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Design & Simulation of DC-DC Boost Type PWM based Solar Charge Controller for Constant Output Power under Partial Shading Conditions

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Abstract: ***Nonlinear Global energy demand is increasing exponentially. This increase in demand causes concern pertaining to the global energy crisis and allied environmental threats. The solution of these issues is seen in renewable energy sources. Solar energy is considered one of the major sources of renewable energy, available in abundance and also free of cost. Solar photovoltaic (PV) cells are used to convert solar energy into unregulated electrical energy. These solar PV cells exhibit nonlinear characteristics and give very low efficiency. Therefore, it becomes essential to extract maximum power from solar PV cells using maximum power point tracking (MPPT). The proposed method has the advantage that it can be applied in either stand-alone or grid-connected Systems comprising PV arrays with unknown electrical characteristics and does not require knowledge about the PV modules configuration within the PV array. The experimental results verify that the proposed solar charge controller method guarantees constant required power under any partial shading conditions.***

Keywords: DC-DC power converters, Maximum power point tracking, Photovoltaic systems, Microcontrollers

1. Introduction

In a (Power-Voltage or current-voltage) curve of a solar panel, there is an optimum Operating point such that the PV delivers the maximum possible power to the load. This unique point is the maximum power point (MPP) of solar panel. Because of the photovoltaic nature of solar panels, their current-voltage, or IV, curves depend on temperature and irradiance levels. Therefore, the operating current and voltage which maximize power output will change with environmental conditions. As the optimum point changes with the natural conditions so it is very important to track the maximum power point (MPP) for a successful PV system. In most PV systems a control algorithm, namely maximum power point tracking algorithm is utilized to have the full advantage of the PV systems [1]. In typical Photovoltaic (PV) installations, PV arrays are formed by connecting multiple PV modules in various configurations (i.e. series, parallel, series-parallel etc.) Bypass diode or bypass switch is connected in parallel with each PV module for protecting the solar PV cells against efficiency degradation and hot-spot failure effects [6].A solar charge controller is used for utilizing the maximum power from the solar PV module and transferring that power to the load. A dc/dc converter (step up/step down) serves the purpose of transferring maximum power from the solar PV module to the load.

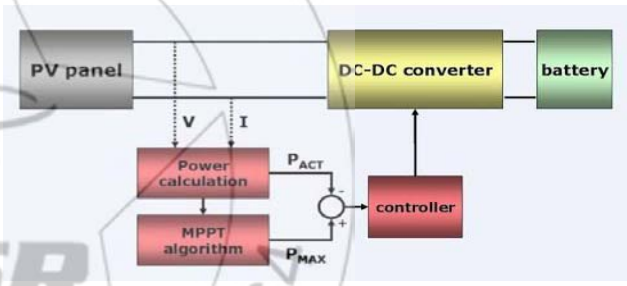

Figure 1.1: Principle Block diagram of a typical MPPT system.

A dc/dc converter acts as an interface between the load & module as shown in Fig 1.1. MPPT requires Voltage & Current Input from Solar panel. The maximum power point is obtained by introducing dc/dc converter in between the load and the solar PV module. The duty cycle of the converter is changed till the maximum power point is obtained.

2. Overview of MPPT Techniques

Solar charge controller is used to obtain the maximum power from these systems. In these applications, the load can demand more power than the PV system can deliver. There are many different approaches to maximizing the power from a PV system, this range from using simple voltage relationships to more complexes multiple sample based analysis. Following two techniques are used frequently for solar charge controlling purpose.

2.1 Perturb & Observe Method

The P&O algorithms operate by periodically perturbing (i.e. incrementing or decrementing) the array terminal voltage and comparing the PV output power with that of the previous perturbation cycle. If the PV array operating voltage changes

and power increases (dP/dVPV>0), the control system moves the PV array operating point in that direction; otherwise the operating point is moved in the opposite direction. In the next perturbation cycle the algorithm continues in the same way.
Perturb & Observe is the simplest method. In this we use only one sensor, that is the voltage sensor, to sense the PV array voltage and so the cost of implementation is less and hence easy to implement [2] & [3]. The time complexity of this algorithm is very less but on reaching very close to the MPP it doesn't stop at the MPP and keeps on perturbing on both the directions. When this happens the algorithm has reached very close to the MPP and we can set an appropriate error limit or can use a wait function which ends up increasing the time complexity of the algorithm. However the method does not take account of the rapid change of irradiation level (due to which MPPT changes) and considers it as a change in MPP due to perturbation and ends up calculating the wrong MPP. To avoid this problem we can use incremental conductance method.

