING CONDITIONS

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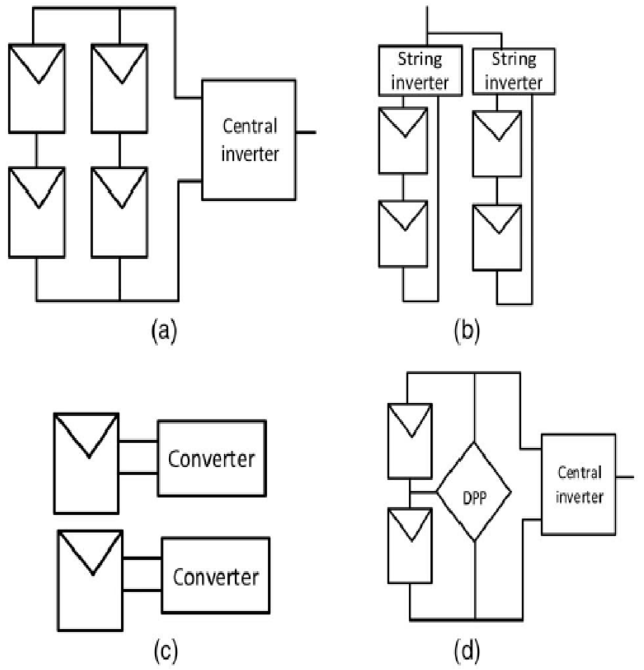
Abstract— **The integration of photovoltaic (PV) modules in buildings causes problems with shadows that can strongly reduce the energy produced by these systems. Moreover, most PV modules are designed for stand-alone applications that have output voltage adapted to lead batteries. Indeed, this historical sizing of PV modules can be discussed in the case of grid-connected systems. In this paper, a cascaded dc/dc converter based on boost chopper is proposed. First, the advantages and the limits of this topology will be shown. Second, this topology will be optimized by switching the panels to maximize the efficiency even at shading conditions. Finally, optimized topologies connected to several PV are evaluated at different situations of typical shadows.**

***Index Terms*— photovoltaic (PV), grid-connected, cascaded dc/dc converter, boost chopper.**

INTRODUCTION

Extracting maximum power from photovoltaic (PV) sources is an important criterion in PV-fed applications, especially in case of partial shading. Normally with no shading, the power–voltage characteristic of PV array has only a single power peak, which is simple to be tracked using any of the conventional maximum power point tracking (MPPT) techniques. During partial shading, the characteristic has multiple peaks (global and local maxima. In the latter case, the conventional MPPT algorithms may fail to track the global maximum power point (MPP), as it will be trapped on the first peak point while searching. To avoid that, the global MPPT should be used to extract the global maximum power. Conventionally, global MPPT is mainly depending on scanning PV characteristics from open-circuit to short-circuit condition to identify the relevant voltage and current of the global MPP. In a fast global MPPT algorithm is presented to identify the global MPP in a relatively short time. Generally, the hardware configuration of the existing inverters for conventional PV systems can be classified into central inverters, string inverters, module-integrated inverters (distributed MPPT converters), and recently, differential power processing (DPP)-based PV systems. The central inverter, shown in Fig. 1.1(a), offers high reliability and simplicity in installation. Central inverter can extract the peak of the overall characteristic of PV array which may be less than the sum of the available maximum power of each module in the array (due to mismatch losses during shading). The string inverters, shown in Fig. 1.1(b), use multiple inverters for multiple strings in a PV array. String inverters provide MPPT on a string level with all strings being independent of each other, which reduce the mismatch losses in case of shading. Distributed MPPT converters, shown in Fig. 1.1(c), use multiple converters for multiple modules in a PV array. Distributed converters provide MPPT on a module level with all modules being independent of each other which results in extracting the exact maximum power.

The following are the different PV converters arrangements,

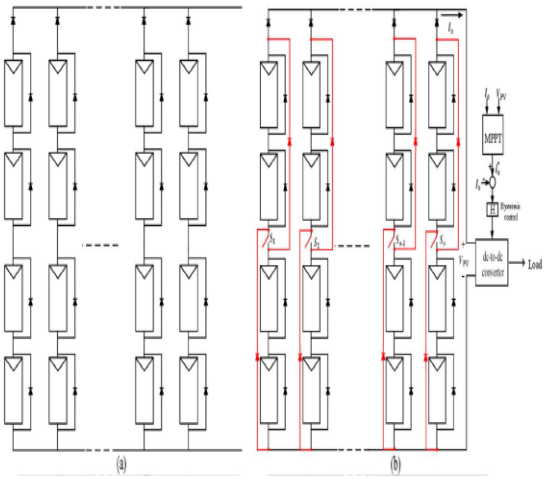


Different PV converters arrangements

However, the used converters should process the full power of the module. On the other hand, the DPP, shown in Fig. 1.1(d), was recently proposed, which is efficiently able to extract the exact maximum power with partially rated converters.

