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Modelling of a Standalone Photovoltaic System with Charge Controller for Battery Energy Storage System

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Abstract

This Paper presents a modelling of Standalone photovoltaic system with designing the voltage controller for its Battery energy storage element. The Photovoltaic (PV) topology comprises the boost converter to harness the maximum power, the bi directional DC-DC converter to maintain the DC link voltage stable through charging and discharging the battery, and inverter to provide high quality power for local loads. The voltage controller designed for battery is to maintain the highest State of Charge (SoC) while preventing battery overcharge when it is partially loaded ad avoid over discharging when the source is not available. Using MATLAB/SIMULINK the proposed model of isolated PV system is created. Non-linear load is considered here to verify the robustness of the proposed control scheme.

Keywords: Photovoltaic system (PV); PI controller; Non linear Load; Total Harmonic Distortion(THD).

Introduction

Now a days the shortage of conventional energy sources has pushed us towards finding alternative sources of energy. There are many alternative sources of energy such as solar, wind, ocean thermal, tidal, biomass, geo-thermal, nuclear energy etc.[1] Among these solar power is more and more attractive due to the severer environmental protection regulation and the predictable depletion of other energy sources. Solar energy is most readily available energy resources. It is non-polluting & Maintenance free. As a result many research works has been carried out for the development of solar power system in recent years. Many types of PV power conversion systems have been developed as grid connected system for reducing power from the utility and standalone system for providing the power to the load power without the utility [2].

This paper presents a control strategy for converter configurations which are used in standalone PV system. The converter topology comprises of Boost converter, Bidirectional DC-DC converter, and full bridge inverter. The goal or objective of these three converters are to harness the maximum power from the solar panel and supply an uninterrupted and high quality power to local loads[3-5].

Battery is the storage element which plays the vital role in standalone PV system. The standalone system requires battery for energy storage to supply the load power during the period without (or) shortage of solar power. Because the P-V characteristics of the PV module is varied with insolaiton level as well as temperature[6-7]. In addition the battery charging needs control for achieving high SoC and consequently longer life time of the battery. The converter which is used in a battery is bi directional DC-DC converter. Stability of DC link voltage can be very important for the whole system and it is achieved by battery converter. If there is any fluctuation in the dc link voltage, performance of other converters i.e both boost converter and full bridge inverter will be deteriorated[8].

Finally inverter acts as voltage source node in the isolated PV system and needs to provide a stable and high quality AC voltage. The inverter is used to supply non-linear load which is represented by a single phase diode rectifier with a capacitor and resistor connected in parallel at the DC terminal of the rectifier. So many residential loads are electronic loads, which are fed by the ac source through a diode-bridge uncontrollable rectifier. This kind of load is also called nonlinear load, it stands for that the relationship between voltage and current is nonlinear[9-10].

System Configuration

Photovoltaic panel

The main component of a solar energy system is Photovoltaic module. The basic device of Photovoltaic system is photovoltaic cells. Cells may be grouped together to form a panel. More no of panels are grouped together to form an array. The PV array is composed of several PV modules which are connected in series and parallel in order to form an appropriate output voltage and power. A solar panel (also solar module, photovoltaic module or photovoltaic panel) is a packaged, connected assembly of photovoltaic cells. The solar panel can be used as a component of a larger photovoltaic system to generate and supply electricity in commercial and residential applications. Solar panels use light energy (photons) from the sun to generate electricity through the photovoltaic effect. PV model is not available in MATLAB/SIMULINK. According to the physical property of the p-n semiconductor, a model has been developed based on the following Equation.

$$I = I_{PV,\,cell} - I_{O,\,cell}\,[\exp\,(qV/aKT)] \quad (1)$$

The above equation (1) describes the I-V characteristics of the Ideal photovoltaic cell shown in fig 1.

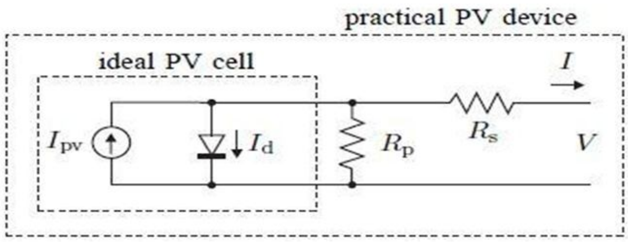

Fig 1: Single diode model of theoretical Photovoltaic cell

where $I_{pv,\ cell}$ is the current generated by the incident light (it is directly proportional to the Sun irradiation), I_d is the Shockley diode equation, $I_{0,\ cell}$ [A] is the reverse saturation or leakage current of the diode [A], q is the electron charge [1.60217646*10^{-19}C], k is the Boltzmann constant [1.380650*10^{-23} J/K], T [K] is the temperature of the *p-n* junction, and a is the diode ideality constant.

