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Study and Treat the Effect of Loads and Radiation Changes for the Standalone Photovoltaic System by a Hybrid Storage System

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Abstract: In this paper, the effect of variation of solar irradiance and load conditions on hybrid standalone Photovoltaic (PV) with energy storage system are studied. An efficient energy management and control system (EMS) based on Proportional-Integral (PI) strategy is proposed. The proposed strategy is designed to share the optimal energy between batteries and super-capacitors (SC) to suit the state of charging, pumping and distributing power over loads. Moreover, the batteries are protected against overcharging state and this leads to rise the batteries' heat and thus shortens. Also, the SC has been supported and protected the batteries, as well as treating the increase in energy and sudden drop due to the high load demand. And, a current control scheme for the three-phase voltage source inverter (VSI) with pulse width modulation (PWM) is used. As a result, maintaining the stability of the energy in cases of voltage surges, and working on the balance and stability of energy in the different ratios of radiation, temperature, or loads. To validate the proposed EMS, MATLAB/Simulink is used and the simulation results are obtained with different case studies of load variation and irradiances. From the simulation results it clear that the proposed EMS show good performance and higher efficiency especially in fast change in solar irradiance.

Keywords: PV system DC; AC micro grid; environment PV performance; PV hybrid storage; Clean Energy Management.

1. Introduction

Nowadays, a hybrid power system with Renewable energy sources and energy storage devices is most used. In the light of the increasing demand for energy, the increase in interest in improving the environment, the decline in demand, and the dependence on fossil fuels due to the environmental pollution, heat retention, and carbon dioxide emission intensively [1-2]. However, the world is looking forward to expanding research, production and improvement of clean energy represented by wind and solar energy, which will dispense with a large part of the fossil fuels, and the introduction of clean energy into actual service in multiple fields, the most important of which is home use, electric cars or the subway. Moreover, clean energy is an important part of strengthening the main networks and using them on a wide range and for all practical, medical and other fields [3]. Figure 1 shows a self-contained of the stand-alone photovoltaic (PV) system consisting of PV system source connected to the DC constant voltage network and to the alternating voltage AC network also via the DC/AC inverter, and it contains a hybrid energy storage system (HESS) of batteries and super-capacitors (SC) [4,5]. The discontinuous and unstable nature of the PV system may lead to production mismatch with demand and voltage fluctuation due to weather conditions and load fluctuations. Furthermore, the HESS system is used to maintain energy demand, ensure system stability and increase reliability in the PV system. The PV system with HESS gives wide attention due to increased reliability and DC voltage stabilization across DC bus [5,6]. The effect of the higher and lower energy density may shortens the battery life. However, batteries need a safety policy during overcharging and deep discharging to control charge sharing. An EMS energy management strategy for an autonomous photovoltaic system with loads on constant voltage or alternating voltage is proposed, as well as working on the state of charge to sustain the life of the battery. The climate makes the energy

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not at a stable level. Therefore, the proposal to manage the energy by means of a hybrid storage system will be one of the most important solutions in addressing these problems to ensure the best effort reaches the consumer regardless of the major disturbances in the source voltage. Also, HESS was proposed in [7-10] with an independent storage source or a hybrid storage source and DC loads only, and it was found that there is no high reliability in the independent storage system due to the high stress on the battery.

Several researches were conducted for the independent storage system only batteries and it was proved that the transfer of energy from source to the consumer is uneven due to severe disturbances that lead to shorter battery life and increase costs. Furthermore, the hybrid standalone PV system with independent source has an output capacity of approximately 128KW and 469 ampere and a design voltage of approximately 273 volts and an output voltage of 500 volts continuous and alternating for multiple uses and with a hybrid storage consisting of lithium battery and capacitors the supercomputer will be studied and demonstrated energy designed and produced and the storage deal with instability situations and the system's survival in a stable state. The proposed strategy and method have very significant benefits in terms of speed of response and treatment of disorders [12-16]. The proposed strategy is based on a stand-alone PI of continuous and alternating voltage with hybrid storage. The battery, however, during power fluctuations it takes longer to stabilize at the permissible limit, as well as the slowdown in the response by the power transformer causes stress on the battery and the charge / discharge rate.

