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Comparative study on charge controller techniques for solar PV system

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Abstract

This paper presents a new technology based solar PV charge controller which contains series, shunt charge controller. The lead acid battery is been chosen for charging and discharging of series, shunt charge controller due to its features. Authors used MOSFET's for the switching purpose and it will reduce the switching losses. The proposed charge controller has been developed using MATLAB and the charging and discharging process of developed charge controller has been verified. Further, the developed charge controller has been maintained within the SOC limits by considering the efficiency of the battery maintained good, hence forth the life time of battery can be increased up to a larger extent. In addition, the analysis on various charge controller has been discussed and based on this it can be proved that; the performance of the proposed charge controller is improved and it requires less number of switches so the cost of the system also reduces. It is most suitable for optimize the energy crises in the rural areas to an affordable level.

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Keywords: Load switching controller, Charge Controller, State of Charge

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1. Introduction

The solar energy has become one of the main renewable energy resource in the world due to its advent features and availability. Solar energy also become of the alternate source to overcome the energy scarcity. The main advantages of solar energy is clean in nature, pollution free, abundant in availability and involves less maintenance [1].The rate at which this energy is emitted is equivalent to the energy coming from a furnace at a temperature of about 6,000 K (10,340ºF). If we could harvest the energy coming from just 10 hectares of the surface of the sun, we would have enough to supply the current energy demand of the world.

Due to non-linear characteristics of solar PV and atmospheric conditions the efficiency of solar PV is reduces drastically. Hence, the maximum power output from the solar PV system is changes with respect to change in irradiation and weather conditions. To achieve the maximum power various maximum power tracking techniques have been explained in detail by authors in [2]. Further, to maximize the transfer of power generated from solar PV to battery bank, a battery charger with a charge controller plays a vital role in that. The main function of a battery charger with charge controller is 1). It helps in tracking maximum power by placing the operating of system at MPP irrespective of change in irradiation. 2). It reduces the battery charging time to back-up the PV arrays. Further it also controls the over-charging and discharging of battery so that it enhances the life time of battery as well. By considering the major advantages of charge controller in this article, authors focused to develop a suitable charge controller which helps to improve the efficiency and life time of battery effectively. In addition, a comparative study has been presented by comparing the charge controllers proposed by the various authors in the literature so far. The algorithm of a PV charge controller regulates the efficiency of battery charging as well as the PV array consumption, and eventually improves the ability of the system to meet the required electrical load demands.

The most commonly used types of solar PV charge controllers are the series, shunt, PWM and MPPT charge controllers. The series controller employs with a kind of control element which is connected in series between the PV array and the battery. This type of charge controller is widely used in small scale PV systems, further it can also be used for larger systems because of its current limitations of shunt controllers. The shunt charge controller regulated the charging of a battery from the PV array by short-circuiting the array internal to the controller. This type of charge controllers mostly used to regulate the Voltage (or) Current to keep batteries from overcharging and deep discharging which causes to damage the battery [3]. The basic example for the charge controller is; let us consider 12volts battery which is fed to 12volts panel which charge up to (16V-20V) which causes the battery so we need charge controller which can protects the battery from overcharging.

Basically, charge controller requires lesser maintenance. Trickle charge panels, such as the (1-5 Watts panels) charge controller is called battery regulator which limits rate of current [3]. There exists various advantages of using charge controllers which protect against overvoltage which reduces the battery performance and life span and also prevent deep charging of the battery [4]. Based on single state and multi-stage; the charge controllers are classified as series; here constant current and constant voltages are best examples of single stage and multistage levels [5].

2. Proposed Method

In this work, the authors mainly focused to implement series, shunt, and combined series and shunt controller. To develop this charge controller authors considered MOSFET's as the switch which can reduces the switching power losses. The block diagram of the system which indicating the operating principle of the system is presented in Fig. 1. In this system switching controller plays a major role which is interconnected with entire system. It is mainly used to control the state of charge of battery [5].

This system takes the input as battery's state of charge; and it enables the systems simultaneously based upon the SOC of the battery. Then other most important block is enable system which is used to enable the switching circuit i.e., MOSFET's which are connected on both source side and load side of the system. If the load side switch is enabling then battery will get discharge through load [6]. Otherwise it enables the source side switch due to this battery gets charge through solar panel. Here the series charge controller is used in source side for charging purpose and shunt charge controller is used in load side for discharging [7].