The light generated current of the photovoltaic cell depends linearly on the solar irradiation and is also influenced by the temperature according to the following equation (2)

$$Ipv = [Ipv, n + K_I\ {}_T]\ G / Gn \qquad (2)$$

Where $I_{pv,\ n}$ [A] is the light-generated current at the nominal condition (usually 25◦C and 1000W/m2), ΔT = T – Tn. (being T and Tn the actual and nominal temperatures [K]), G [W/m2] is the irradiation on the device surface, and Gn is the nominal irradiation.

The saturation current I_0 of the photovoltaic cells that compose the device depend on the saturation current density of the semiconductor (J_0, generally given in [A/cm^2]) and on the effective area of the cells. The saturation current I_0 is strongly dependent on the temperature and proposes a different approach to express the dependence of I_0 on the temperature so that the net effect of the temperature is the linear variation of the open circuit voltage according the practical voltage/temperature coefficient.

$$Io = [I\ sc, n + K_I\ {}_T] / \exp\{[Voc, n + K_I\ {}_T] /aVt\}-1 \qquad (3)$$

Boost converter

A DC-to-DC converter is an electronic circuit which converts a source of direct current (DC) from one voltage level to another. With so many types of DC-DC converter available such as buck, boost, cuk, fly back, SEPIC etc., here the boost converter is adopted in order to increase the voltage from the Solar panel. Because the output voltage which is obtained from the solar panel is minimum. The boost converter is used to couple different voltage levels between the dc link and the terminal output of solar panel; moreover, it can make the solar panel operating at any environmental condition.

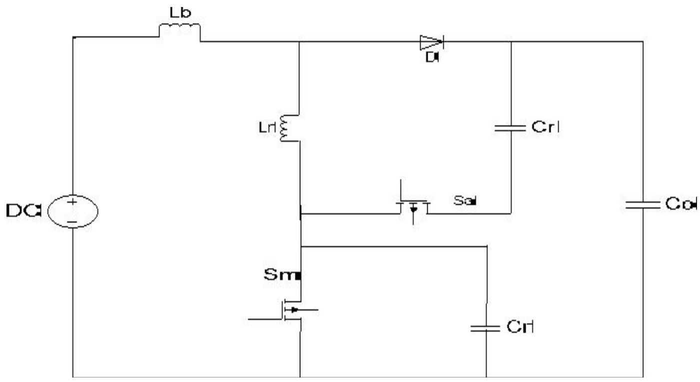

Fig 2: Boost Converter

In fig (2) unlike the conventional boost converter, in addition to the boost inductor L_b and the high-frequency (HF) rectifier output diode D; the resonant inductor L_r in series and resonant capacitor C_r in parallel are connected to the main switch S_m . The auxiliary switch S_a with series connected clamping capacitor C_c is connected between the drain of the S_m and the cathode of the D. The small capacitor C_n is used as a high-frequency bypass filter at the output of each module. Both the switches are driven in a complementary manner.

Table I Components values

Components	Values
Boost Inductor	1.75 mH
Resonant Inductor	8.264 µH
Resonant Capacitor	0.47 nF
Clamping Capacitor	1.1µF
Output Filter Capacitor	400 µF

Here the Boosting technique may achieved by obtaining the resonance condition by suitable switching techniques. The condition which can be for achieving resonance condition is the boost inductor value should be higher than that of the resonance inductor and the clamping capacitor value should be higher than the resonance capacitor.

Battery Charger

In a standalone photovoltaic system the essential component is battery. The most widely used and least expensive battery is the lead acid battery. Other types of batteries are also available such as Nickel-Cadmium and Nickel-Metal-Hydride. Both these batteries are considerably more expensive and not as readily available. The battery model is available in MATLAB/ SIMULINK/Sim Power Systems, it is modelled as a nonlinear voltage source whose output voltage depends not only on the current but also on the battery state of charge, SOC, which is a nonlinear function of the current and time.

