Performance of Constant Power Supply in Grid-connected PV System with Hybrid Energy Storage System

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Abstract: *The photovoltaic energy influenced by the change of solar irradiance and the fluctuating load profiles requires an energy storage system. In this paper, the Hybrid Energy Storage System (HESS) is created from a Lithium-Ion battery and a Supercapacitor (SC) module coordinated to achieve a high-energy and high-power storage system; it is connected to a DC link through the buck-boost bidirectional converters. It is then advantageous to combine these two energy storage devices to gain better power and energy performances. This paper focus on improving the complete integration of solar energy into the power grid by dispatching, or supplying a constant level of power. And the HESS will absorb and supply the necessary levels of power to keep the systems output power constant.*

Keywords: *HESS, Photovoltaic, power grid, buck-boost converter.*

1. INTRODUCTION:

Renewable energy sources have been increasing in popularity and therefore have become an interesting topic of research due to their ability to allow the world to become less reliant on fossil fuels such as oil, coal, and gas. This means that solar energy has the potential to greatly increase Earth's longevity by decreasing greenhouse gas emissions. Increasing the efficiency of a power source will inevitably increase the rate of return on the investment into solar energy. Solar energy is naturally an intermittent renewable resource, which means providing varying power levels due to natural and meteorological conditions. So, the intermittence of solar energy poses a great challenge in power electronics when it is connected directly to the utility grid [1]. In order to help these challenges, energy storage systems can play a significant role by enhancing the operating capabilities of the power system, ensuring its reliability, and lowering the cost while reducing future infrastructure investments [2].

Battery storage devices have been widely utilized for different applications. However, for high power applications, battery storage systems come with several challenges, such as the thermal issue, low power density, low life span and high cost. Compared with batteries, supercapacitors have a lower energy density but their power density is very high, and they offer higher cyclic life and efficiency even during fast charge and discharge processes [2]. Therefore, a hybrid energy storage system (HESS) that consists of a battery bank and SC bank can be potentially used to develop an economical energy storage system. When a hybrid energy storage system is incorporated in a solar framework, it is also able to absorb and supply the necessary levels of power to provide a constant output power to the power grid from this solar farm [3]. In this paper, the control and power management of the hybrid battery-supercapacitor storage system are developed to improve the performance of the system in terms of efficiency, power quality and reliability.

In this paper, the hybrid storage system is integrated in a PV-grid connected system in order to be controlled and tested under different cases. Connecting this system to the grid has two main benefits; injecting the surplus energy to the grid and using the grid as a backup system to supply the load in the critical cases, this will help to avoid the batteries oversized. Then, to manage and to optimize the photovoltaic power under different scenarios, a simple algorithm has been proposed, it takes into account, the PV extracted power, the battery state of charge (SOC), the quick response of the supercapacitor, the load needs, and the grid-injected power.

2. SYSTEM TOPOLOGY:

Fig.1. shows the topology of proposed grid-connected PV system with hybrid energy storage. The PV energy source are connected through suitable power electronic interfaces to extract maximum power. Batteries and supercapacitors are used as energy storage devices to balance the power flow. The bidirectional buck-boost DC-DC converter topologies are used to control the power flow between the batteries, supercapacitors and utility grid. The voltage source inverter is used to interface the renewable energy resources to the utility grid. The photovoltaic energy system (PVES) consists of a 100kW solar farm that outputs power through a DC/DC converter. The hybrid energy storage system (HESS) consists of a 720V, 1157Ahr li-ion battery bank, a 780V, 2.543F supercapacitor bank, and a DC/DC converter connected to each bank.

