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Sigma Converter for Partial Shading Problem in PV Cell

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Abstract: The search for new energy sources gained momen- tum in the 1970s following the oil crisis when the price of energy in the form of fossil fuel rose dramatically and energy insecurity was felt. The obvious choice of a clean energy source which is abundant and could provide security for the future development and growth is suns energy using photovoltaic PV system. A major challenge in using a solar PV source containing a number of cells in series and parallel is to deal with its non linear characteristics and non uniform radiation. Often PV modules are subject to nonuniform radiation and shading over the surface. Shade is a significant design factor and measuring the extent of shade on a solar array can be challenging due to the fact that shadows moves as the position moves throughout the day and the year. This is further complicated by the changes in the source of shade itself. For example a tree can sway in the wind or lose its leaves during winter, changing the type of shade it cast on solar array. Shade impact depends on its severity and area on PV panel. It may cause current mismatch among PV panel which results in loss of PV power. In this paper study of partial shading , design and simulation of a converter based on sigma conversion concept which enables module level dc/dc converters for eliminating the reduction in output power due to partial shading, soiling etc has done. Converters are designed such that it will provide a constant output voltage eventhough shading occurs on certain PV modules. Thus the system is simple, power can be extracted from unshaded module and reliable.

Index Terms: photovoltaic systems,partial shading, series con- figuration,parallel configuration,bypass diodes,sigma converter.

I. Introduction

The worlds energy requirement is ever growing since the last few decades. The two main drivers for increase in the energy demand are growth in the worlds population and techno economic growth of countries, particularly developing countries. From 2000-2012.The international energy agency estimates that in 2013, total world energy consumption was 9301 Mtoe or $3.89 * 10^{20}$ joules. The coal was the source of energy with the largest growth. The use of oil and natural gas also had considerable growth, followed by hydropower and renewable energy. Renewable energy grew at a faster rate than any other time in history during this period, which can possibly be explained by an increase in international investment in renewable energy.

Renewable energy is energy collected from the renewable sources which are naturally replenished on a human time scale such as sunlight, wind, rain, tides, waves and geothermal heat.Based on Ren21's report on 2016, renewable contributed 19.2% to human global energy consumption and 23.7% to the generation of electricity in 2014 and 2015. The hydropower is the most popular renewable power source and wind is the fastest growing renewable power sources. Solar is the third biggest renewable power source. Global installed capacity of solar power is more than 100GW. Solar energy is the obvious choice of clean energy source which is abundant and could provide security for the future development and growths. A photovoltaic (PV) system is a power system designed to supply usable solar power by means of a photovoltaic. PVsystems range from small rooftop mounted or building integrated systems with capacities ranges from a few to several tens of kilowatts to large utility scale power stations of hundred of megawatts . Operating silently without any moving parts or environmental emissions, PV systems have developed from being niche market application into a mature technology used for main stream electricity generation.

India is ranked 11th in solar power generation in the world on January 2014. Though working silently and can be extremely reliable, they have potential performance problems which can stem from external or internal issues. A major challenge in using a solar PV source containing a number of cells in series is to deal with its non linear internal resistance. The problem gets more complex when the array receives non uniform shading. Shade is a significant design factor affecting the performance of many photovoltaic systems. Measuring the extent of shade on a solar array can be challenging due to the fact that shadow moves as the sun position moves throughout the day and year. This is further complicated by the changes in the source of shade itself. For example a tree can sway in the wind or lose its leaves during the winter, changing the type of shade it casts on a solar array. Shade import depends on the severity and area of the shade. It may cause current mismatch which result in loss of power.

The partial shading occurs due to bird spilt, dust, soil, potential shading, snow etc. The V-I characteristics and P-V characteristics are shown in figure 1.1. They show the effect of shading and clouding on a PV cell. But the study of partial shading is a key issue since the field testing is difficult, time consuming and depends heavily on the prevailing weather conditions.

Many proposals have been put forward by the researchers. The use of bypass diodes in ant parallel with modules partially solves the problem of power reduction but the system becomes costlier and there are additional power losses when the current passes through the diodes. The idea of reconfiguring the connection of solar cells by using self reconfiguring solar cell array, solar array switching unit etchant switching algorithm was developed to continuously rearrange solar cells in series and parallel connections to facilitate the PV systems to work as constant power source, even in different operating condi- tions. Increase in number of switches and control algorithm complexity are main problem then. In later works proposals

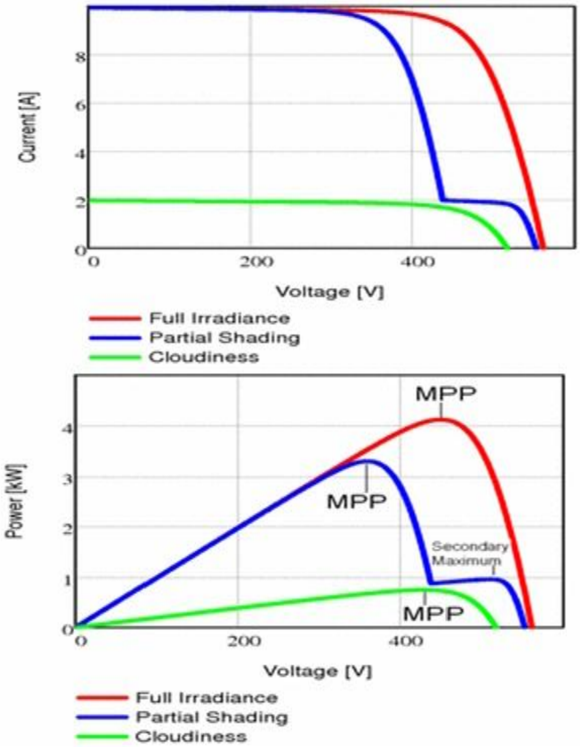

Fig. 1. Effect of shading on PV system emerged relating reconfiguration with less switches and simple algorithm.