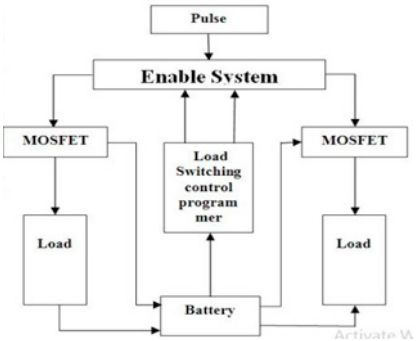

Fig 1. Functional Block Diagram of the system

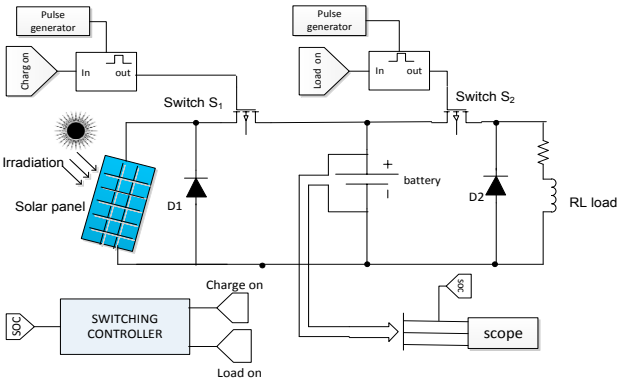

Fig 2. Development of series charge controller using SIMULINK

In the proposed method, the authors developed design of series, shunt, combined series and shunt controllers using MATLAB/Simulation. Which give the more advantages, further protects the battery from overcharging and deep discharging conditions. By considering these advantages, it extends the life of battery, further, design of system is simple in structure in compare with other techniques.

3. Modelling of Charge Controller

Generally charge controllers are classified based on single stage and multi stage regulators; further these are again classified as constant current and constant voltage regulators. For constant current purpose series charge controller is used and for constant voltage purpose shunt charge controller is used and for both constant current, constant voltage purpose we used the combined series shunt charge controller which are discussed detail in below by using load switching control program developed in MATLAB. Mathematical model of solar PV module has been modeled by guidelines provided in [8].

3.1 Series Charge Controller

The series charge controller is primarily used to regulate voltage and current flow between the solar panel and battery; further, it can be used to disables current flow when batteries are fully charged and to keep batteries from over charging conditions, which helps to improve the battery performances [9].

The Fig. 2 indicates the simulation diagram of series charge controller. Switch S_1, S_2 are the main switching devices, Diodes D_1, D_2 can be used as freewheeling diodes. In this the switching elements are connected in series for charging the battery. The operation of switches S_1, S_2 are depends on the state of charge of the battery. Here in the proposed series charge controller, the functioning of the system is based upon the load conditions which are generate by switching control program. When the battery state of charge falls to 20% the device which is connected to Switch S_1 is on (i.e., charge on = 1) and for Switch S_2 is off i.e., (load on = 0) so the battery starts charging, and it continues up to full charge. Whenever the battery is fully charged, it starts discharging so that now load on=1 and charging on=0.As already mentioned the switching condition of switches S_1, S_2 are depends on battery state of charge followed by the program incorporated in the load switching controller and based on this the pulses given to switches to enable the system as shown in Fig. 2. Further, to develop this controller relays can also be used other than MOSFET's. Due to its advantages, MOSFET's are most preferred switching devices in the charge controllers, also the power losses are less in MOSFET's in compare with relays [10]. The diodes are connected at the panel side and

load side in order to protect from reverse power flow. The advantage of series controller is certain flexibility concerning the input source. The main disadvantage is that charging efficiency is low as the charging current always has to flow through two switches. The main application of series charge controller is it can be used for high power applications such as grid interconnected system.

3.2. Shunt charge controller

This type of charge controller is shunt charge controller, which can be used to regulate voltage and current flow between the battery and load. Further, it is used to divert the excess charge to the shunt load (like electric water heater) and to provide supply the continuous power the load without any interruption [5].