Bi-Directional DC-DC converter

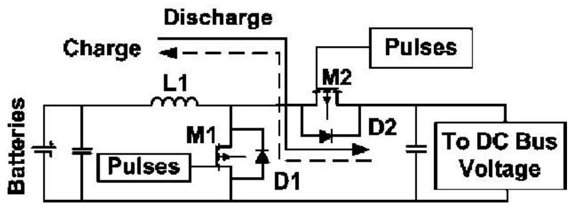

Fig 3: Bidirectrional DC-DC Converter & its modes of operation

Since utility grid is not available in the standalone system, a good control performance of the bidirectional converter is very important. It is necessary to keep the dc link voltage constant through charging or discharging the Lead-acid battery when the power output of the source or power demand of load alters. During the boost phase, the battery pack voltage level of *48 V* is boosted to *200 V* and applied at the inverter side. On the other hand, during buck phase the solar array output voltage is regulated to the desirable level to recharge the batteries. In this topology, boost converter operation is achieved by modulating *M2* with the anti-parallel diode *D1* serving as the boost-mode diode. With the direction of power flow reversed, the topology functions as a buck converter through the modulation of *M1,* with the anti-parallel diode *D2* serving as the buck-mode diode. It should be noted that the two modes have opposite inductor current directions.

PI Controller

Battery life time is reduced if there is low PV energy availability for longer period or improper charging discharging. So the battery charging needs control for achieving high State of Charge (SOC) and longer battery life. Hence proper controller for battery charging is an inevitable need for this hour. The main function of the battery charging controller in standalone PV system is to fully charge the battery without permitting overcharging while preventing reverse current flow at night and deep discharge under load conditions

A PI Controller (proportional-integral controller) is a special case of the PID controller in which the derivative (D) of the error is not used. Setting a value for G is often a trade-off between decreasing overshoot and increasing settling time.

Inverter

The inverter acts as a voltage source node in the isolated system and needs to provide a stable and high quality output ac voltage. The single-phase bridge circuit of Fig. 4 may be thought of as two half-bridge circuits sharing the same dc bus. Thus the single phase ‘full-bridge’ (often, simply called as ‘bridge’) circuit has two legs of switches, each leg consisting of an upper switch and a lower switch

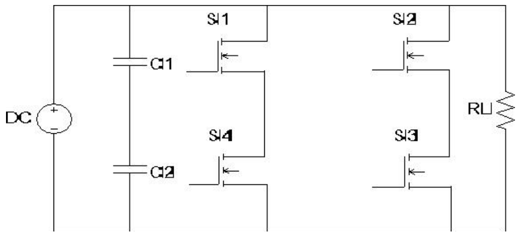

Fig 4 : Full Bridge Inverter

The two pole voltages of the single-phase bridge inverter generally have same 0 magnitude and frequency but their phases are 180 apart. Thus the load connected between these two pole outputs (between points 'A' and 'B') will have a voltage equal to twice the magnitude of the individual pole voltage.

Non-linearLoad

Nonlinear load is considered to verify the universality and robustness of the control scheme. When the connection of renewable energy to the utility network is not available or unduly expensive, for example, in some remote areas, the stand-alone PV system becomes more and more attractive by using energy storage element. This stand-alone system is very suitable for household application. Residential loads are mainly composed of household electric appliances, such as TV sets, laundry machines, computers, fluorescent lamps, battery chargers, air conditioners, and refrigerators etc. So many residential loads are electronic loads, which are fed by the ac source through a diode-bridge uncontrollable rectifier. This kind of load is also called nonlinear load, it stands for that the relationship between voltage and current is nonlinear.

The inverter is used to supply nonlinear load which is represented by a single phase diode rectifier with a capacitor and resistor connected in parallel at the dc terminal of the rectifier.