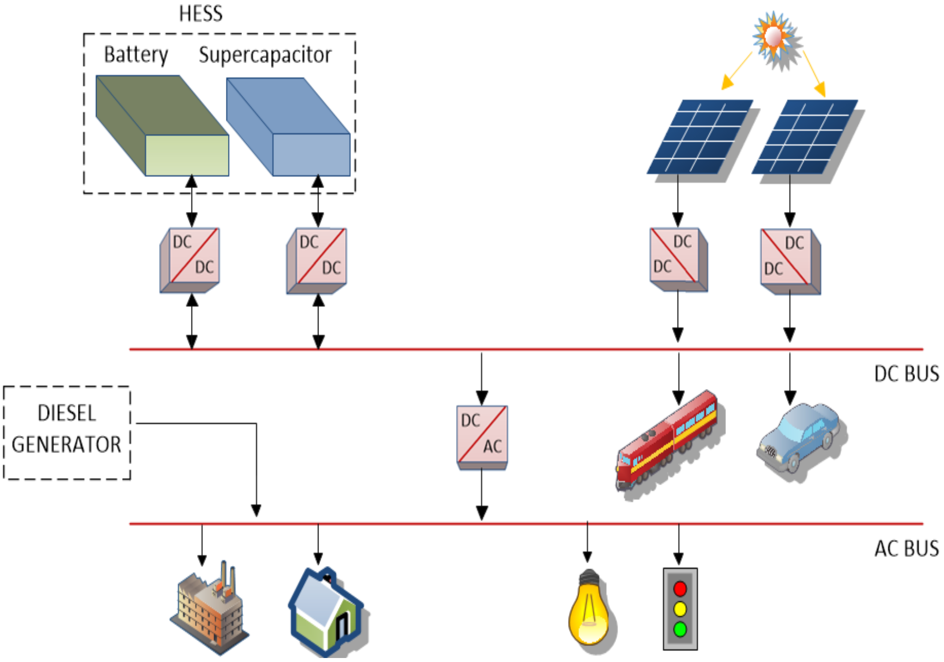


Figure 1. standalone PV system with dc and ac load

As a result, in this paper a hybrid PV system with HESS is presented to protect the batteries from overvoltage and then extended its life time. The designed and proposed system with a production capacity of 128 KW works to manage energy and preserve battery life through preventing deep discharge of the battery during low output due to high temperature, low radiation, or due to an overload request. As well as reducing the charging / discharging cycles, so the system will be stable, has a long life, free from technical problems, and reduces the financial costs that lead to the consumption of more batteries.

This paper is organized as follows: section 2 presents proposed hybrid PV system Structure, section 3 reports energy management and control strategy of the energy storage system, section 5 presents simulation Results and Discussion, and conclusion is presented in section5.

2. Proposed Hybrid PV system Structure

The proposed system consists of a PV system with a boost inverter include an INC-MPPT controller, a DC/AC inverter, and a hybrid storage of lithium batteries, super-capacitors are shown in the Fig. 2. The proposed work defines that the capacity of the lithium battery decreases as the number of cycles decreases. The battery capacity affects the operating time and system performance. So, determining the SOC is considered one of the most important matters affecting the battery life. Besides, the proposed strategy is designed for limits of $20\% \le SOC_{bat} \le 80\%$ for both battery while the supercapacitor is limited to $0\% \le SOC_{SC} \le 100\%$.

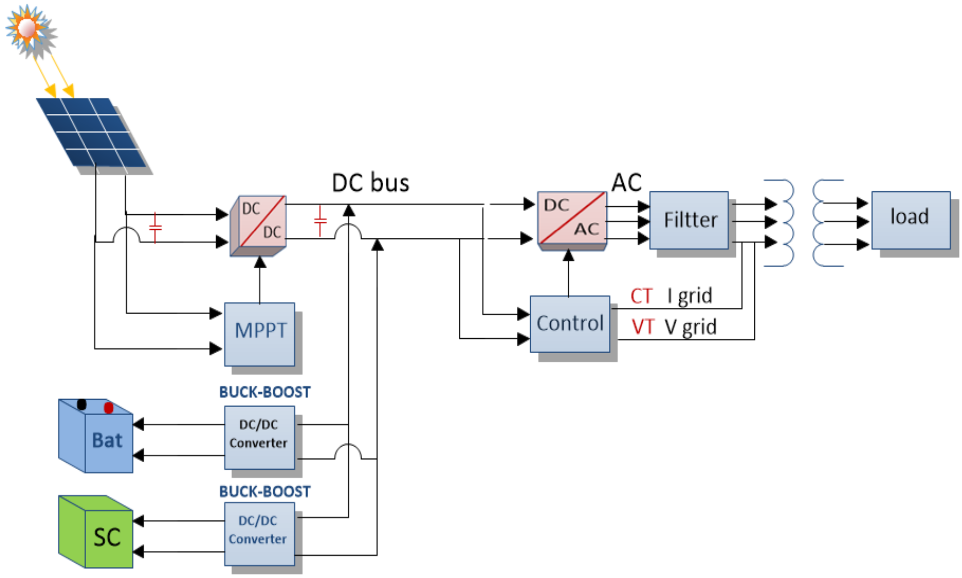


Figure 2. hybrid standalone PV system with battery-supercapacitor storage system

Table 1. The summarize management of hybrid PV system

Current of The battery	$P_{PV} < P_L$	$P_{PV} > P_L$
I b < I b max	Mode I Battery: Boost constant -voltage Super capacitor: Boost constant-voltage	Mode II Battery: Buck constant-voltage Super capacitor: Buck constant -voltage
I b >I b max	Mode VI Battery: Boost current limited Super capacitor: Boost constant-voltage	Mode III Battery: Buck current limited Super capacitor: Buck constant- voltage

The modes operation of the hybrid proposed system can be divided into four modes as presented in Figure 3 as following:

Mode I: When Ppv < PL, the load power decrease is supplemented by storage (batteries and super capacitors).

Mode II: When the light or sunlight increases more, the load power will be Ppv > PL, so the batteries and super capacitors will be in a charging state.

Mode III: When the light is increased so much that the Ppv> PL becomes very large and the battery current exceeds the maximum. Ib> Ibmax turns the battery into a limited buck current to protect the battery from over current. But the super capacitor can withstand the high currents without any side damage in the power density. So, work continues with a hard buck mode.

Mode IV: When the battery and the supercapacitor are in a storage state and suddenly there is an instantaneous breakdown of the light or sunlight, or the load increases, which requires pumping a high storage current to support I bus-dc where the current Ib > Ib max, the battery is transformed into the limited boost state in order to preserve the battery and ensure its operation. According to the appropriate discharge.