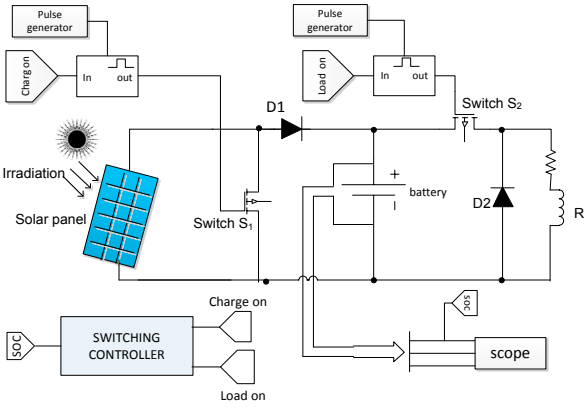

Fig. 3.Development of shunt charge controller using SIMULINK

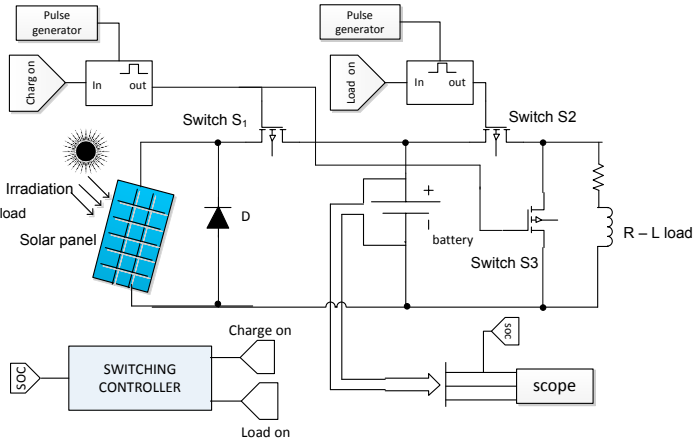

Fig. 4.Development of combined series and shunt charge controller using SIMULINK

The Fig. 3.depicts shows the simulation diagram of shunt charge controller, the switching elements which are connected in shunt generally used for connect the load to the battery. In only the difference in shunt charge controller is the switching element is connected in parallel, and further the operation of the controller is same as the series charge controller. The functioning of the proposed shunt charge controller is depends on the switching signals generated by the switching controller. Further for automatic functioning of switches, the program has been developed by considering the state of charge conditions of battery. Whenever the battery state of charge is reaches 80% then the switches S_1 and S_2 will get turn on at a time. Hence, the two switches on and off at same time as load on, and charging on =1 and 0 at same time. The condition when both the switches are off the battery starts charging continue till reaches maximum level of charge. At the time when reached fully charge condition, it starts discharging as per the switching signals generated by the switching controller. The main disadvantage of shunt charge controller is power loss is more at the panel side due to continuous current flow due to it produces a hot stop produced in PV module. The shunt charge controller is mainly used for low power applications in the real time scenario. To overcome the demerits of the series and shunt charge controller, the combination of series and shunt charge controller is developed.

3.3 Combined Series and Shunt Charge Controller

Here the combined series and shunt charge controller is used to regulate voltage and current flow between the solar PV panel and to the load in which series controller is used to charge the battery, on the other hand shunt

controller is used to connect the load to avoid the excess flow to the battery and continuous power to the load [11].

The Fig. 4 shows the above simulation diagram of combined series and shunt charge controller. It is basically designed based upon the functional block diagram which is shown in Fig. 1. So in this combined system series controller is used in control unit and shunt controller used in load distribution unit which are used to keep battery in safe operating region. Here the program for combined system is written in same as the series controller model. In this case charge on is connected to the both series and shunt switches with enabled system. Whenever state of charge of battery is 80% then switch S_1 will conduct [charging on] = 0 and switches S_2 and S_3 [load on] = 1 then battery charge is discharged through load. Whenever charge of battery is 20% then [charging on] = 1 and [load on]= 0 then battery will charge through series charge controller. At the same time the battery charges fully, then a shunt controller will short circuit and the series charge controller will open the PV array so that it stop the charging current flow to battery. With help of this type of charge controller, it is able to continuously supply power to load at any instant of time.

4. Results and Analysis

To verify the effectiveness of the proposed charge controller models have developed using MATLAB environment and various test conditions have been performed, further the result presented shows the superiority of the proposed charge controller is given in the following section.