Simulation Results

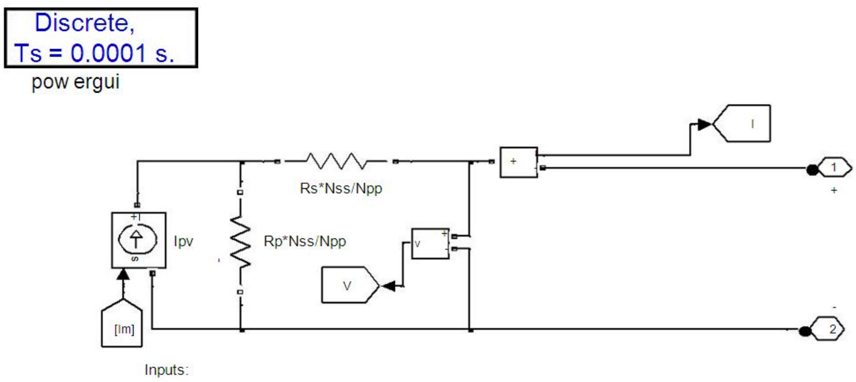

Fig 5: Photovoltaic circuit model built with MATLAB/SIMULINK

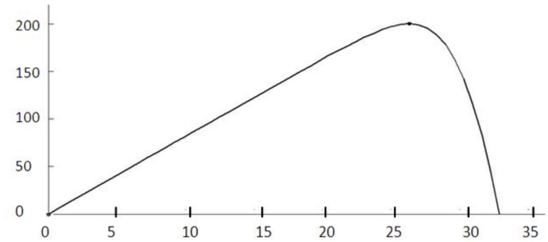

Fig 6: P-V Curve of Solar array

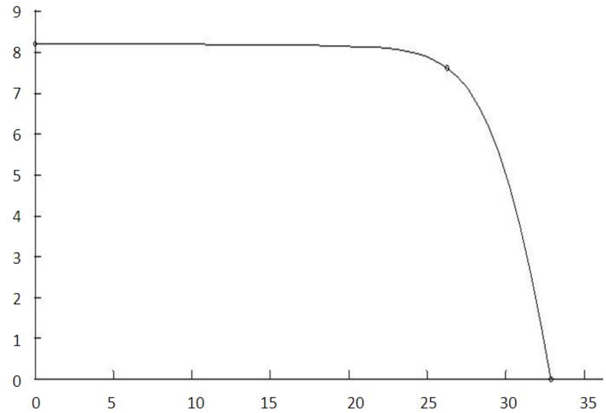

Fig 7: I-V Characteristics of PV array

The Fig (5) Represents the PV model designed by using simulink model which is described by the mathematical equation in chapter III. From that the otput of the PV array has been showned in the fig (6&7). It ha represented in the form of P-V characteristic and I-V characteristic Respectively.

The fig (10) represants the Combined model of a system which consists of boost converter , battery and inverter. The battery consist of Bi directional converter, battery module and PI controller to control the charging state.