As seen in Figure 2, the power flow of the entire system components through the DC bus that will integrate with AC network. The total of the power generated by the PV system and storage system that consists of a battery bank and SC can be determined as follows [17-20]:

$$P_{dc} = P_{PV} + P_L + P_{ST} \tag{1}$$

$$P_{ST} = P_{BAT} + P_{sc} \tag{2}$$

$$P_{dc} = P_{PV} + P_{SC} + P_L + P_{bat} \tag{3}$$

Following this scheme, the trucking DC voltage will be developed as in Equation (3) we can write:

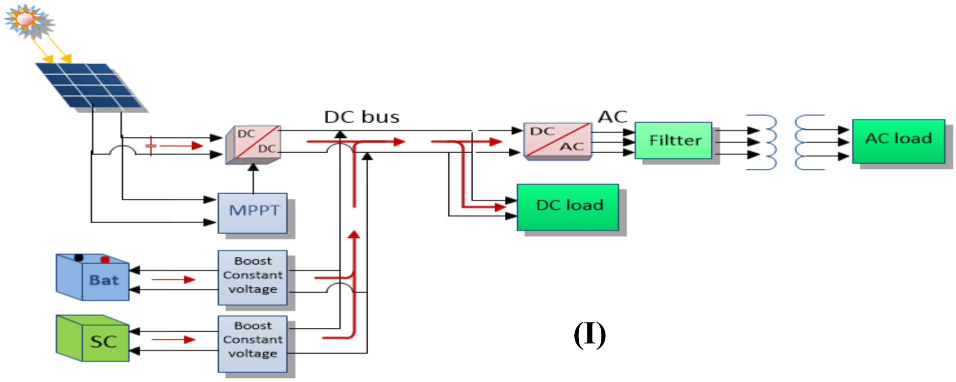
$$C_{DC}V^{*}{}_{DC}V_{DC} = [I_{PV} + I_{sc} + I_L + I_{bat}]V_{DC} \tag{4}$$

By cancelling the V_{DC} from both sides of equation (4), we get

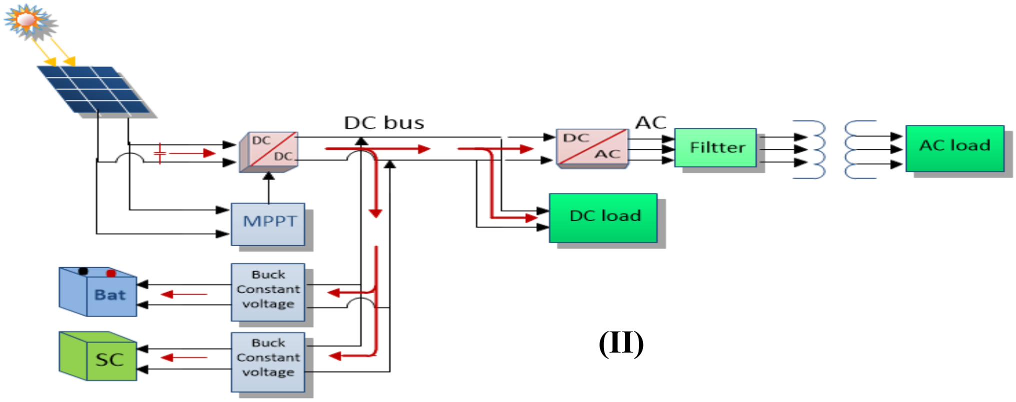
$$V^{*}{}_{DC} = \frac{1}{C_{DC}}[I_{PV} + I_L + I_{sc} + I_{bat}] \tag{5}$$

The power in the microgrid should be balanced as follows under different loads and supply conditions:

$$P_{PV} - P_{loss} = P_L + P_{bat} + P_{sc} \tag{6}$$



(I)



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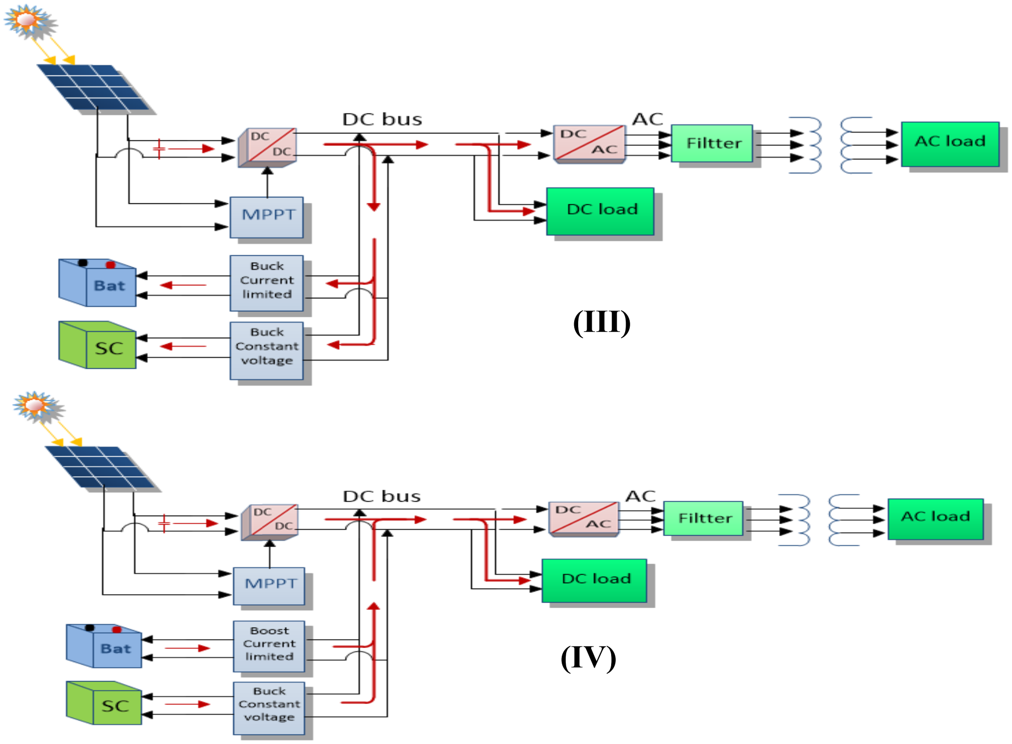