Perturb & Observe Algorithm. The Perturb & Observe algorithm states that when the operating voltage of the PV panel is perturbed by a small increment, if the resulting change in power ΔP is positive, then we is going in the direction of MPP and we keep on perturbing in the same direction. If ΔP is negative, we are going away from the direction of MPP and the sign of perturbation supplied has to be changed.

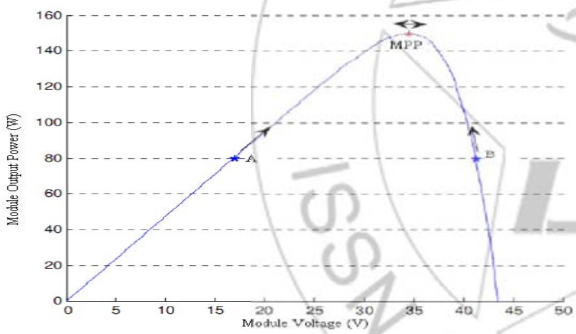

Figure 2.1: Solar panel characteristics showing MPP and operating points A and B

Figure 2.1 shows the plot of module output power versus module voltage for a solar panel at a given irradiation. The point marked as MPP is the Maximum Power Point, the theoretical maximum output obtainable from the PV panel. Consider A and B as two operating points. As shown in the figure above, the point A is on the left hand side of the MPP. Therefore, we can move towards the MPP by providing a positive perturbation to the voltage. On the other hand, point B is on the right hand side of the MPP. When we give a positive perturbation, the value of ΔP becomes negative, thus it is imperative to change the direction of perturbation to achieve MPP. The flowchart for the P&O algorithm is shown in Figure 2.2.

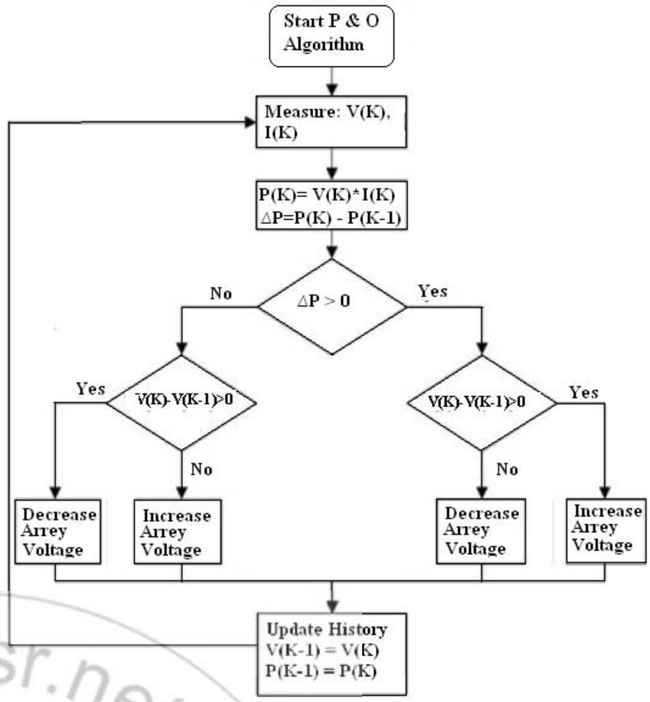

Figure 2.2: Flowchart of Perturb & Observe algorithm

2.2 Incremental Conductance Method

Incremental conductance method uses two voltage and current sensors to sense the output voltage and current of the PV array [2] & [3] as shown in Fig 2.3. At MPP the slope of the PV curve is 0.

The left hand side is the instantaneous conductance of the solar panel. When this instantaneous conductance equals the conductance of the solar then MPP is reached. Here we are sensing both the voltage and current simultaneously. Hence the error due to change in irradiance is eliminated. However the complexity and the cost of implementation increase.