In this work another solution is analysed by connecting separate dc/dc converter with each sub module. The MATLAB simulation of the above method has done. In this method dc/dc converters connected with each module so that a constant output voltage is obtained even though shading occurs to any modules in the panel. The hardware model of PV module with sigma converter is obtained.

The basic ideas behind the work as well as the previous work done on the partial shading problem are discussed in the literature review given in section two. The detailed characteristic of the proposed circuit is discussed in the section three. The design, simulation, result discussion is given in section four. The conclusion is made at section five.

II. Literature Survey

Executing research for generating clean energy has not al- ways been the passion of scientists or the aim of policy makers. The search for the new energy source gained momentum only in the 1970s following the oil crisis when the price of energy in the form of fossil fuel rose dramatically and energy insecurity was felt. The oil crisis led to general public awareness of the limitation of fossil fuels. Many governments including those USA, Japan, and several European countries started ambitious programmes in search of renewable energy sources. Apart from the fundamental limitations of fossil fuels, ecological, considerations linked with the production of the green house gasses and global warming are other driving forces in pro- moting renewable energy sources. Excessive dependence on oil imports unstable energy prices poor air quality high levels of financial risk and uncertainty are other factors deterring the use of conventional energy sources. The rapid growth of energy demand and limited quantity of conventional energy sources have inspired the world towards green energy sources such as solar ,wind ,tidal, and biomass which are renewable in nature. A solar cell is an electronic device which directly con- verts sunlight into electricity. Light shining on the solar cell produces both a current and a voltage to generate electric power. This process requires firstly, a material in which the absorption of light raises an electron to a higher energy state, and secondly, the movement of this higher energy electron from the solar cell into an external circuit. The electron then dissipates its energy in the external circuit and returns to the solar cell. A variety of materials and processes can potentially satisfy the requirements for photovoltaic energy conversion, but in practice nearly all photovoltaic energy conversion uses semiconductor materials in the form of a p-n junction

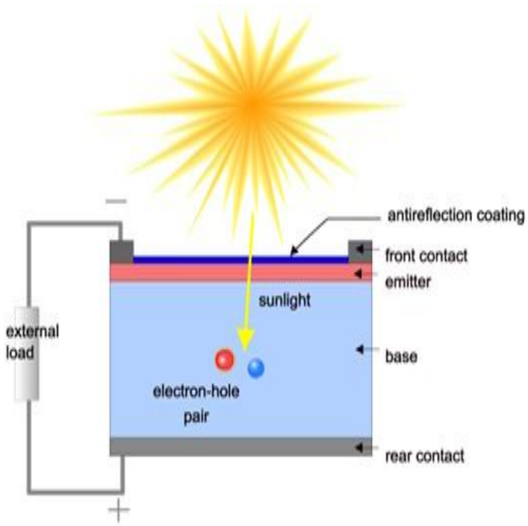

Fig. 2. Basic diagram of PV cell

However, PV system is still facing problems like low con- version efficiency, high capital cost, and variations of output power with different levels of radiation, dynamic weather situation and temperature. Nowadays partial shading condition is having more importance as obstacles such as shadows of trees, buildings and other structures conceals some portion of array. Under such a situation the power of solar array reduces and sometimes PV module becomes permanently damaged.

An ideal solar cell is represented by current source where current produced by cell is directly proportional to radiations falling on it. Though the practical behaviour of solar cell is deviated from the ideal due to the equivalent circuit of PV system is shown in fig.2. IL denotes current produced from light, diode D indicates recombination losses and is connected in shunt manner with current source but in reverse direction. The resistances Rs and Rsh denote Ohm losses occur in cell

The cell current is expressed as:

$$I_{pv} = I_L - I_{os} e^{(\frac{q}{AkT})(V_{pv} - I_{pv} R_s)} - 1 - V_{pv} + I_{pv} R_s / R_{sh} \quad (1)$$

The photocurrent is dependent on the solar irradiation and cell temperature, and is given as:

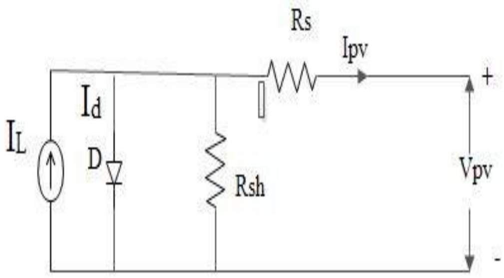

Fig. 3. Equivqlent Circuit of PV Cell

$I_{(}ph) = \lambda[I_{(}sc) + k_i T - T_r]$ (2)

where λ is the solar irradiation (as a ratio of 1000 W/m2), Isc is the cell S.C. current at a 25C and 1000 W/m2(A), ki is the S.C. current temperature coefficient (A/K), T and Tr are the actual and reference tempera1ture (K)
Reverse saturation current of the diode varies with temper- ature, and can be expressed as

$I_{(}os) = I_{(}or)(T/T_r)^3 e^{(qEg/AK)((1/T_r)-(1/T))}$ (3)

where Ior is the reverse saturation current at reference temperature and irradiation (A), Eg is the band-gap energy of the semiconductor used in the cell (J/C).
The shunt resistance, Rsh, is inversely related with shunt leakage current to the ground. In general, the PV efficiency is insensitive to variation in such resistance, which can be assumed to approach infinity with no leakage current to ground. Moreover, a small variation in Rs will significantly affect the PV output power. Therefore, the shunt resistance is usually neglected in the cell equivalent circuit

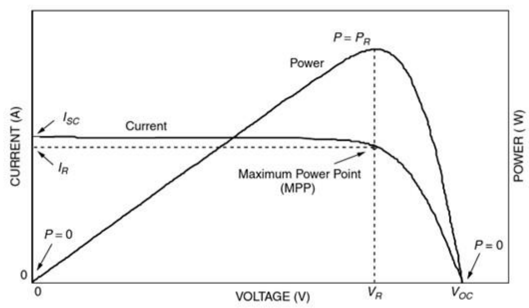

Fig. 4. General I-V and P-V characteristics of a PV system

The figure below shows a generic I –V curve for a PV module, and the product of voltage and current, i.e., power curve of the module. At the two ends of the I V curve, the output power is zero.The maximum power point (MPP) is the spot near the knee of the I V curve at which the product of current and voltage reaches its maximum. The voltages, current and power at the MPP are often assigned subscripts (e.g., R, m, mp, max.)