I. INFERENCE ANALYSIS

In existing system, each string in the PV array is divided into two equal sections. Hence, one controlled switch (Si) and two diodes are needed for each string. These extra diodes and switches are rated at half of the open circuit voltage of the string voltage and short circuit current of the module. The proposed topology has two states of operation, namely, state1 and state2. The following sections illustrate the difference between these two states.



(a)Conventional PV array (b) Switched PV based system.

A. *State-1*

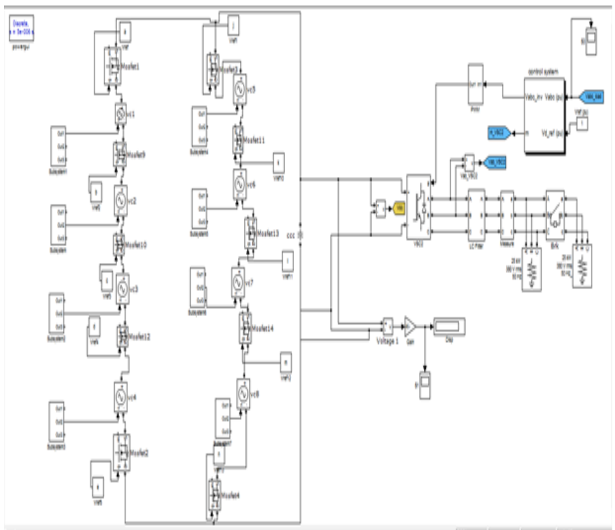
State1 is activated when all of the controlled switches are closed as shown in Fig. 3.1(a), which represents the conventional connection of the PV array. In this state, the highest possible output voltage is the open circuit voltage of the whole string (i.e., Voc), whereas the highest possible output current is the short circuit current of modules multiplied by the number of strings (i.e., nI_{sc}). The output converters should be able to withstand both values.

B. *State-2*

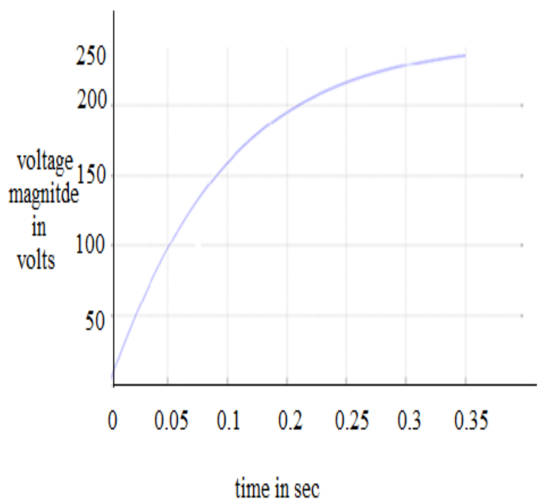
State2 is activated when all of the controlled switches are opened as shown in Fig. 3.1(b). In this state, the highest output voltage is the half of the open circuit voltage of the whole string (i.e., 0.5Voc), whereas the highest output current is double the short circuit current of the module multiplied by the number of strings (i.e., 2nIsc). To avoid using an output converter with a high current rating (compared to state1), the MPPT will limit the output current reference to the current rating of semiconductor devices of output converter (for instance, 125% of the highest current of state1, i.e., 1.25nIsc). This can be generally given as nkIsc where 1 < k < kmax, and kmax < 2. The highest possible output voltage of state2 is approximately equal to half of the highest possible output voltage in state1. Therefore, in case of resistive or battery load, the output converter should have buck and boost capability to successfully provide the power to the load irrespective of the value of the input voltage. In this work, the SEPIC converter is used to ensure drawing of the desired current from the PV array with the privilege of a continuous input current and similar output and input voltage polarities. For three-phase ac loads or grid-connected applications, a dc-to-dc SEPIC/Boost converter followed by three-phase two-/three-level voltage source inverter can be used (two-stage conversion). Alternatively, a single-stage quasi Z source inverter, which has bucking and boosting capabilities, can be used.

C. *Selecting one of the states*

During shading, the extracted power in state2 may be higher than the extracted power in state1 based on the value of k. In order to check which of the two states yields a higher power, the MPPT algorithm will activate state1 first, then it searches for the global MPP (Pmpp1) and saves it. Afterward, it activates state2 and searches for the corresponding global MPP (Pmpp2) in this state and saves it as well. Based on the saved global MPPs, the MPPT will decide to switch the system to the state which gives higher power. The MPPT routine should be repeated every predetermined period using timer interrupt flag to update the system state to minimize the possible power loss due to changing of shading condition. When the existing reconfigurable approach is employed, the current rating of semiconductor switches of the output converter should be higher than nIsckmax. Through limiting the value of kmax to 1.5, the switches' current ratings can be limited to 150% of their ratings in case of conventional PV array (i.e., m × n fixed PV array dimension).