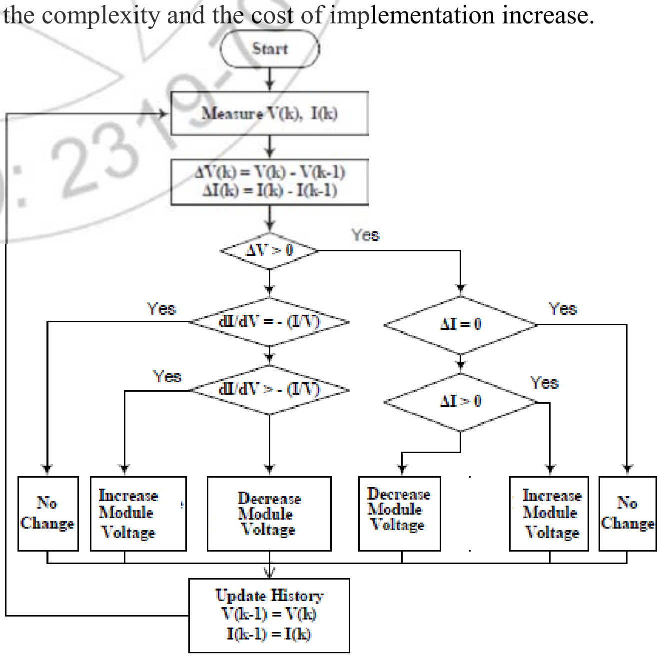

Figure 2.3: Flowchart of Incremental Conductance algorithm

As we go down the list of algorithms the complexity and the cost of implementation goes on increasing which may be suitable for a highly complicated system. This is the reason that Perturb and Observe and Incremental Conductance method are the most widely used algorithms.

The comparisons between the characteristics of two MPPT techniques are given in table 2.1.

MPPT technique	Convergence speed	Implement complexity	Periodic tuning	Sensed parameters
Perturb& observe	Varies	Low	No	Voltage
Incremental conductance	Varies	Medium	No	Voltage, current

Now we will go through the DC-DC boost type converter method which is used in proposed technique of solar charge controlling.

2.3 Boost circuit (Step Up) & its Topology

DC-DC converter is an electronic circuit which converts a source of direct current (DC) from one voltage level to another. The DC-DC converters are widely used in regulated switch-mode dc power supplies and in dc motor drives applications. [4] & [5]. Often the input of these converters is an unregulated dc voltage, which is obtained by rectifying the line voltage, and therefore it will fluctuate due to changes in the line voltage magnitude. Switch-mode DC-DC converters are used to convert the unregulated dc input into a controlled dc output at a desired voltage level. The heart of MPPT hardware is a switch-mode DC-DC converter. MPPT uses the converter for different purpose: regulating the input voltage at the PV MPP and providing load matching for the maximum power transfer. The dc-dc Converter circuit consists below Non-Isolated Topology, which do not have isolation transformer.

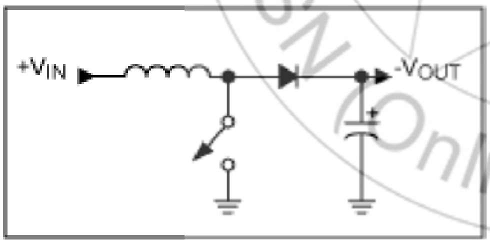

Figure 2.4: Boost Circuit

The boost topology is used for stepping up the voltage (as shown in Fig.2.4). The grid-tied systems use a boost type converter to step up the output voltage to the utility level before the inverter stage. Thus, the additional boost capability can slightly increase the overall efficiency under a low-irradiance and high-temperature condition. [8].

3. Simulation Model & Results

Proetus Software is used for to verify the Components value & functionality of PWM Based DC-DC boost converter solar charge controller circuit.

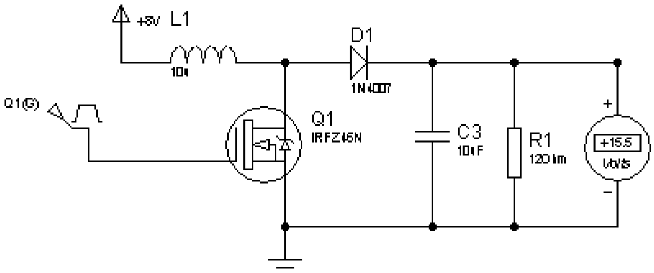

Figure 3.1: Simulation model of Boost Circuit.

Below observation table is prepared for the observing the output voltage of booster circuit with different circuit parameters.