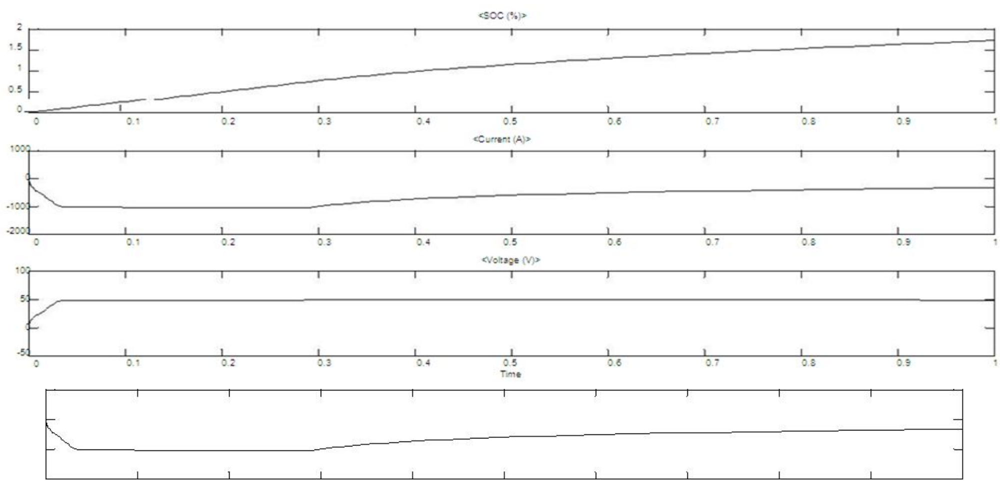

Fig 8: SOC, Voltage and Current of Battery during charging Condition

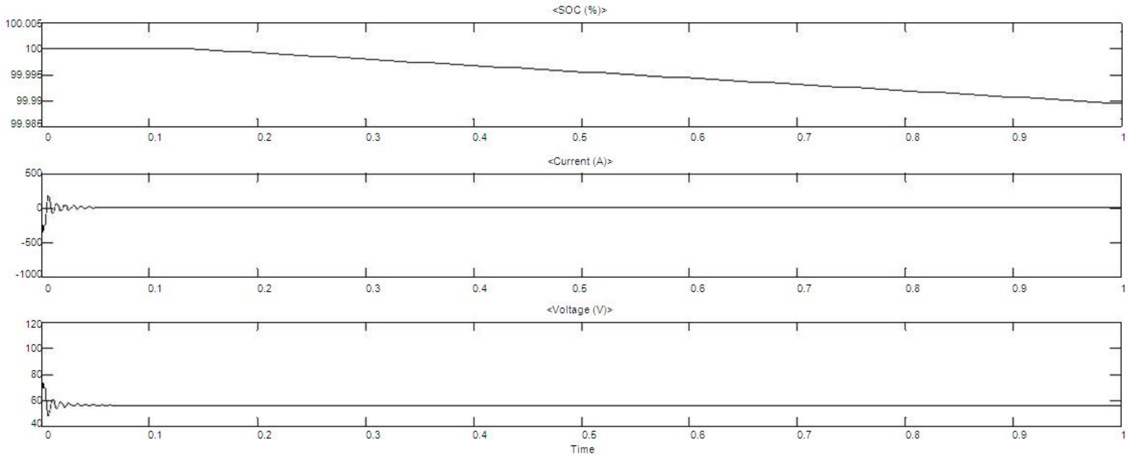

Fig 9: SOC, Voltage and Current of Battery during discharging condition

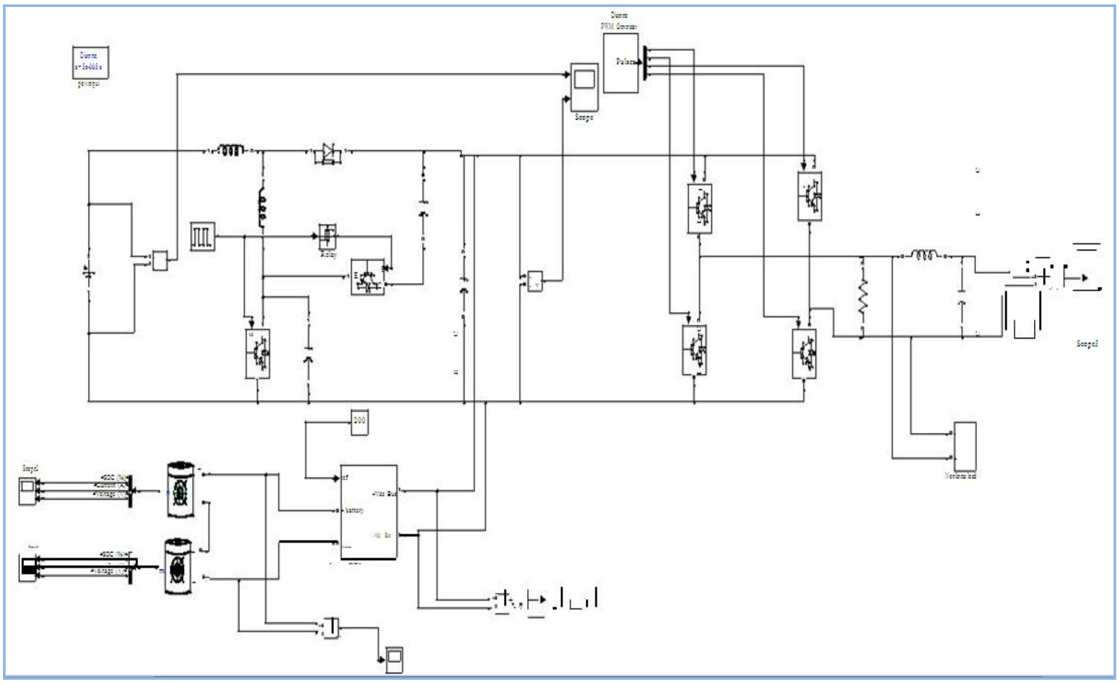

Fig : 10 Combined Model with Non-linear load

The Fig (8&9) represents the SoC, Voltage and current of the Battery during charging and discharging condition. During the charging condition the converter can act as Buck Mode and convert the voltage as 200V from the boost converter to the battery nominal voltage 48V. It will not over charge the battery i.e. above the 48 V. During the discharging condition the converter can act as Boost mode and convert the voltage into nearly 230V when the source is absent, i.e. at cloudy season or during night time. The PI controller is used here to control the overcharge and deep discharge