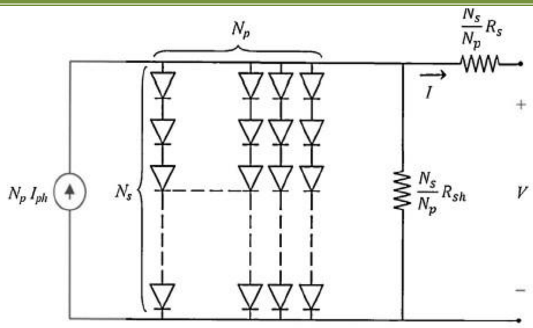

Fig. 5. Equivalent circuit of PV array

A typical crystalline semiconductor PV cell produces less than 2 W at 0.5 V approximately; the cells must be connected, typically in series, on a module to produce enough high power. A PV array is a group of several modules which are electrically connected in series and parallel to generate the required current and voltage levels. The equivalent circuit of a solar array with Ns and Np series and parallel cells is shown in Figure.

Many researchers have studied the characteristics of PV arrays under partial shading condition. A mathematical model is developed in MATLAB environment and experimentally verified for partially shaded solar panels (Patel and Agarwal, 2008). A Simulink model utilizing SimPowerSystemsblockset is also developed to model the PV array under the same condition (Said et al., 2012). Artificial neural networks(ANN) are exploited to estimate the IV characteristics under partial shading conditions (Dolan et al., 2011).It is found from these publications, and others, that the PV curve under partial shading, unlike normal operation, has multiple peaks, whose number depends on the array topology, making maximum power point tracking (MPPT)more challenging. In Karatepe et al. (2007), a novel power compensation and MPPT con- trol system is presented for PV arrays under complicated non-uniform irradiation conditions. The proposed system is based on forward biasing bypass diode of shaded modules by monitoring dynamic resistance and voltage of PV modules. Another MPPT, taking into account shading effects and uti- lizing a multi-stage buck-boost chopper circuit, is introduced in (Bellini et al., 2010).It proposes a new MPPT algorithm to maximize the power produced in any given ambient/junction temperature and solar irradiation levels. Provision of early automatic diagnosis of PV arrays with quick and efficient responses is highly necessary and has-been studied by many researchers (Chao et al., 2008; Davarifar et al., 2013; Houssein et al., 2010; Syafaruddin et al.,2011; Rezgui et al., 2014). Since the accuracy, fast computation and simplicity are imperative issues in this kind of study, ANN, as an intelligent technique, can be a prominent solution. Detection and assessment of partial shading is vital for monitoring and supervising purposes as well as invoking appropriate model predictive control MPPT algorithms. A simplified expression could be used to monitor the equivalent thermal voltage in order to detect partial shades on small areas (Sera et al., 2009). In Spataru et al. (2012), fuzzy inference systems are employed to detect partial shading through the associated increase in series resistance of partially shaded cells.

The idea of reconfiguring the connection of solar cells by using self reconfiguring solar cell array, solar array switching unit etchant switching algorithm was developed to continu- ously rearrange solar cells in series and parallel connections to facilitate the PV systems to work as constant power source, even in different operating conditions. Increase in number of switches and control algorithm complexity are main problem then. In later works proposals emerged relating reconfiguration with less switches and simple algorithm.

To reconfigure, several SPVA configurations have been proposed. They are series, parallel, series-parallel (SP), to- tal cross tied (TCT), bridge linked (BL) and honey comp (HC) configurations. These configurations are compared in MATLAB programming analysing the various configurations for different random shading patterns for varied sizes; it is observed that in most cases TCT gave a higher amount of power for symmetrical array size and HC configuration for asymmetrical array sizes. The usual reconfiguration algorithm is connecting solar cells after checking whether partial shade happened. It will make the PV cells to compensate overly and defectively. To avoid this shading degree model based fuzzy control algorithm has suggested.

From above, it is found that array reconfiguration method has been most frequently analyzed. It is also found that lot of switches are used which leads to maximize the cost of overall system. Very less work has been published to minimize the number of switches in the switching matrix. If the number of switches will reduce it will ultimately reduce the cost of energy.
than open loop. In the simulation set a

III. Different Configuration of Modules

Solar PV modules can be considered as a big solar cell (ar- ray of solar cells connected in series and parallel) with longer voltage and current output than a single solar cell. A solar PV module is obtained by interconnecting smaller solar cells. The ways in which interconnection of solar cells is obtained in a thin film technology and in a wafer based technology are difficult. In thin film technology, cells are interconnected during process of manufacturing of solar cells. While in wafer based technology solar cells are manufactured first and then interconnected to make PV modules. The interconnection of solar cells for generating required power is done in different levels. In the first level of interconnected to increase the power output, cells are connected in the form of a solar PV module. These days solar PV modules are available with the power rating ranging from 3Wp to 300Wp. in the second level of interconnection solar PV modules are connecte together in the form of array to get the power in which is more than a single PV module power output. A solar PV array can be provide us power ranging from few hundred watts to several megawatts.