Figure 3. Modes operation of the proposed system

3. Energy Management and Control Strategy of the Energy Storage system

A. Battery Control Strategy

In order to balance the battery power, a durability control method is required. Several control methods have been reported in the literature to control battery current in various applications. The combined current control mode is introduced by [18]. The main disadvantages are the low efficiency in the case of light load as well as in the unbalanced load and it has a very complex design. In order to avoid this problem, a common control strategy in this system has been suggested. The proposed method diagram consists of the state of charge (SOC), and the generation of the reference current of the battery as shown in Fig.4. In order to generate the reference current, the error between the actual Vdc reference and the actual Vdc enters into the PI controller as shown in the equation (7) .

$$I_{ref} = K_P e_{vdc}(t) + K_I \int_0^t e_{vdc}(t)\, dt \tag{7}$$

When

$$e_{vdc}(t) = V_{dc}^{*} - V_{dc} \tag{8}$$

In order to generate the reference battery current, take the low pass filter for reference current in above equation (7). Therefore, the reference current of battery is compared with actual current of battery and the error of this comparing is entering to PI controller to introduce a voltage reference as indicated in the equation (9) [19-22].

$$V_{ref} = K_P e_{I-bat}(t) + K_I \int_0^t e_{I-bat}(t)\, dt \tag{9}$$

$$e_{I-bat}(t) = I_{bat}^{*} - I_{bat} \tag{10}$$

The state of charge (SOC) represented by the battery is an important parameter for representing the state of the battery.

$$SOC = 100\left(1 + \frac{\int I_{bat}\ dt}{Q_{bat}}\right) \tag{11}$$

where Q_{bat} is the battery capacity.

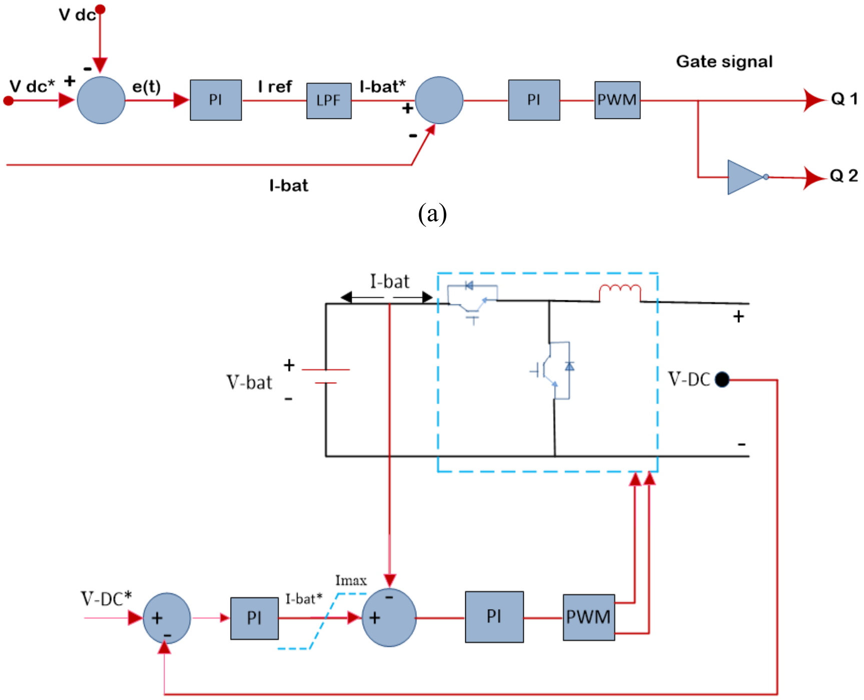
The charge-discharge of the battery depends on the power available, the demand and the SOC. The battery energy constraints are calculated of the SOC limits.

$$SOC_{min} \leq SOC \leq SOC_{max} \quad (12)$$

where, SOC $_{min}$ and SOC $_{max}$ are the minimum and the maximum allowable states for the battery safety.