Simulation model



Dc voltage

The present systems have a major drawback of adding a tiny proportion into the PV system in order to get a minor change in magnitude. A DC to DC converter is designed and MPPT used for tuning. No specific optimization has been used in the existing work are the drawbacks.

II. BASICS OF POWER TRACKING IN SOLAR PV

Photovoltaic (PV) energy has increased interest in electrical power applications. It is crucial to operate the PV energy conversion systems near the maximum power point to increase the efficiency of the PV system. However, the nonlinear nature of PV system is apparent from the current and power of the PV array depends on the array terminal operating voltage. In addition, the maximum power operating point varies with isolation level and temperature. Therefore, the tracking control of the maximum power point is a complicated problem. To overcome these problems, many tracking control strategies have been proposed such as perturb and observe, incremental conductance, parasitic capacitance, constant voltage, neural network and fuzzy logic controller (FLC). These strategies have some disadvantages such as high cost, difficulty, complexity and instability.

The general requirements for maximum power point tracking (MPPT) are simplicity and low cost, quick tracking under changing conditions, and small output power fluctuation. A more efficient method to solve this problem becomes crucially important. Hence, this paper proposes a method to track maximum power point using adaptive fuzzy logic controller (AFLC). FLC is appropriate for non-linear control. In addition, FLC does not use complex mathematic. Behaviors of FLC depend on shape of membership functions and rule base. There is no formal method to determine accurately the parameters of the controller. However, choosing fuzzy parameters to yield optimum operating point and a good control system depends on the experience of designer. FLC with fixed parameters are inadequate in application where the operating conditions change in a wide range and the available expert knowledge is not reliable. AFLC can solve this problem because it can re-adjust the fuzzy parameters to obtain optimum performance.

There have been renewed interests in solar micro grids in recent years, and thus, led to further studies in maximum power point tracking (MPPT). MPPT in solar photovoltaic (PV) micro grid systems is normally achieved either by the perturb and observe method or by the incremental conductance method (ICM). In the ICM approach, the output resistance of the PV panel is equal to the load resistance as expected from the celebrated maximum power transfer theorem; this may be shown by linearizing the I–V output characteristic of a PV panel about the operating point. Thus, the equivalent resistance r at the maximum power point is given by,

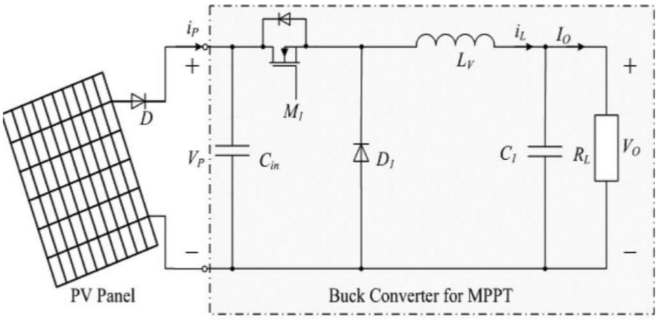
$$-r = -\frac{\Delta V}{\Delta I} = R_{LR} = \frac{V_P}{I_P} \qquad ($$

Where RLR is the regulated resistance in order to achieve MPPT, VP and IP are the PV voltage and current at the MPP. The actual load resistance is matched to r by a buck converter through the control of the duty cycle D, the regulated resistance RLR is as follows:

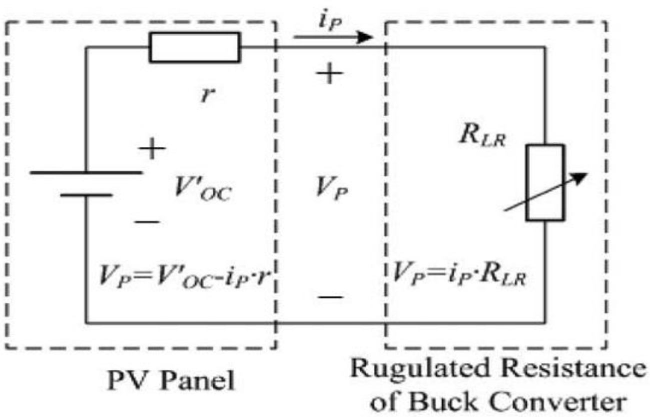
$$R_{LR} = \frac{V_P}{I_P} = \frac{1}{D^2}\frac{V_O}{I_O} = \frac{1}{D^2} \qquad (4.2)$$

Where D is the duty cycle of the buck converter and RL represents the micro grid load connected to the PV panel. Consider two levels of illumination intensity at points_1 and _2, the current at the MPP decreases going from point_1 to point_2 that changes the value of the PV resistance at the MPP. In order to achieve MPPT, the regulated resistance RLR should be adjusted by changing the duty cycle D. The buck converter should work in the continuous current mode (CCM) in order to satisfy. In discontinuous conduction mode (DCM), this relationship is not valid and the stable operation of the converter is more complex. In continuous conduction, for a load power change, the duty cycle changes temporarily during a transient, but it reverts to Vout /Vin in the steady state. On the other hand, in discontinuous conduction, the power is a function of the dead time, and therefore, a different control strategy is required that involves dual-control moving from CCM to DCM and vice versa. This is particularly true for partially shaded conditions, where local peaks (for the shaded regions) in the P–V characteristics exist alongside the global peak, the maintenance of continuous conduction in these areas for low light levels ensures that the MPPT controller can maintain a stable response.