Table 3.1: Observation table for simulation readings

Sr.	Input solar voltage (Vin)	Duty cycle in %	PWM Pulse width (kHz)	Capacitor Value (uf)	O/p voltage PWM Based Booster circuit.
1	8 V	50	10 K	10 uf	15.5
2	8 V	75	10 K	10 uf	14.9
3	8 V	90	10 K	10 uf	12.1
4	8 V	25	10 K	10 uf	17.0
5	8 V	50	50 K	10 uf	14.3
6	8 V	50	100 K	10 uf	12.6
7	8 V	50	10 K	10 uf	18.1
8	8 V	50	10 K	20 uf	16.9
9	5 V	50	10 K	10 uf	14.3
10	5 V	75	10 K	50 uf	15.2
11	5 V	75	10 K	10 uf	17.2

Table 3.2: Simulation Results for parameter selection

Input solar voltage (Vin)	Duty cycle in %	PWM Pulse width (kHz)	Capacitor Value (uf)	O/p voltage PWM Based Booster circuit.
8 V	50	10 K	10 uf	15.5
5 V	50	10 K	50 uf	14.3

From the above simulation table 3.2 it is observe that the below combination of Duty cycle ,PWM pulse width & capacitor value gives best results for 8V as well as for 5 V & considered the same combination for Hardware design also.

4. Hardware set up & Boost topology of DC-DC Boost type PWM based solar charge Controller for Constant Output Power under Partial Shading Conditions (Proposed)

4.1 Boost Topology

The boost converter is a high efficiency step-up DC/DC switching converter. The converter uses a transistor switch, typically a MOSFET, to pulse width modulate the voltage into an inductor. Rectangular pulses of voltage into an inductor result in a triangular current waveform. We'll derive the various equations for the current and voltage for a boost converter and show the tradeoffs between ripple current and inductance. For this discussion we assume that the converter is in the continuous mode, meaning that the inductor's current never goes to zero.

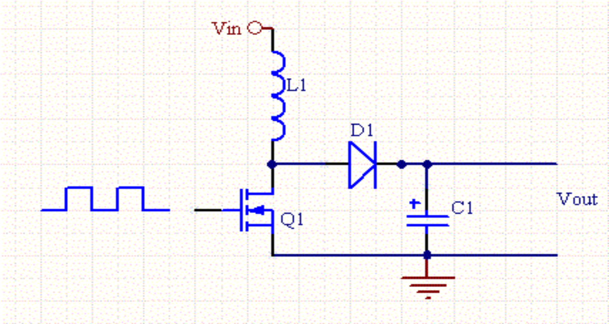

Figure 4.1: Boost type dc-dc Converter (MOSFET – Circuit)

$$V_{out} = \frac{V_{in}}{1 - D}$$

So it is clear that the output voltage is related directly to the duty cycle of the pulses.

The main question when designing a converter is what sort of inductor should be used. In most designs the input voltage, output voltage and load current are all dictated by the requirements of the design, whereas, the Inductance and ripple current are the only free parameters [7]. It can be seen form Equation 1, that the inductance is inversely proportional to the ripple current. In other words, if you want to reduce the ripple, then use a larger inductor. Thus, in practice a ripple current is decided upon which will give a reasonable inductance.

There are tradeoffs with low and high ripple current. Large ripple current means that the peak current is ipk greater, and the greater likelihood of saturation of the inductor, and more stress on the transistor. So when choosing an inductor make sure that the saturation current of the inductor is greater than ipk. Likewise, the transistor should be able to handle peak current greater than ipk. The inductor should also be chosen such that the it can handle the appropriate rms current. It should be noted that when there is a light load the circuit can slip into discontinuous mode, where the inductor becomes fully discharged of its current each cycle. When a load is reapplied the inductor needs to recharge, and so the transistor's duty cycle increases pulling the inductor towards ground, and because of the increased duty cycle Vout decreases when we really want it to increase. This causes an instability, which is well known for boost converters, and not a problem with buck converters.

One way to combat this instability is to choose a large enough inductor so that the ripple current is greater than twice the minimum load current. When this condition is met then the inductor is always in continuous mode. This can be expressed as follows:

$$L = \frac{(V_{out} - V_{in} + V_D)(1 - D)}{\min(i_{load}) f}$$

For higher efficiency the diode should be an ultra-fast recovery diode. These design equations have been incorporated into a convenient.