A. Series Configuration of PV system

Series connection is done in order to increase the output voltage. It is assumed that all modules have the same charac- teristics .i.e. they are identical.

When two cells which are identical, are connected in series, the voltages of the two cells are added while current through them will remain the same as that of a single cell. A series combination of cells is as shown in figure below; in order to connect the cells in series, positive terminal of one cell should

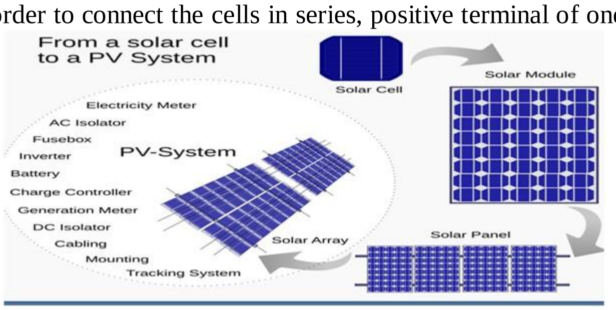

Fig. 6. Formation of PV system

be connected to the negative terminal of the next cell. In silicon solar cells the side which look bluish is generally the negative terminal of the cell

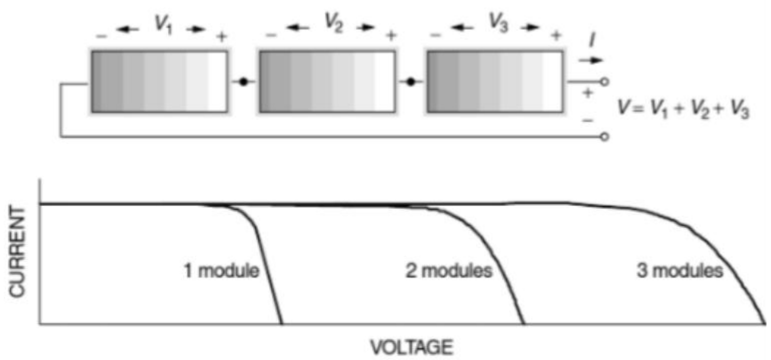

Fig. 7. circuit diagram and charecteristics of series connected PV system

For modules in series, the I V curves are simply added along the voltage axis. That is, at any given current (which flows through each of the modules), the total voltage is just the sum of the individual module voltages. The figure above shows the I V curve for 3 modules in series.

The overall module voltage Vmodule is found by,

$$V_{module} = n(V_d - IR_s) \qquad (4)$$

where n is the number of cells in series.

B. Parallel Configuration

In order to increase the current output the parallel connection of cells are used. Here also it is assured that all cells have the same characteristics.

When two cells are connected in parallel the current from the two cells will be added while the voltage of the combination will remain the same as that of the single cell. When more than one series connected cells are connected in parallel (or more than one parallel connected cell are connected in series) both current and voltage higher than the single cell can be obtained.

For modules in parallel, the same voltage is across each module and the total current is the sum of the currents. That is, at any given voltage, the I V curve of the parallel combination is just the sum of the individual module currents at that voltage. The figure above shows the I V curve for 3 modules in parallel.

C. Series-Parallel Configuration

In high power applications, the array usually consists of a combination of series and parallel modules for which the total

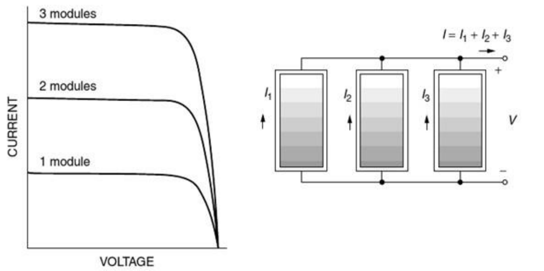

Fig. 8. circuit diagram and charecteristics of parallel connected PV system

I V curve is the sum of the individual module I V curves. The figure below show 2 parallel strings, each of which containing 3 modules.

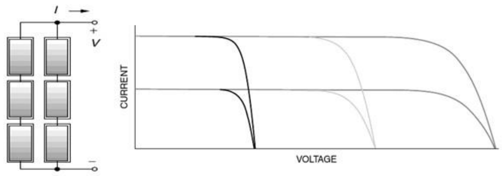

Fig. 9. circuit and charecteristics of series parallel configuration

IV. Problesm Faced By Solar Technology

- Use expensive semiconductor materials
- Large storage system is required for continuous operation.
- Energy production happens in sun.
- Maintenance cost is high.
- Solar panel must be kept clean and free of shades.
- Efficiency currently ranges around 20% up to a top range of around 40%

V. PARTIAL SHADING

The photovoltaic (PV) industry is experiencing rapid growth due to improving technology, lower cost, government subsi- dies, standardized interconnection to the electric utility grid, and public enthusiasm for an environmentally benign energy source. The PV array is typically installed on the roof of a house, and partial shading of the cells from neighboring structures or trees is often inevitable. Then impact of partial shading on PV system performance has been studied at great length in the past. Some past studies assume that the decrease in power production is proportional to the shaded area and reduction in solar radiance.

The objective of this section is to study the impact of shading on a solar panel performance. First, the circuit model of a PV cell and its I-V curve are reviewed. This is followed by the impact of partial shading on the I-V and P-V curves of a circuit containing two cells with and without bypass diodes in series and parallel sub modules.

A. Physics of Shading

Now consider when the nth cell is fully shaded (i.e., ISC = 0). Since the current I generated by the non-shaded cells travels through Rp, the shaded cell becomes reverse biased, i.e., negative voltage equal to $I(R_p + R_S)$ appears across its terminals.