The PV voltage is relatively constant over the full range of solar intensity (VP = 41.6 V in the example to follow), thus the minimum inductance is a function of duty cycle D and the output current of the PV panel IP or a function of duty cycle D and the inductor current IO that feeds the micro grid under a constant switching frequency (fs= 20 kHz). Evidently, the minimum inductance to achieve CCM falls off as the solar intensity increases. Conversely, the higher value of inductance required at light loads may be achieved without increasing the volume of the inductor.

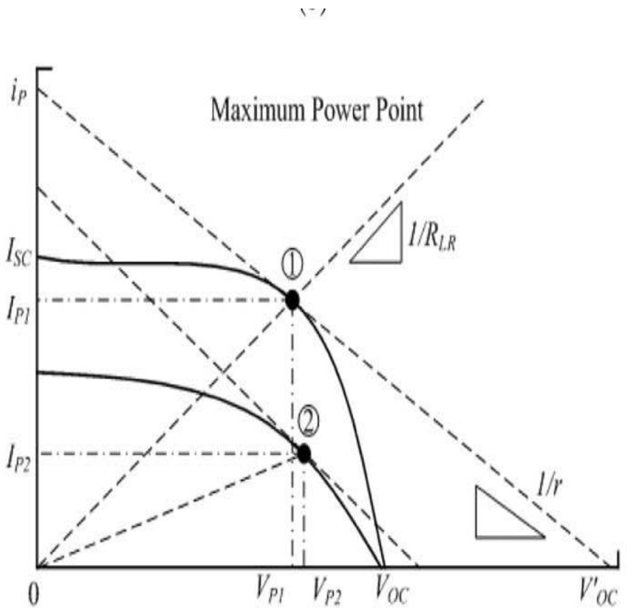


Maximum power transfer in a PV micro grid.

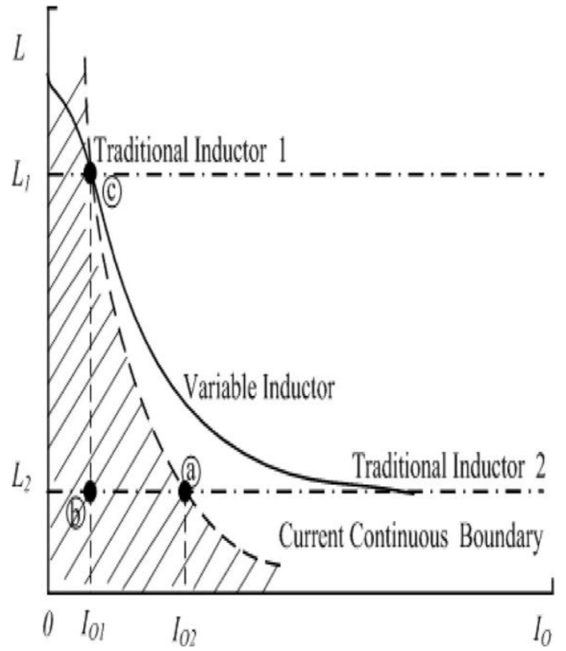


Thevenins equivalent circuit

MPPT based on impedance matching.



A. *Characteristics of Variable Inductor*



Characteristics of Variable Inductor

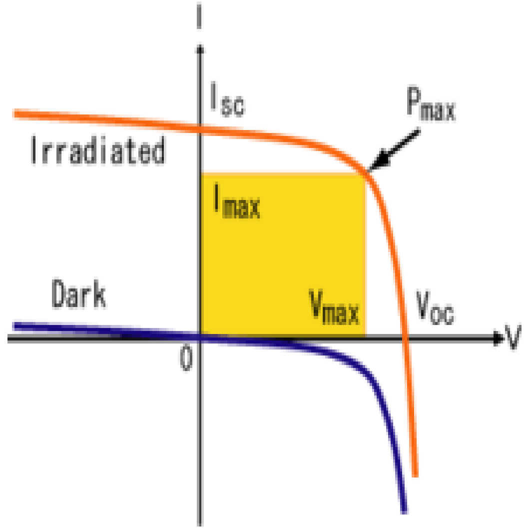
The role of the variable inductor in the stable operation of the buck converter. Continuous conduction can only be achieved with inductance values above the dashed line in Fig (the shaded area is off limits). The lower limit of load current (corresponding to low solar insolation) is given by I_{01}. As long as the inductance is greater than L_1. Evidently, at higher currents (and higher insolation levels), say I_{02}.a smaller inductor L_2. would suffice, with the added advantage of a reduced volume occupied by the inductor. Conversely, setting the inductance at L_2.Would limit the lower load range to values of current (and solar insolation) greater than I_{02}. The variable inductor with the L–Icharacteristic shown in Fig.4.4 has the advantages of increasing the load range. The increased inductance at low insolation levels maintains continuous conduction, and this, in turn, means that the control strategy of the MPPT controller extends to lower power levels; this facilitates the extension of the MPPT algorithm to partial shading.