Depth-of-discharge (DOD) % after a half-cycle period and DOD is expressed as:

$$DOD = 100\% - SOC \quad (13)$$



(a)

(b)

Figure 4. (a) control battery strategy, (b) control strategy with bidirectional DC-DC converter

B. Supercapacitor Control Strategy

The mathematical model of the SC is expressed by equations in a simplified manner as presented in Figure 5. The proposed scheme mainly contains the generation of the supercapacitor of the reference current (I sc, ref) as well as the current fast acting control [20-25].

$$I_{sc,ref} = i_{load} - \frac{1}{T}\int_{t_o}^{t_o+T} + i_{load}dt + (v_{dc,ref} - v_{dc}) \quad (14)$$

$$C_{dsc} = i_{sc}(1 - \delta_{sc}) + \frac{v_{dc}}{R_{L,eq}} \quad (15)$$

The dynamics of the supercapacitor error current ($I_e = I_{sc\ ref} - I_{sc}$) can be written as:

$$i_{sc} = \frac{di_e}{dt} + \gamma i_e + i_{sc,ref} \quad (16)$$

Using (15), the supercapacitor current can be written as

$$i_{sc} = \delta_{sc} i_{sc} + C_{dsc}\frac{dv_{dc}}{dt} - \frac{v_{dc}}{RL,eq} \quad (17)$$

Using (16) and (17), the control variable is obtained as:

$$\delta_{sc} = \frac{i_{sc,ref}+\left(\frac{v_{dc}}{R_{L,eq}}\right)}{i_{sc}} + \frac{\gamma}{i_{sc}} i_e + \frac{1}{i_{sc}}\frac{di_e}{dt} - \frac{C_{dsc}}{i_{sc}}\frac{dv_{dc}}{dt} \quad (18)$$

$I_{sc,\ ref:}$ generation of supercapacitor reference current

where γ, Ksc and RL, eq are the error co-efficient of supercapacitor current, direct supercapacitor current feedback gain and equivalent load resistance, respectively.

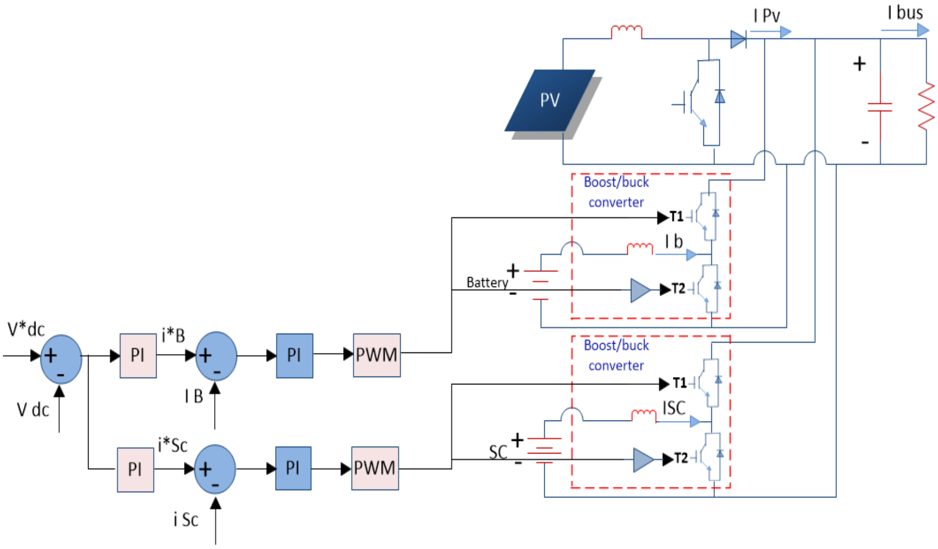
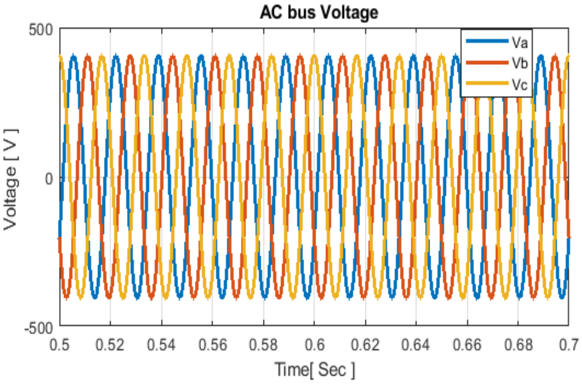


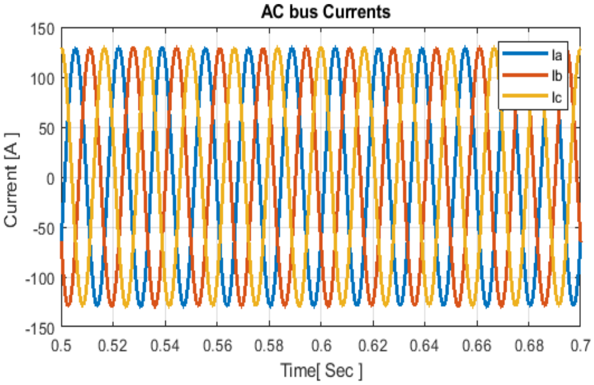
Figure 5. proposed control diagram of the battery and supercapacitor

4. Simulation Results and Discussion

Case study 1: At Nominal Condition (full load)



(a).



(b).

Figure 6. AC bus simulation results (a) AC bus voltage (b) AC bus currents

To verify the proposed control strategy, a Matlab software is used. Moreover, the performance of the proposed work is tested under three case studies to enhance the efficiency of the hybrid proposed PV system. In this case 1: when the power generation is equal to the required load capacity, the storage (batteries and super capacitors) does not store or consume energy and in this case the designed photovoltaic system produces 128.5 kw of photovoltaic energy. Figure 6 shows the AC bus simulation results for nominal full load conditions. Also, Figure 7 presented the steady state DC-link voltage (Vdc). In this case, the independent PV system is simulated in the steady as shown in Figure 8 and Figure 9 where this illustrates the operation of the PV system in MPP. In this case, the storage system (batteries and supercapacitors) is stable, i.e., without charging or discharging, and the power of PV and load curve remains constant throughout the time as in Figure 10.