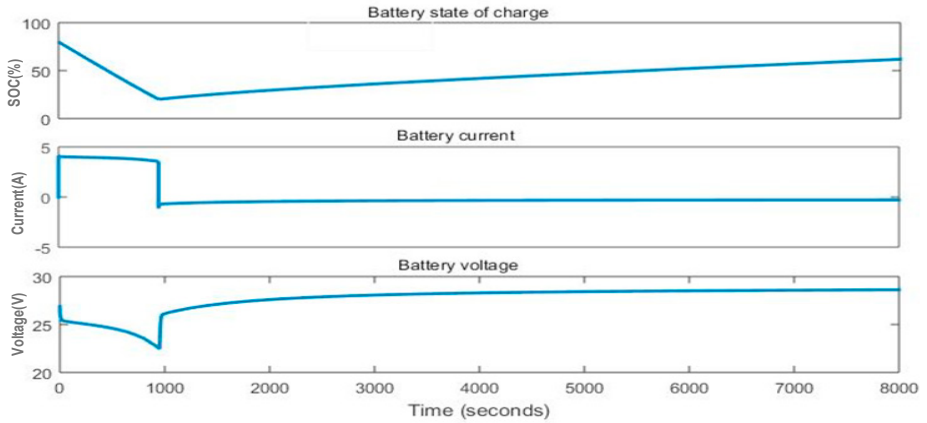

Fig 5. Output waveform of series charge controller.

From the performance curves we can observe the battery state of charge when reaches to 40% the battery starts charging here authors used lead acid sealed battery so the charging time is more than the discharging time as observed the battery charges slowly. As this is series charge controller authors can observe the constant current line when the battery starts charging and the corresponding voltage waveform which follows the current wave form.

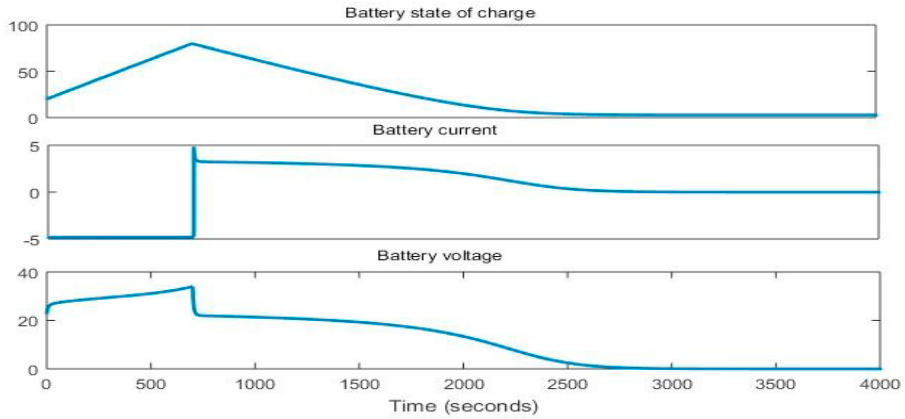

Fig 6. Output waveform of shunt charge controller

The above performance curves show the result of shunt charge controller. In this result authors can observe that initially the state of charge is 20% and the battery starts charging and when reaches 80% the battery starts discharging through load. Authors can observe corresponding voltage and current curves which depends on battery state of charge. From the performance curves as it is combination of series and shunt charge controller we can observe the constant voltage and constant current and opposite load current and load voltage waveform .As the series charge controller is used for charging and shunt charge controller is used for discharging the battery through load.

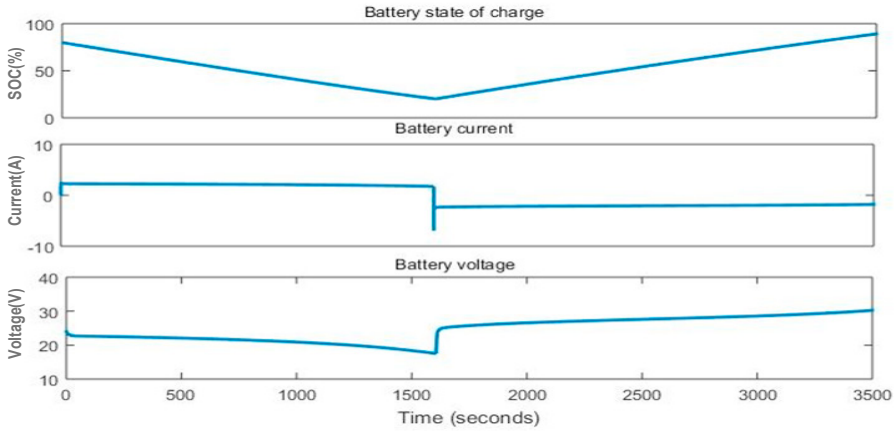

Fig. 7.Output waveform of battery for combined series and shunt charge controller