The voltage across an inductor is related to its flux linkage, and this, in turn, is related to the current, the dependence of the inductance on its current must be taken into account

$$V = \frac{d\lambda}{dt}, \lambda = L(i)i$$
$$= L\frac{di}{dt} + i\frac{dL}{dt}$$
$$\left(L + i\frac{dL}{di}\right)\frac{di}{dt} = L_{eff}\frac{di}{dt}.$$

L_{eff} is readily found from the L/I characteristic of the inductor. The L_{eff} versus current characteristic is more insightful. For the purposes of this paper, we shall use L_{eff} for characterizing the inductor.

B. *Maximum Power Point Tracking*



Current-voltage characteristics of a solar cell.

Maximum power point tracking (MPPT) is a technique that grid tie inverters, solar battery chargers and similar devices use to get the maximum possible power from the PV array. Solar cells have a complex relationship between solar irradiation, temperature and total resistance that produces a non-linear output efficiency known as the I-V curve. It is the purpose of the MPPT system to sample the output of the cells and apply a resistance (load) to obtain maximum power for any given environmental conditions. Essentially, this defines the current that the inverter should draw from the PV in order to get the maximum possible power (since power equals voltage times current).

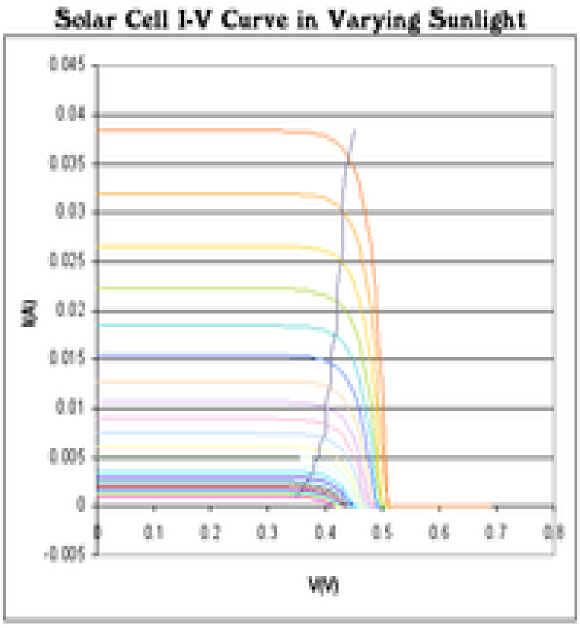
i. *Working of MPPT*

Maximum Power Point Tracking, frequently referred to as MPPT, is an electronic system that operates the Photovoltaic (PV) modules in a manner that allows the modules to produce all the power they are capable of. MPPT is not a mechanical tracking system that "physically moves" the modules to make them point more directly at the sun. MPPT is a fully electronic system that varies the electrical operating point of the modules so that the modules are able to deliver maximum available power. Additional power harvested from the modules is then made available as increased battery charge current. MPPT can be used in conjunction with a mechanical tracking system, but the two systems are completely different.

To understand how MPPT works, let's first consider the operation of a conventional (non- MPPT) charge controller. When a conventional controller is charging a discharged battery, it simply connects the modules directly to the battery. This forces the modules to operate at battery voltage, typically not the ideal operating voltage at which the modules are able to produce their maximum available power. The PV Module Power/Voltage/Current graph shows the traditional Current/Voltage curve for a typical 75W module at standard test conditions of 25°C cell temperature and 1000W/m2 of insolation. This graph also shows PV module power delivered vs module voltage. For the example shown, the conventional controller simply connects the module to the battery and therefore forces the module to operate at 12V. By forcing the 75W module to operate at 12V the conventional controller artificially limits power production to »53W.

Rather than simply connecting the module to the battery, the patented MPPT system in a Solar Boost™ charge controller calculates the voltage at which the module is able to produce maximum power. In this example the maximum power voltage of the module (VMP) is 17V. The MPPT system then operates the modules at 17V to extract the full 75W, regardless of present battery voltage. A high efficiency DC-to-DC power converter converts the 17V module voltage at the controller input to battery voltage at the output. If the whole system wiring and all was 100% efficient, battery charge current in this example would be VMODULE ¸ VBATTERY x IMODULE, or 17V ¸ 12V x 4.45A = 6.30A. A charge current increase of 1.85A or 42% would be achieved by harvesting module power that would have been left behind by a conventional controller and turning it into useable charge current. But, nothing is 100% efficient and actual charge current increase will be somewhat lower as some power is lost in wiring, fuses, circuit breakers, and in the Solar Boost charge controller.