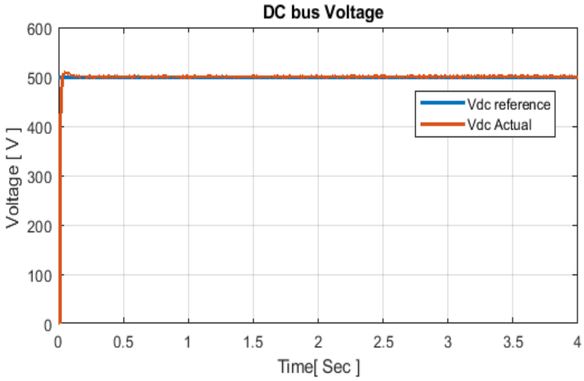


Figure 7. Steady state DC-link voltage (Vdc)

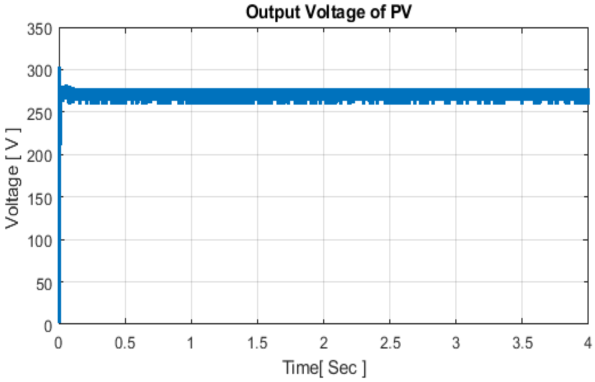


Figure 8. Steady state PV voltage at MPP

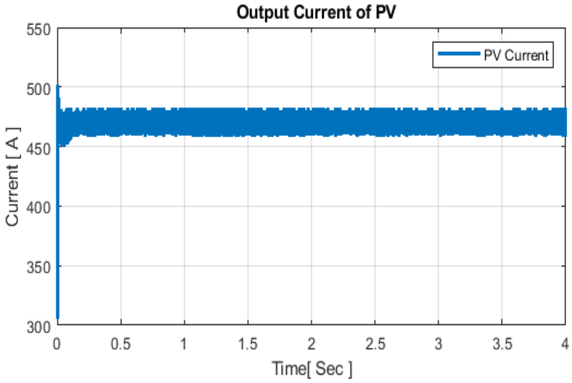
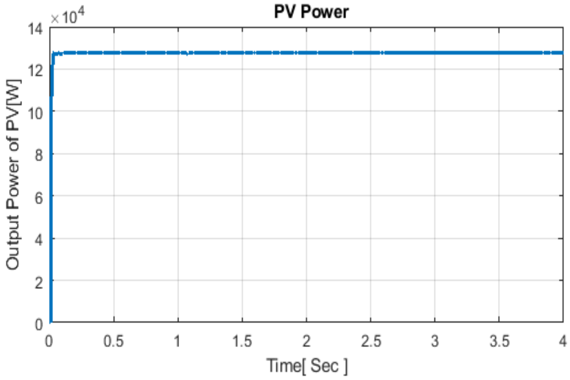
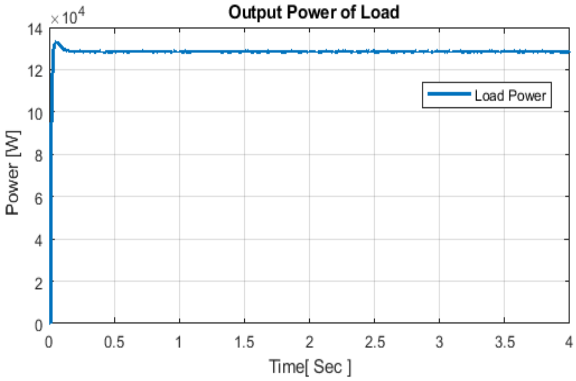


Figure 9. Steady state PV current at MPP



(a)



(b)

Figure 10 output power of (a) PV system and (b) power load under nominal condition

Case study 2: operation with load variation

Hybrid storage system used here helps to reduce load demand and problem of difference weather conditions. When the loads differ, there is mismatch between power generation and load. This gap can be filled by using lithium battery and super capacitors, so the storage system must provide the energy for the load with the additional power. There is a three resistive load and the simulation results are captured for the output voltage (AC), output voltage (DC), load current (AC), and power from the generation and demand giant, i.e., the load varies between 110kw, 115kw, 128kw where the variance of this load appears in the output voltage relative to the steady state, which indicates that the load variation remains stable and unchanging output voltage. This indicates the effectiveness of the inverter current control technique responsible for maintaining a stable 500v voltage across the load. Also, the robust control strategy makes the actual DC bus volatge is stable and tracking the reference value with fast response time about less than 0.1sec as shown in Figure 11, Figure 12 shows the waveform under the same load difference, also on the output side the result is clear about load variation as the load changes after some specified times. However, this current waveform has little effect, which indicates the stability of the control loop in the inverter. As for the power curves shown. when the power generation is greater than the load capacity, the hybrid storage system begins to store energy and the charging state increases its SOC. Besides, when the energy demand is greater than the PV generation, the storage system begins with a vacuum in order to provide the necessary energy to cover the load and the SOC starts to decrease. And when the power is increased. While when the generation power equal to the load capacity, the storage does not need to take or give the charge and thus the SOC maintains its ratio. The overall active power for the system is indicated in Figure 12.