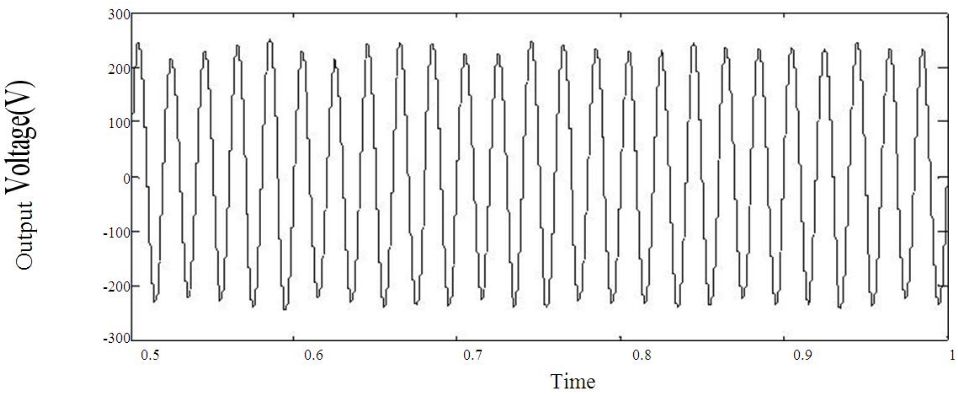

Fig 11 : AC output power from the inverter with non linear load connected

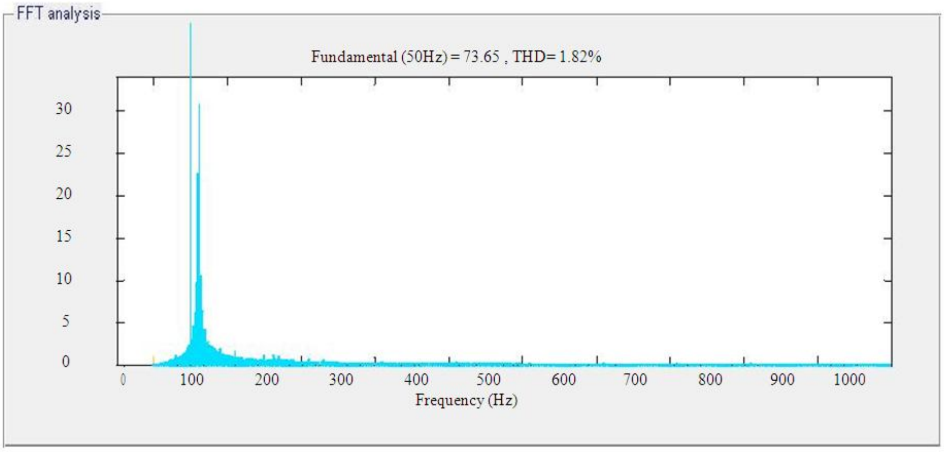

Fig 12: THD analysis with Non-linear load

Here the fig (11) shown that the AC output power from the inverter when the non-linear load is connected. Non-linear load is used here to verify the universality and robustness of the control scheme. From the THD analysis fig(12) it is clearly understand the control scheme is effective one.

Conclusion

In this paper, a comprehensive study of a stand-alone PV system for household application is analyzed. Mathematical models and control are provided for the three converters, which are boost converter, battery converter and inverter. The proposed coordinated control strategies are verified by Mat lab/Simulink with detail models. The battery converter can guarantee a constant dc bus voltage, and the inverter can generate a high quality ac voltage with nonlinear load. The charge controller designed is very effective in way to controlled charge and discharge i.e. which may avoid over charging during high insolation and deep discharge during high insolation. At which the non-linear load is considered here and the robustness of the control scheme can verified by determining the total harmonic distortion. With these results, the control methods can be utilized for reliable and high quality stand-alone PV system.

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