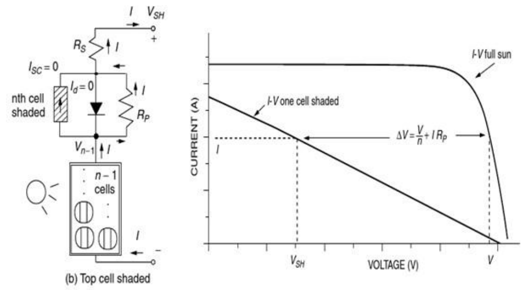

Fig. 10. an illustration of physics of shading

The voltage of the module with one shaded cell:

$$V_{sh} = V_{n-1} - I(R_p + R_s) \qquad (5)$$

$$V_{sh} = ((n-1)/n)V - I(R_p + R_s) \qquad (6)$$

The drop in voltage caused by the shaded cell:

$$\Delta V = V - V_{sh} = V - (1 - 1/n)V + I(R_p + R_s) \qquad (7)$$

$$\Delta V = V/n + I(R_p + R_s) \qquad (8)$$

$$\Delta V \approx V/n + IR_p \qquad (9)$$

B. Effect of Shading on A Single PV Module

Consider a PV module connected to a resistive load as in figure below. The cell first works at the maximum radiation and then at a reduced radiation. The I-V & P-V characteristics are plotted on the both cases.

Fig. 11. circuit of single PV module

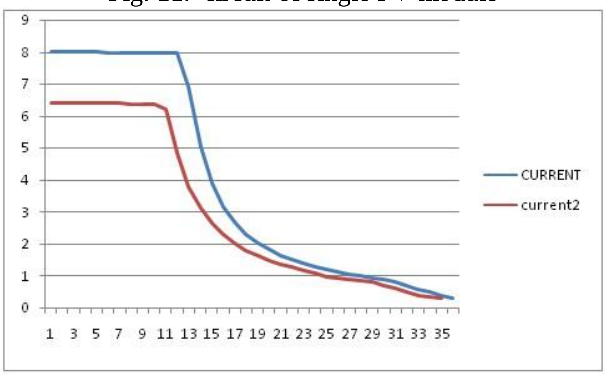

Fig. 12. effect of shading in I-V Characteristics of PV module

The current and thereby the power of a shaded module got reduced compared to the maximum radiated case. It is also found that the MPP shifted from its actual point when the module got shaded. A partially shaded module may generate

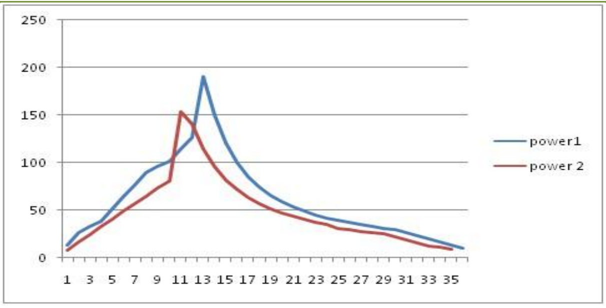

Fig. 13. effect of shading in P-V Characteristicsof PV module

or consume power depending on Isc and operating current I. A fully shaded module a voltage drop under any current, the shaded module will be consuming power.

C. Effect of Shading on Series Configuration

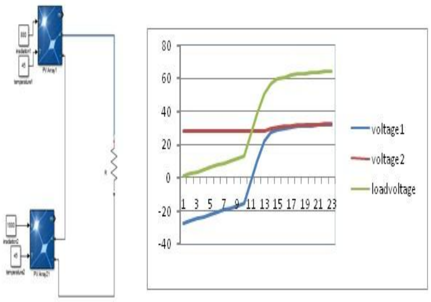

Fig. 14. series configuration and effect of shading on voltages of modules and load

Consider the circuit shown in figure, which shows two modules, one is shaded and other is normally radiated. It is seen that the current is constant but the magnitude is determined by the partially shaded module the shaded module seem to be act as a load which consumes energy from the fully radiated module. This cause a total reduction in the output power of the entire system. If one cell is shaded its I_{sc} falls, i.e. if it is half shaded its I_{sc} got halved.

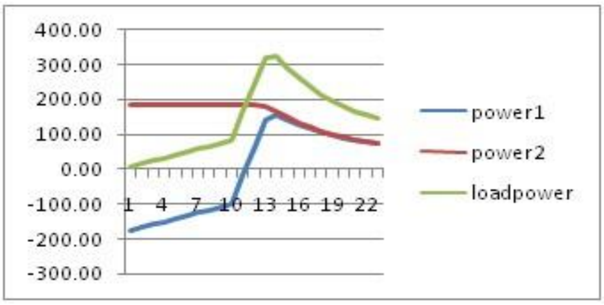

Fig. 15. effect of shading on power of modules and load

D. Effect of Shading On Parallel Configuration

Consider two modules in parallel, on shaded and other fully radiated. The voltage and power characteristics are shown in