To verify the effectiveness of the proposed charge controller, a comprehensive analysis has been provided based on the parameters used to develop other charge controllers. Table 1 shows the performance comparison of various charge controllers with the proposed charge controller. By using of proposed charge controller the number of switches has been reduced to 2, due to this switching losses in the circuit can be reduces to minimal level. The design of system is simple in structure and improves the performance of the system in compare with the existing charge controllers.

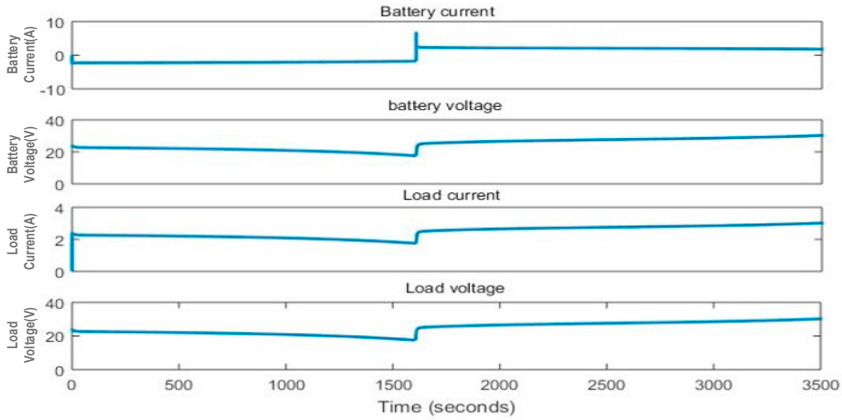

Fig 8.Output waveform of load for combined series and shunt charge controller

Table.1. Comparative study on various types of charge controller

S.NO	Title	Type of Controller	Number of switches	Type of switches	Type of battery	Type of converter	Limitations	Remediation
1	Design considerations and performance evaluation of outdoor PV battery chargers [12]	Current controller	9	Circuit breakers	NiCad, NiMH, Lead acid batteries	DC- DC converters	Reducing the usable capacity nickel-based batteries, High cost due to more CB and converter	Capable of charging the major type of NiCad, Ni–MH, Li-ion and sealed lead-acid
2	Adaptive fuzzy controller based MPPT for photovoltaic systems[13]	MPPT, FLC controllers	2	MOSFET	–	DC- DC boost converter	High cost due to controllers and converter	Better performance to track MPP by using FLC
3	ANN based MPPT method for rapidly variable shading conditions[14]	MPPT controller	4	IGBT	–	Boost converter	Output specific voltage level for charging Low tracking speed and accuracy	Accurate and fast estimation of GMPP
4	Design and implementation of the low cost and fast solar charger with the rooftop PV array of the vehicle[15]	Digital signal processor	2	MOSFET	Lead acid battery	Buck converter	Depending on the PV module size – No MPPT control – Long charging time – High implementation cost	Fast charging of battery Reducing no of sensors and cost
5	Proposed method	Series, shunt, combined series and shunt charge controller	3	MOSFET	Lead acid battery	–	No MPPT control Working with specific type of battery	Efficiency of the battery maintained good Low cost because no converter is used Improve charging process and life time of the battery Charging period is reduced

5. Conclusion

In this paper authors proposed a new technology based charge controller. The charge controller has been modelled effectively using MATLAB/SIMULINK environment. The performance of the controller is effectively tested by considering various test conditions and results presented shows the effectiveness of the system. In addition the feature of the proposed controller is also described in the manuscript by discussing the features and limitations of the existing methods. The proposed charge controller is developed with cost effective solution and reduces the circuit complexity. Authors considered load switching controller program to develop control and coordinate the functions of battery state of charge and switching operation of MOSFET's. This paper contains a proof of concept for an optimized and safe battery charging system for home and other commercial systems by utilizing a direct connection between solar PV panel and battery system. With help of this charge controller authors utilized the solar in efficient way and extend the lifetime of battery as well. Due to this, it can be understood that the state of charge of battery is also improved.

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