Actual charge current increase varies with operating conditions. As shown above, the greater the difference between PV module maximum power voltage VMP and battery voltage, the greater the charge current increase will be. Cooler PV module cell temperatures tend to produce higher VMP and therefore greater charge current increase. This is because VMP and available power increase as module cell temperature decreases as shown in the PV Module Temperature Performance graph. Modules with a 25°C VMP rating higher than 17V will also tend to produce more charge current increase because the difference between actual VMP and battery voltage will be greater. A highly discharged battery will also increase charge current since battery voltage is lower, and output to the battery during MPPT could be thought of as being "constant power".



Solar cell I-V curves

Photovoltaic cells have a complex relationship between their operating environment and the maximum power they can produce. The fill factor, more commonly known by its abbreviation 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 V_{oc} and I_{sc}, and in tabulated data it is often used to estimate the power that a cell can provide with an optimal load under given conditions, $P=FF*V_{oc}*I_{sc}$. For most purposes, FF, V_{oc}, and I_{sc} 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 usually 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 has an approximately exponential relationship between current and voltage (taking all the device physics into account, the model can become substantially more complicated though). As is well known 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/V ratio (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 is the load which draws maximum power from the device, and this is sometimes called the characteristic resistance of the cell. Note however that 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.

C. Classification of MPPT

There are three main types of MPPT algorithms: perturb-and-observe, incremental conductance and constant voltage. The first two methods are often referred to as hill climbing methods, because they depend on the fact that on the left side of the MPP, the curve is rising (dP/dV> 0) while on the right side of the MPP the curve is falling (dP/dV< 0).

i. *Perturb-and-observe (P&O) method*

This method is the most common. The algorithm perturbs the operating voltage in a given direction and samples dP/dV. If dP/dV is positive, then the algorithm knows it adjusted the voltage in the direction toward the MPP. It keeps adjusting the voltage in that direction until dP/dV is negative.P&O algorithms are easy to implement, but they sometimes result in oscillations around the MPP in steady-state operation. They also have slow response times and can even track in the wrong direction under rapidly changing atmospheric conditions.

ii. *Incremental Conductance (INC) method*

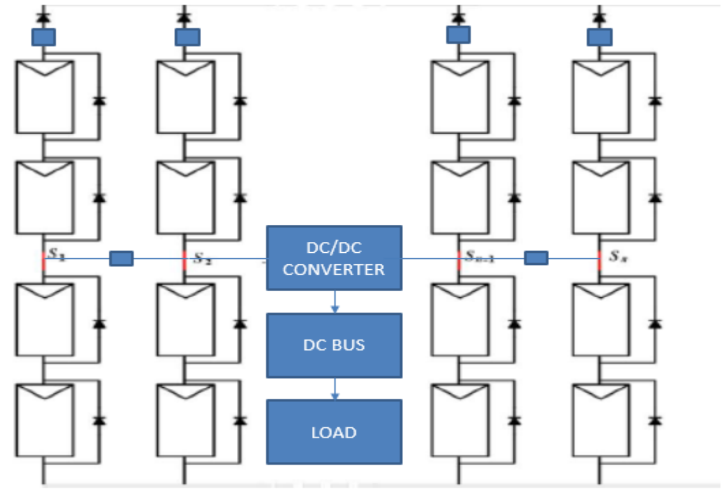
This method uses the PV array's incremental conductance dI/dV to compute the sign of dP/dV. INC tracks rapidly changing irradiance conditions more accurately than the P&O method. However, like the P&O method, it can produce oscillations and be confused by rapidly changing atmospheric conditions. Another disadvantage is that its increased complexity increases computational time and slows down the sampling frequency.

iii. *Constant voltage method*

This method makes use of the fact that the ratio of maximum power point voltage to the open circuit voltage is often close to a constant value, with 0.76 being a common estimate. One problem with this method arises from the fact that it requires momentarily setting the PV array current to 0 to measure the array's open circuit voltage. The array's operating voltage is then set to (for example) 76% of this measured value. But during the time the array is disconnected, the available energy is wasted. It has also been found that while 76% of the open circuit voltage is often a very good approximation, it does not always coincide with the maximum power point. Thus this method may not give as much efficiency as others, especially if conditions are highly variable or the physical behavior of the cell deviates from expectations. Its main advantage is that it is relatively simple to implement and thus usually less expensive.

III. OPERATIONAL ANALYSIS

In proposed model number of series and parallel switches are added across every panel in order to add even a tiny voltage level depending on the requirements by switching arrangements during partial shading conditions.