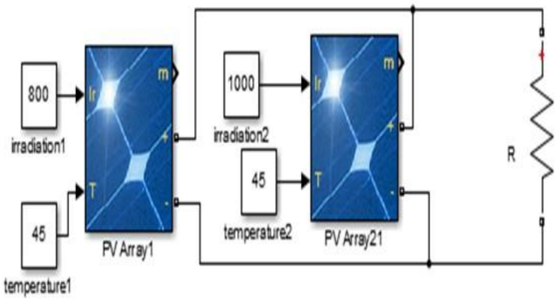

Fig. 16. circuit of parallel configuration

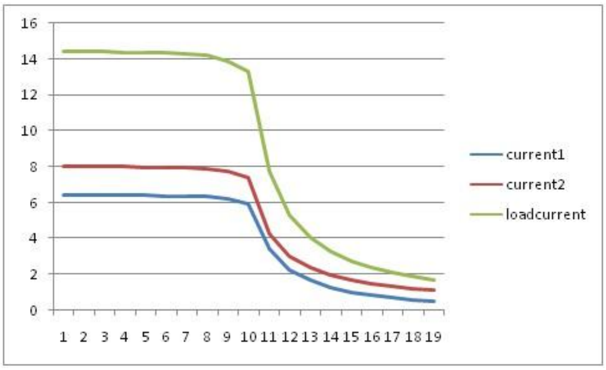

Fig. 17. effect of shading on current of modules and load

figure below. The loss in output can see in this case also. The shift in the MPP can also noted in parallel configuration. The MPP is low in parallel configuration than compared to the series configuration. This is because cell output current shows a stronger dependency (linear) on irradiation than the voltage (logarithmic). If one sub module is working at its MPP, the other one sharing the same voltage will work also in the vicinity of its MPP, thus resulting in a higher MPP power.

E. Effect of Shading With Bypass Diodes Configuration

In order to reduce the problem of shading, bypass diodes is connected in parallel with each module. It is the easiest way to eliminate shading effect and preventing damage to each module.

The P-V characteristics and circuit diagram of the bypass diode case is shown in figure. The circuit shows three strings of a panel such that in the first string two modules are shaded, in the second one is shaded and final fully radiated strings are given. In the P-V characteristics it is found that the whole power of the shaded module is dissipated and it causes multiple peaks appeared. So it is too difficult to track the global maximum power point.

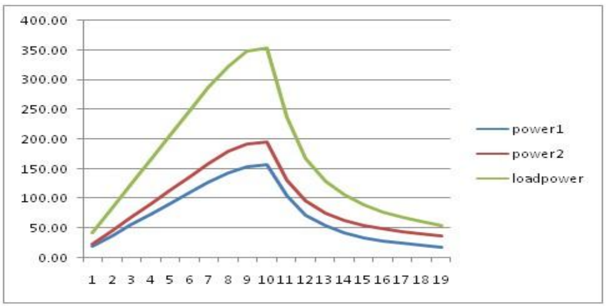

Fig. 18. effect of shading on current of modules and load

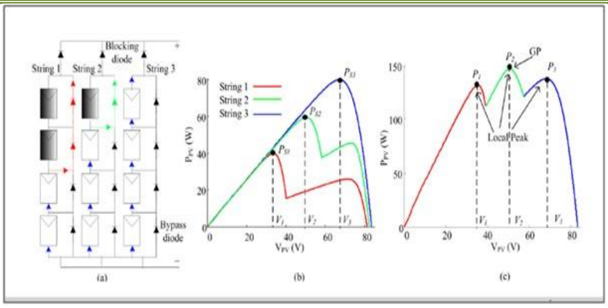

Fig. 19. modules with bypassdiodes and shading effect on MPP

VI. Sigma Converter

In any PV system weather it is grid connected or residential, the panels or modules are connected in series or parallel with or without bypass diodes, in order to obtain the required energy. But this long strings of panels (and hence cells) bring with them many complications, as explained in the previous chapter.

Placing a DC/DC converter on each half panel or panel substring and the connecting these converters in series strings avoid many of these problems. This type of approach of module integrated converter is known as sigma converter. Each panel has its own converter and a single DC-AC inverter is the required to connect to the grid. Using modular structure eliminates the need of a wide and plain roof for domestic systems. This is a common approach utilised in smaller res- idential scale installations. The block diagram representation of a sigma converter is shown in figure below,

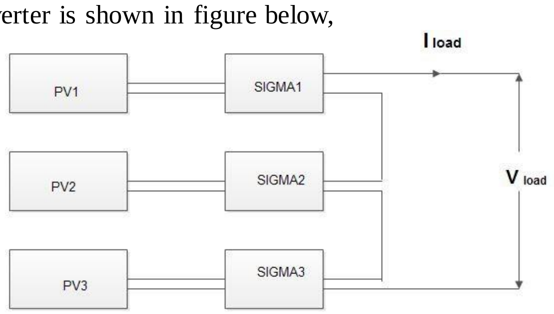

Fig. 20. Block diagram of sigma converter

As shown in figure 3.1 the converters are connected in paral- lel with a panel or a string. Then the combination is connected in series with each other. The converters used can be buck, boost, and buck-boost and Cuk converters. Due to simplicity in design boost converters are preferable. Boost converters have lots of advantages over buck and other converters.

A. Boost Converter

The boost converter, also, benefits the advantage of having glow part count and simple design. Owing to its capability of enhancing output voltage, boost converters are one of the most applicable candidates in MIC structure. In fact, capability of increasing the output voltage with simple structure and without using high-cost and heavy transformers makes the boost con- verter the most popular converter for MIC applications among all step-up converters. This topology presents the ability of obtaining needed DC link voltage by less PV modules. If the desired converter output voltage is designed so high that the open circuit voltage of the PV panel sets below it, a boost characteristic ensures that the maximum power point (MPP) will always be tracked. The boost inductor which is located on the PV module side will reduce electromagnetic interference (EMI) noises and losses resulting from current ripple in the converter. The seriesconnection of boost converters causes the output current for all converters to be the same. Also, it allows every converter to reduce its voltage boosting factor, so it will reduce the voltage stress on the power switches and contribute to higher efficiency and better performance of the whole system. Since the output currents of neighboring MICs are equal, their output voltage is proportionate to their delivered power. However, boost converter limitation is that their output current is less than their input current. Thus, at high percent of shading their input current would be so that their output current forces the string current to be that low.

B. Advatages of Converter Per Panel Approach

A panel integrated converter approach whether dcdc or dcac has many advantages.