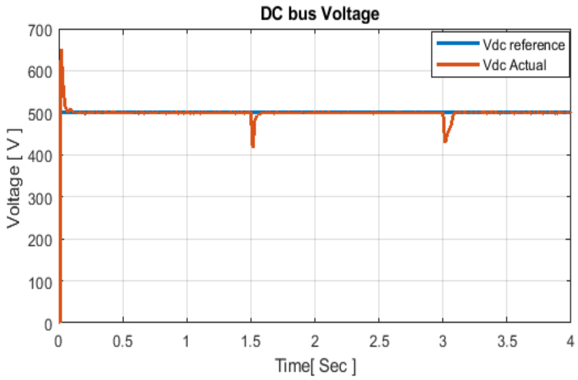
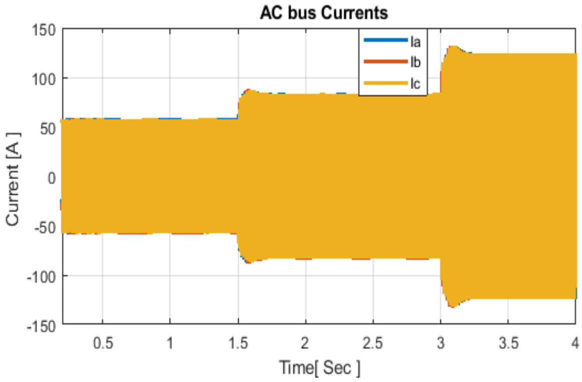
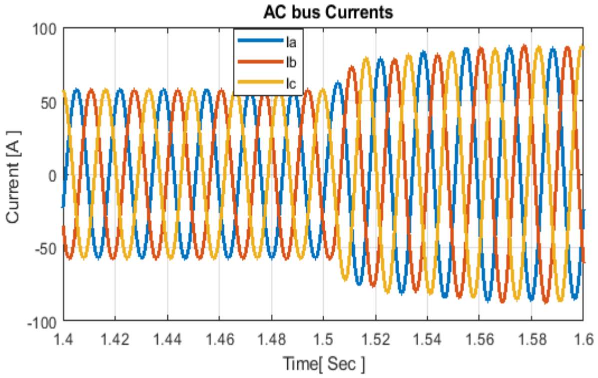


Figure 11 Steady state DC-link voltage (Vdc) under load variation



(a)



(b)

Figure11(a). Load current, (b). (i_0) under load variation

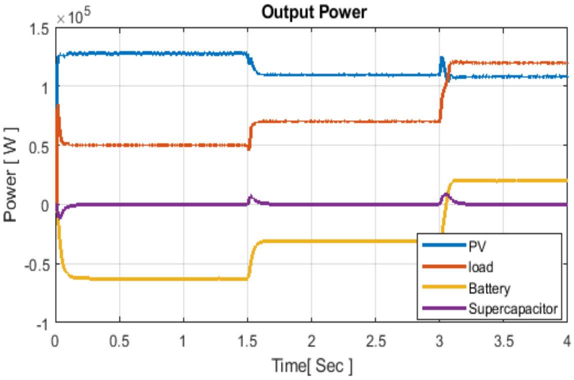


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Figure 12. PV, output load and hybrid storage power under load variation

Case study 3: operation with solar irradiance variation

when not enough power is generated from PV, the HESS should be providing the required energy by the discharging process and this condition is called lack of production. On other the hand, the PV energy is greater than the load capacity, HESS starts the process of storing excess energy and this process is called overproduction. Fig. 13 reports irradiance profile used in this case which is desired from higher value of 1000W/m² to 200W/m². Figs. 14 and 15 show the output voltage of the DC bus, AC bus respectively under different solar irradiance. Fig. 15 reports the output current at AC bus during the step change of the irradiance this current represents the three ABC phases of proposed inverter with good stability. The changing in the power of PV system due to the irradiance can be avoided using proposed battery-SC storage system. Besides, the study of change in generation energy in responding to the required load capacity, can provides by HESS compensation energy for the load through the vacuum discharge. When the solar energy generated by the PV system is greater than the load capacity, then HESS is in the state of charging and storing the energy. During charging the storage energy is negative and during discharging it is positive which can be seen in Fig. 16 which gives an idea of the charging and discharging process of HESS. Fig.17 shows the SOC for both the battery and the SC during the fast change in the solar irradiance radiation change. As a result, SC fast response to this change in the DC bus voltage by switched to its discharging mode.