Block diagram of Proposed System

MOSET switches are used. The following case study has been presented to show the pros and cons of the proposed system compared to other available options. Different simulation models with global MPPT (for the aforementioned PV technologies) and a model of the proposed system with its proposed MPPT have been built for assessment. A PV array of two strings is assumed, each string consists of six series modules. In the presented case, different shading patterns are applied to the modules (assuming that the written number inside each module represents the isolation level of this module). The total extracted power is calculated for the proposed scheme as well as the other aforementioned options (assuming lossless systems). It has to be noted that incase of central inverter, the maximum extracted power is the global maximum of the overall characteristic of the PV array, while it will be the summation of strings global maxima incase of string inverters (independent strings operation).

In case of DPP or module-integrated converter option, the extracted power will be the summation of modules maxima (independent modules operation). In this section, the extracted power in the proposed scheme is calculated at k = 1.33, i.e., it will be permitted for the output current of state2 to increase by 33%above the maximum current of state1; which means that the semiconductor devices with a higher current rating (33% higher than the highest current in state1) should be used in the output stage. The results show that during normal operating condition with no shading, all techniques are extracting the same amount of power.

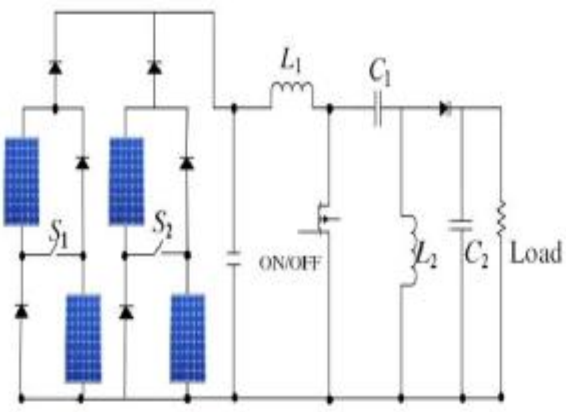
On the other hand, incase of shading condition, the DPP technique gives the highest extracted output power as it extracts the exact maximum power. The simulation results also show that the extracted power from the proposed technique during partial shading is always higher than the central inverter scheme while lower than the DPP scheme. Based on the shape of shading pattern and the value of k, the extracted power from the proposed system may be lesser or higher than the power extracted from string inverters scheme.

A. MPPT Placement

Traditional solar inverters perform MPPT for an entire array as a whole. In such systems the same current, dictated by the inverter, flows through all panels in the string. But because different panels have different IV curves, i.e.

different MPPs (due to manufacturing tolerance, partial shading, etc.) this architecture means some panels will be performing below their MPP, resulting in the loss of energy. Some companies are now placing peak power point converters into individual panels, allowing each to operate at peak efficiency despite uneven shading, soiling or electrical mismatch.

B. Converter stage after PV Panel



Converter stage after pv panel

The above shown topology is used both in existing and proposed, as this work is common for any number of pv panels.

C. Inverter

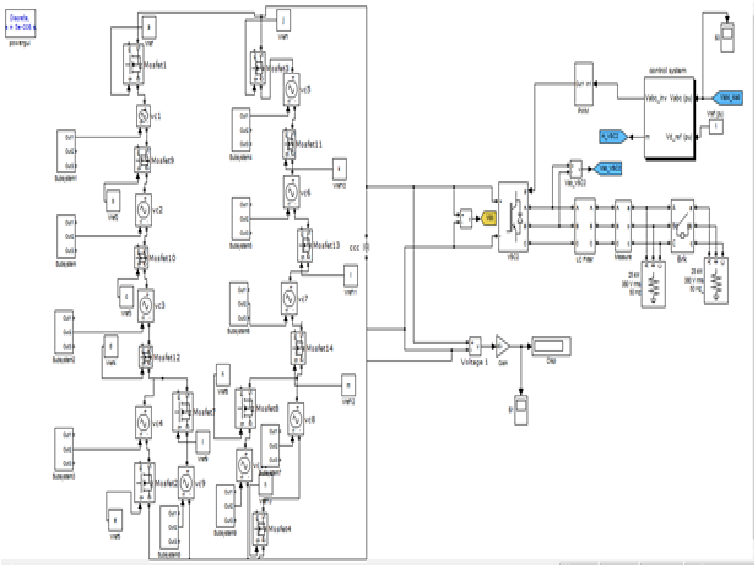
An inverter is an electrical device that converts direct current (DC) to alternating current (AC); the converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits. Solid-state inverters have no moving parts and are used in a wide range of applications, from small switching power supplies in computers, to large electric utility high-voltage direct current applications that transport bulk power. Inverters are commonly used to supply AC power from DC sources such as solar panels or batteries. There are two main types of inverter. The output of a modified sine wave inverter is similar to a square wave output except that the output goes to zero volts for a time before switching positive or negative. It is simple and low cost (~$0.10USD/Watt) and is compatible with most electronic devices, except for sensitive or specialized equipment for example certain laser printers. A pure sine wave inverter produces a nearly perfect sine wave output (<3% total harmonic distortion) that is essentially the same as utility-supplied grid power. Thus it is compatible with all AC electronic devices. This is the type used in grid-tie inverters. Its design is more complex and costs 5 or 10 times more per unit power. The electrical inverter is a high-power electronic oscillator. It is so named because early mechanical AC to DC converters was made to work in reverse and thus was "inverted" to convert DC to AC.