Topology: Boost

Inductance based on the specified minimum load current

Item	Value	Units
Volts In	8	V
Volts Out	14	V
Load Current	1	A
Freq.	4	KHz
Vripple	0.14	V
Duty Cycle	49.62962962963	%
Ipp Inductor	0.8	A
Ipk Inductor	1.4	A
Irms	0.64291005073286	A
L	1054.6296296296	uH
C	886.24338624339	uF

4.2 Proposed PWM DC-DC Boost type solar charge controller

The PV module senses the Solar energy and send the respective voltage to the Charge controller Circuit, Parallel to that Microcontroller will generate pulse of 10 KHz which is continuously supplied to gate of MOS-FET Circuit & MOS-FET circuit will remain ON- OFF according to duty cycle which is already set for getting the required voltage level at the output side of MOSFET , With this MOSFET Output voltage Switch-mode DC-DC converters will convert the unregulated dc input into a controlled dc output at a desired voltage level. The electrical energy is then stored in the lead-acid battery that is later used to power the respective components.

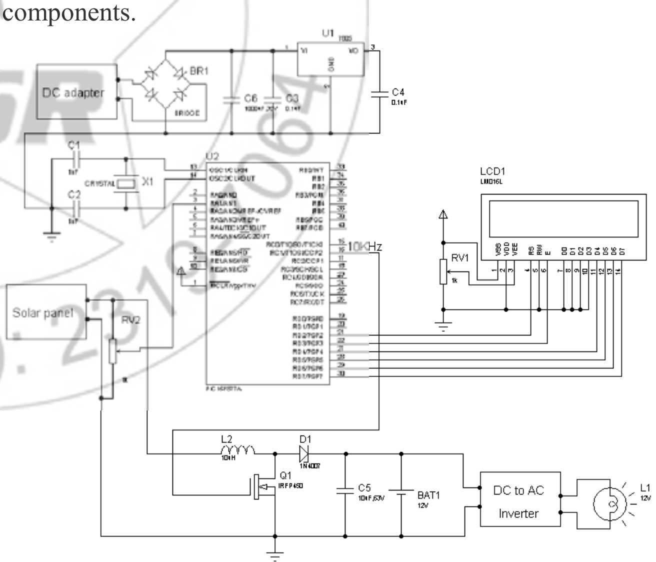

Figure 4.2: Proposed controller diagram

4.3 Operational Description

To verify the functionality and performance of the proposed system shown in Fig.4.2, a prototype of the PWM based DC-DC Booster converter and control circuit is proposed. The PIC 16F877A microcontroller is used to provide the control signals for the Boost converter. The PIC 16F877A microcontroller is used to provide the control signals for the Boost converter. The PIC 16F877A will be used to provide the control signals for the Boost converter.

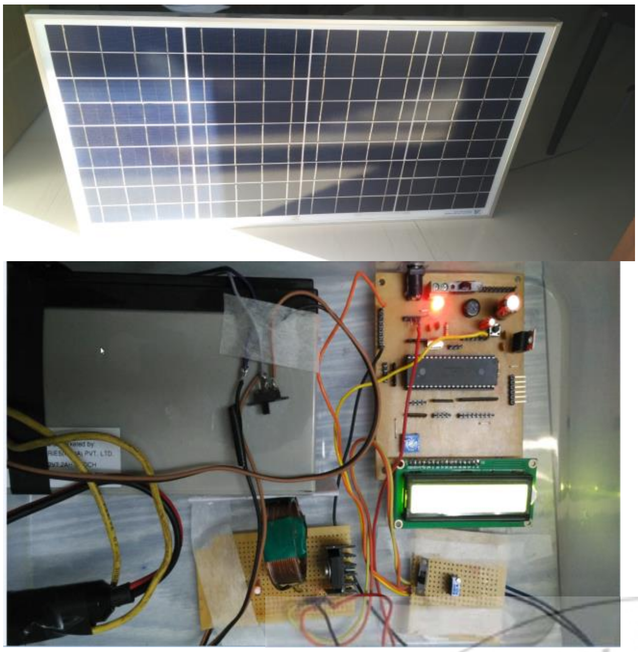

Figure 4.3: Hardware Setup

Voltage measurement is required at the point where the solar panel output is connected to the input of the Boost DC-DC converter. The voltage at this point is the operating voltage of the PV module. Also it is necessary to determine the atmospheric condition, which is important in connection with the accuracy of solar charge controller. The measured values will be scaled down to be compatible with PIC 16F877A i.e. the voltage rating i.e. 5V.