1) Better Utilization on a per Module Basis:

Each converter module can independently control and so optimize the power Flow to or from its source. For a battery string, each converter can independently and opti- mally charge its connected battery, reducing equalization time and increasing charge efficiency. In a solar power application, each converter can independently perform maximum power point tracking (MPPT) for its PV panel. In an otherwise ideal installation, this will compensate for mismatches in panels of like manufacture, which can be up to 2.5%. It offers the further advantage of allowing panels to be given different orientations and so open up new possibilities in architectural applications. A third advantage is the greater tolerance to localized shading of panels. These reasons taken together are the most important advantage of per-panel distributed converters in PV applications.

2) Mixing of Different Sources Becomes Possible:

Independent and intelligent power flow control can de- couple each source from the others in the string. Batter- ies could be replaced individually as required since old and new batteries can now be mixed. Existing PV panel strings could be extended by adding new higher output panels without compromising overall string reliability or performance

3) Better Protection of Power Sources:

Intelligent protection can be applied on a per source basis. For example, a weak Battery can be protected from permanent damage during deep discharge. A single shaded PV panel can deliver its reduced power rather than being bypassed by a diode for its own Protection.

4) Redundancy of Both Power Converters and Power Sources:

An intelligent converter module can bypass a failed source or indeed a failed converter if appropriately designed, allowing the complete installation to continue operation at slightly reduced capacity.

5) Better Data Gathering:

Each power source/power converter module will have an inherent data collection capability and most likely a control network connection, so that data gathering and reporting will add minimal additional complexity or cost. Batteries or PV panels requiring inspection or replacement can be individually identified.

6) Greater Safety during Installation and Maintenance:

Depending on design, each converter module may be able to isolate its connected power source, so that the wiring of series or parallel connections of these modules can be performed Safely. The power sourceconverter connection is a safe low voltage connection.

7) Cost Justification or Advantage:

In most applications, many small converter modules, one per source, will displace one large converter. The total VA (power) rating of the power switching devices will remain the same, but the cost of the distributed solution could be more attractive in time because;

a) The hardware functionality of the modules could be standardized. They could be made in signifi- cant volumes by a number of manufacturers. They could be integrated, packaged and sold with the dc source. They could be adapted to different applications through software updates

b) The advantages of greater efficiency and reliability would increase the return on the installation invest- ment

c) The advantages of per module data acquisition, intelligent protection and control could displace ad- ditional hardware that might otherwise be required.

C. Series versus Parallel String of Module Integrated Convert- ers

The present grid connected module integrated converters can lay claim to most of these advantages. However, this approach of direct grid connection has the disadvantage of a large difference between the converter input voltage (low) and output voltage (high). This requires a transformer based converter, which requires more mass and volume, is more expensive and is less efficient than a simple nonisolated dcdc converter.

A series rather than parallel connection of converters allows the input-output voltage ratio to be close to unity, which leads to the highest switch utilization and removes the need for a transformer. Efficiencies of close to 100% are possible and converters can be small, light and low cost.

A series connection utilizes low voltage MOSFETs, Schot-tky diodes, inductors and capacitors that have been developed for low voltage dcdc converters. A parallel connected converter requires high voltage fast recovery diodes and MOSFETs, which are at a performance versus cost disadvantage.

D. Survey of Series Connected DC-DC Converter Research

Enslin et al. present“A low-power low-cost highly efficient maximum power point tracker (MPPT) [designed] to be inte- grated into a photovoltaic (PV) panel.” The resonant switching buck converter with a synchronous rectifier achieves better than 98% efficiency for much of its operating region. Its simple analog implemented MPPT algorithm is reported to allow the dcdc converter modules to be placed in series and operate correctly with no inter-module communication, although no detailed analysis of such a series connection is presented.
The control of modular dcdc converters with series input and parallel output connections is examined by Giri et al. . They show a common converter control signal is all that is required to ensure input voltage and output current sharing. The converters considered are buck derived and isolated by necessity of the common input and output connection.

VII. Design and Simulation

In MIC topology, a DC-DC converter is combined with the PV module such that the module is no longer connected in series with neighbouring modules directly. The converter and the module both constitute an integrated element which can be connected to other elements in the whole array by output terminals of the converter, and construct a series-connected string.

A. Circuit Diagram

As the MIC solves many of the disadvantages of shading compared to other conventional methods, a sigma converter is designed, simulated and fabricated in this project work. A boost converter is chosen as sigma converter for this work. The circuit diagram of the proposed work is as shown in figure4.1.

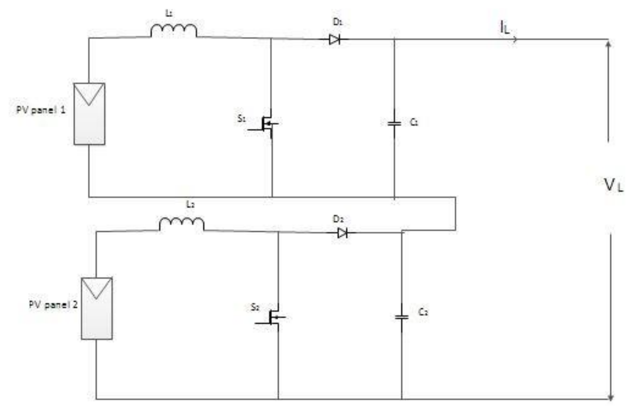

Fig. 21. circuit of PV module with sigma converter

The circuit consists of two PV modules with sigma con- verters connected in series with each other. The circuit will work normally at full radiation. The load will receive the sum of voltages and power from the circuit. The current will be same since they are in series connection. Similarly it is seen that single dc bus as well as single inverter is required for the system to connect to the grid.

When any module undergo shading , thereby reduce the voltage and act as a load, the boost converter of that particular module will enhance the voltage to the required set value and maintain the output voltage constant. Thus the load wont get affected by the shading.