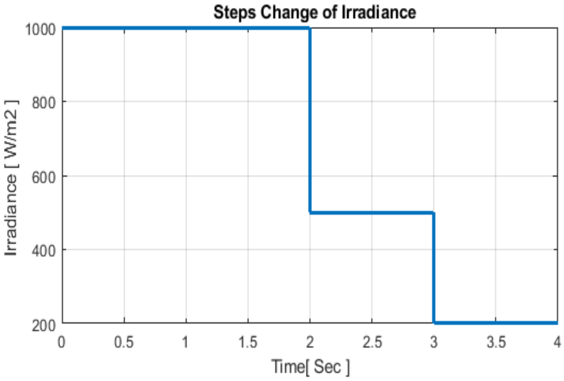


Figure 13. step change of irradiance (1000,500,200) w/m^2

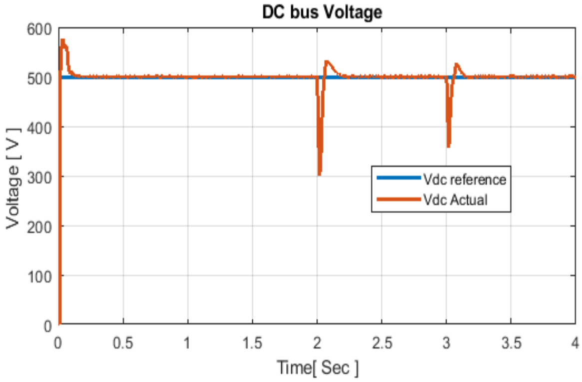


Figure 14. Steady state DC-link voltage (Vdc) under solar irradiance variation

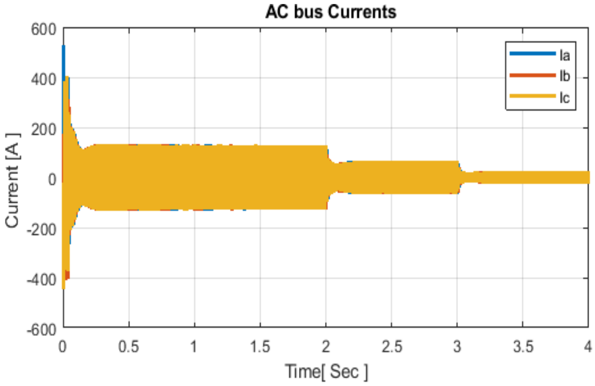


Figure 15. Load current (i_0) under solar irradiance variation

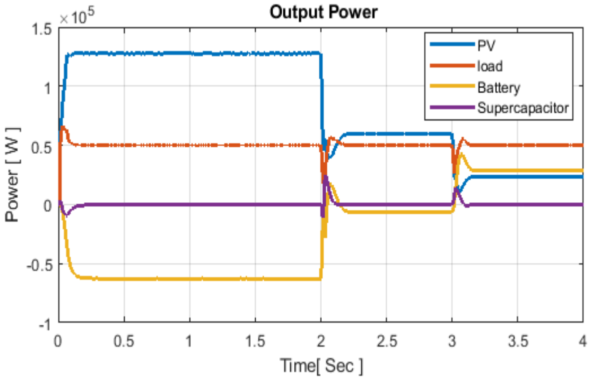
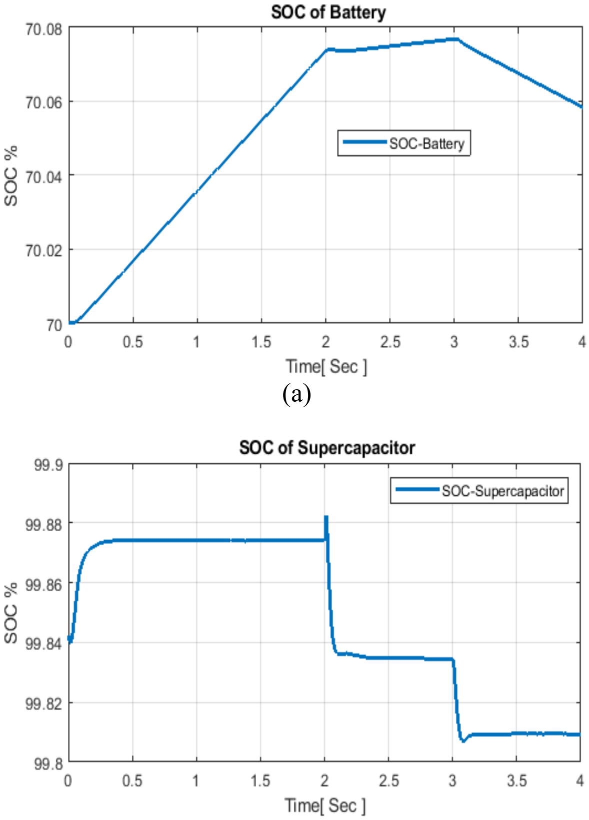


Figure 16. PV, output load and battery power under solar irradiance variation



(a)

(b)

Figure 17. SOC of HESS system under solar irradiance variation (a) SOC of battery (b) SOC of the SC

4. Conclusion

In this paper energy management system and control of a hybrid photovoltaic (PV) system is presented. A maximum amount of PV system has been extracted using INC-MPPT controller to maintain power flow between DC and HESS. A constant voltage of the DC connection is maintained by charging and discharging the lithium battery. A current control strategy for VSI inverter is designed as closed-loop control were found to be robust to the specific controller parameters. The performance of the proposed system is verified by simulation with case of changing the load or radiation. The results show that the necessary energy has delivered from storage to the load when the load power is greater than the source energy. Also, when the source power is greater than the load energy, the excess energy goes to the storage system, and this indicates on balance storage system. In addition, the VSI provides stable output voltage and little variance under sudden load changes. The suggested control method is effective on a standalone PV device with lithium battery as backup and supercapacitors.

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