The proposed system solar panel is operating at open-circuit voltage before connecting this solar panel to the load through the PWM Based solar charge controller circuit. When the solar panel is connected to the proposed charger circuit, it does not operate at the open circuit voltage anymore, and the voltage drops to a new point instantly. This new operating voltage depends on the impedance of the load. In order to utilize the Maximum power from solar panel under partial shading conditions also, PV module senses the Solar energy and send the respective voltage to the Charge controller circuit, parallel to that Microcontroller will generate pulse of 10 KHz which is continuously supplied to gate of MOS-FET Circuit & MOS-FET circuit will remain ON- OFF according to duty cycle which is already set for getting the required voltage level at the output side of MOSFET , With this MOSFET Output voltage Switch-mode DC-DC converters will convert the unregulated dc input into a controlled dc output at a desired voltage level. The electrical energy is then stored in the lead-acid battery that is later used to power the respective components. The step size of duty cycle is chosen to be 0.5, so the converter can smoothly operate.

4.4 Hardware Results

Though numerous rechargeable batteries exist, the most commonly used battery in solar systems is the lead-acid battery. This is mainly because of the price to power ratio is superior to all other types and due to the fact that this is a proven technology. The lead acid battery of 12V is charged using PWM Based DC-DC Boost converter charge controller technique. The observation table is as follows when Load is connected.

Table.4.1: Observation table for Time in Hrs.Vs

Time (Hrs.)	Voltage (Vin) to Booster Circuit	Voltage (Vo) From Booster Circuit	Battery Voltage (VL)
10.30	5.6	14.03	8.3
11.00	6	15.40	8.75
11.30	6.1	15.49	9.0
12.00	6.3	17.21	9.4
12.30	6.3	17.05	9.8
1.00	6.2	13.49	10.3
1.30	6.11	17.21	10.8
2	6.0	17.05	11.33
2.30	5.8	18.03	11.66
3	5.55	16.80	12.15
3.30	5.41	16..39	12.21
4	5	13.25	12.27
4.30	5	13.20	12.33

Battery Voltage. (To check Proposed PWM based Converter efficiency

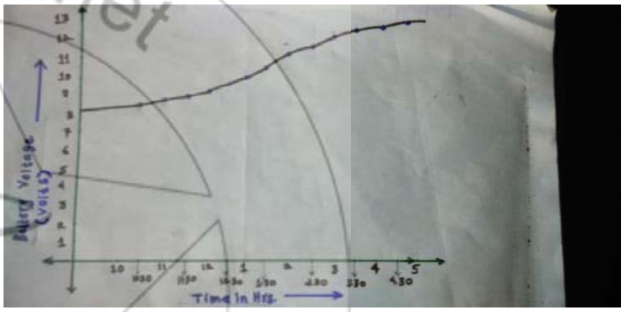

Figure 4.4: charging Diagram for battery

Fig.4.4 shows the charging diagram of lead-acid battery. The first stage of battery is called bulk charging. In this stage a constant current is applied to the battery. The charging voltage can range from about 11V to 15V (for a 12V battery), the only requirement being that the charging voltage must be higher than the current battery voltage. The corresponding voltage can be set with duty cycle so that the required power can be delivered to the battery during this partial shading conditions also. When the battery reaches 80% capacity, the entire battery has a voltage of approximately 12.30.

5. Conclusion

From the results acquired during experiments (From Table no. 3.2, Table 4.1 & Fig 4.4) , it is confirmed that, with a well-designed system including a proper converter solar panel can be easily constructed to achieve an acceptable efficiency level of the PV modules. Thus, the efficiency of PV module is increased. The advantage of PWM based DC-DC Boost converter solar charge controller is it provides continuity & performs under partial shading also & continuous charging of battery is possible & same is verified with the help of Simulation as well. Such kind of PWM based solar charge controller can also be employed to perform output voltage regulation on a passive load or a motor water pump, if required.

The proposed charge controller scheme provides a solution to improve the existing methods. The proposed scheme helps in achieving accurate and fast response in standalone and grid-connected solar PV energy conversion systems under partial shading conditions, It can be applied in fast-changing solar irradiation areas where solar PV is used & Contentious Charging is required for (eg: Space research centre, Spaceships etc..) To apply PWM based DC-DC Boost converter solar charge controller system does not required knowledge of different types of Configuration of PV panel & also different Non–Linear characteristics of Solar PV panel to utilize maximum power from PV array.

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