If the system is grid connected or is connected to a battery this method could provide the MPP operation always even though the modules undergo partial shading. This will be possible by using a good MPP tracker in the control circuit.

VIII. Designing of The Sigma Converter

The load chosen is simply a resistance of 15 ohm because around this load the maximum power of the series panels are obtained. The solar panel taken is 1SOLTECH-1STH-230P for the simulation purpose. It is found that the maximum voltage obtained from the panel is 34V. So the reference value is chosen around 40V. The switching frequency is chosen to be 50 kHz .Then the required calculations are as follows: The duty ratio of the pulse generated is given by,

$D = 1 - (V_{in}/V_o) = 1 - (34/40) = 0.15$ (10) The minimum value of inductance in the boost circuit is given by,

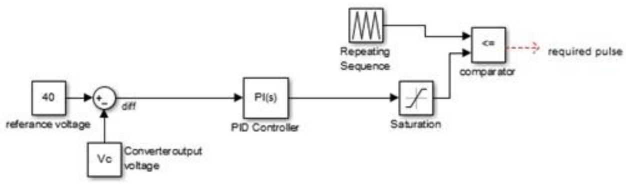

Fig. 23. control circuit

B. Control Circuit

In the control circuit the reference voltage is chosen to be 40V. Since the load is simply resistive the point MPP operation is not possible here, as the current depends on load. The result expected is to keep the output voltage a constant, when the panel undergo shading. The control circuit first of all compare the voltage from the converter of each sections and an error is generated. This error signal is modified in the PID controller and saturated. The required switching pulse is provided by comparing the error signal with a repeating sequence having the required switching frequency

C. Results and Discussion

$$L_{min} = D(1-D)^2R/2F = (0.15(1-0.15)^2*15)/(2*50*10^3) = 16.25\mu H \quad (11)$$

The approximate value of the inductance is given by,

$L = 1.25 * 16.25\mu H = 20.32\mu H$ (12) Let $\Delta V_o/V_o$ be 0.01, then the minimum value of capacitance is given by,

$$C_{min} = (D/R)(\Delta V_o/V_o)F = 0.15/(15 * 0.01) = 20\mu F \quad (13)$$

A. Simulation Of The Sigma Converter

In the simulation two panels are chosen and shading is provided to the one module. The basic simulation diagram of sigma converter is as shown below;

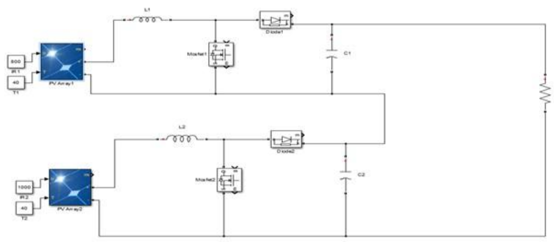

Fig. 22. simulation diagram

The circuit is operated in three cases as both fully shaded, one partially shaded and one completely shaded. The control circuit is provided separately for each switches of each section. MOSFET switches are selected for the switching purpose as it is a low voltage application.

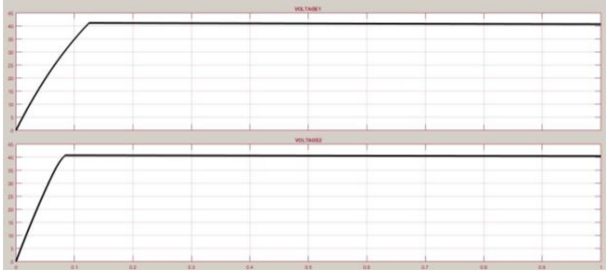

Fig. 24. effect of shading on converter voltages

The below figure shows the effect of shading on the outputs of each stage. In this case on of the panel is shaded while the second one is fully radiated. It is found that the normal panel system attains its reference value faster than the other one. The shaded panel also attains the set value and this is because of the charging time taken by the capacitor as the input voltage got reduced due to shading. The voltage, current and power across the load is as shown below;

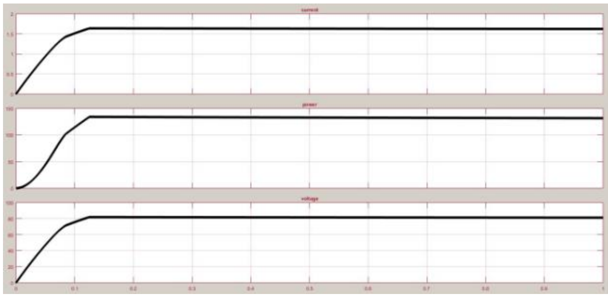

Fig. 25. current ,voltage and power accross load on shading

IX. Conclusion

Now a day the implementation and usage of solar energy is increasing. A lot of residential as well as commercial installations are happening each and every part of the world. The problems like shading and soiling are common in these systems. In this project the effect of shading on series and parallel configuration has studied. The study also done with bypass diodes, one of the simplest methods to overcome shad- ing. But certain disadvantages of these entire configurations had found. To overcome all these and to extract efficient power sigma converter concept had proposed. Simulation, fabrication and testing of the sigma converter done in circuit with two panels. The sigma converter implemented in this paper uses boost converter to enhance the output voltage. The output voltage had kept constant , though the panels undergo shading.

X. Future Scope

A converter per panel approach offers many advantages including,

1) Individual panel maximum power point tracking , which gives great flexibility in panel layout, replacement and insensitivity to shading.
2) Better of PV sources and redundancy in the case of source or converter failure
3) Easier and safer installation and maintenance.
4) Better data gathering.

The implementation of sigma converter done in this project with simple boost converter , as it have many advantages over the other converters.This can also be done with buck, buck- boost or Cuk converters. The efficiency of the prototype is calculated at different cases like shaded and normal cases, and it is found that a maximum of 95% efficiency is obtained from the circuit.

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