D. Operation with batteries

At night, an off-grid PV power system uses batteries to supply its loads. Although the battery pack voltage when fully charged may be close to the PV array's peak power point, this is unlikely to be true at sunrise when the battery is partially discharged. Charging may begin at a voltage considerably below the array peak power point, and a MPPT can resolve this mismatch. When the batteries in an off-grid system are full and PV production exceeds local loads, a MPPT can no longer operate the array at its peak power point as the excess power has nowhere to go. The MPPT must then shift the array operating point away from the peak power point until production exactly matches demand. (An alternative approach commonly used in spacecraft is to divert surplus PV power into a resistive load, allowing the array to operate continuously at its peak power point.) In a grid-tied photovoltaic system, the grid is essentially a battery with near infinite capacity. The grid can always absorb surplus PV power, and it can cover shortfalls in PV production (e.g., at night). Batteries are thus needed only for protection from grid outages. The MPPT in a grid tied PV system will always operate the array at its peak power point unless the grid fails when the batteries are full and there are insufficient local loads. It would then have to back the array away from its peak power point as in the off-grid case (which it has temporarily become).

IV. Simulation Results

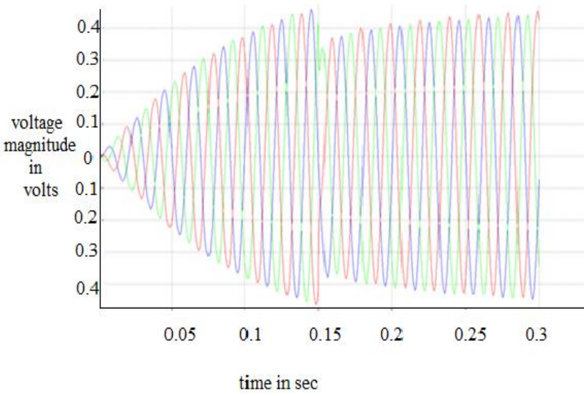
A. Model with Optimization



Simulation model

In order to prove the robustness of the proposed work, improved model shown in the above model file is an implementation of both switching arrangements with some possibilities of switching PV panels and already existing converter stages. The rectifier used for the conversion is gated through a closed loop control of the output AC voltage. The AC voltage is hence controlled even if there exists both transient or stable increase and decrease in the input DC. In case of stable variation from solar voltage, we have switching arrangements for PV panels. Hence, two stage stability is achieved in control to maintain a stable AC output. The simulation output shows the switching of PV panels via a an n channel mosfet, when turned on by supplying '1' pulse to the gate it is connected into the circuit. If it is '0', then turned off. Hence, such switching adds or deletes a particular PV panel based on the amount of DC required. Hence, a small change in the DC output could be achieved through this switching method. This is highly needed, because, partial shading is expected always which depends on nature. Further, in inverter stage, the AC is switched waveform is applied to LC filter in order to smoothen the wave and to make it as smooth sine wave. The same is applied to a three phase load.

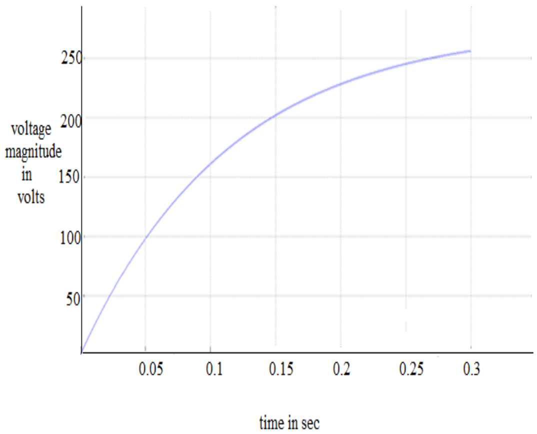
B. Load Voltage (3 Phase)



Three phase load voltage

C. DC Voltage

The graph shows DC voltage in which x axis denotes time in sec and y axis denotes magnitude of DC voltage in volts



V. Conclusion & Future work

In this project, a switched PV-based system is presented to enhance the total extracted power from PV array during shading conditions. The proposed scheme is compared with other existing techniques for PV energy harvesting systems. The comparison shows a promising performance for the proposed reconfigurable PV array compared to the conventional PV array with central and strings inverters approaches. A prototype has to be built in next phase of our project tenure for experimental validation. The experimental results support the claims of the proposed concept.

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