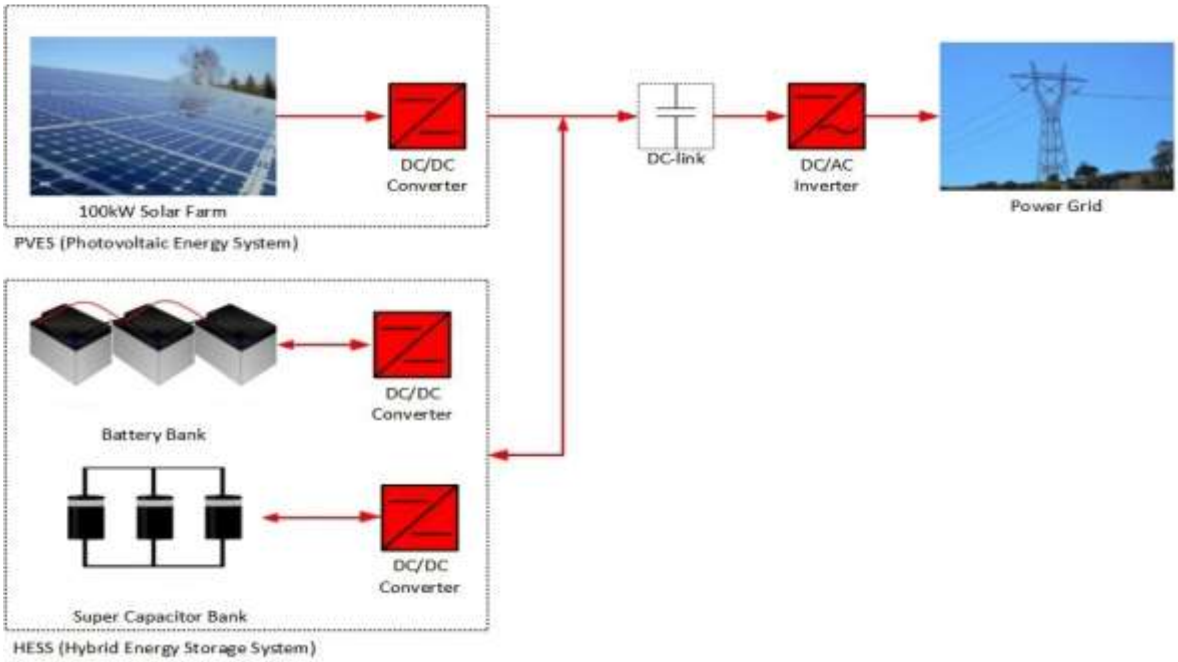


Figure1: Solar Farm with Hybrid energy storage system [1]

3. PV SYSTEM MODELLING AND CONTROL TECHNIQUE:

In this paper, a commonly one diode, solar cell model has been used, which is shown in Figure 2 [5]. First, we present the approach to calculate the parameters of PV system. SunPower SPR-305-WHT solar cells is used to simulate in this system. The maximum power point voltage is 54.7V. If we assume the string voltage as 440V, the number of series and parallel connected PV module is calculated as the following equation.

The number of modules connected in series, $N_s = \frac{\mathrm{V_{string}}}{\mathrm{V_{MPP}}} = \frac{440}{54.7} = 8$

The number of modules connected in parallel, $N_p = \frac{RequiredPower}{StringPower} = \frac{100kW}{2400W} = 42$

So, the total number of modules is 336 modules. And then the required output voltage of boost converter is 780V.

So, Duty ratio of Boost converter, $\mathrm{D} = 1 - \frac{V_{in}}{V_{out}}$

$$\mathrm{D} = 1 - \frac{437.6}{780} = 0.439$$

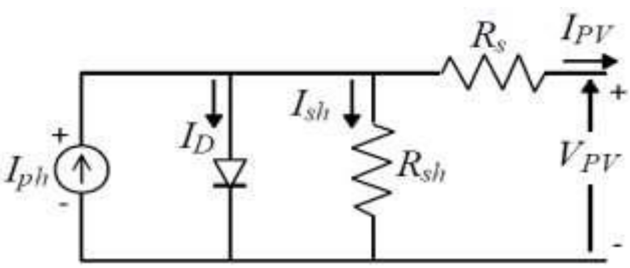


Figure 2. One diode photovoltaic cell model

A. MPPT control of PV array

The conversion efficiency of light energy into electrical energy is very low for PV systems. Since, it is required to fully convert the available light energy into electrical energy. For this purpose, the PV system is operating at Maximum Power Point (MPP). MPP is the ideal point at which PV system generates its maximum/rated power. To perform maximum power transfer, an Incremental Conductance Algorithm (ICA) based Maximum Power Point Tracking (MPPT) is incorporated in boost converter.

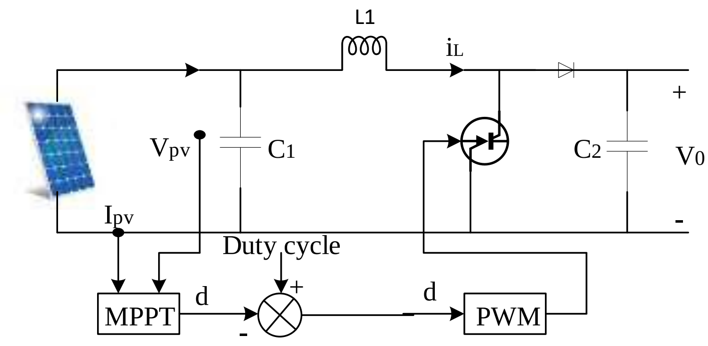


Figure 3. Proposed Maximum Power Point Tracking (MPPT) system

B. Control of Three-phase Inverter

The inverter control diagram is shown in Figure 4. It is based on the direct-quadrature theory, where the phase-neutral grid voltages, v_{abc}, and currents, i_{abc}, are transformed into the dq voltages, v_{dq}, and currents, i_{dq}, components for and easier current control. The Phase Locked Loop (PLL) synchronizes with the fundamental positive sequence component of the grid voltage. The d current reference is directly obtained by the grid power control. The q current reference is set to zero for null grid reactive power injection. Inverter reference voltages are obtained in the dq frame by using a feed forward scheme [4]. Then, the gating signals for inverter is supplied by using PWM.

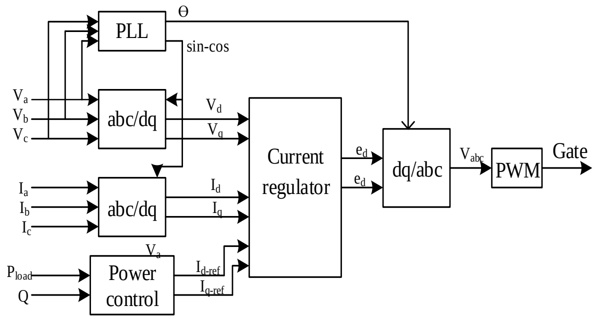


Figure 4: Grid-connected inverter control system

4. HYBRID ENERGY STORAGE SYSTEM CONFIGURATION:

The optimal active hybrid system topology was chosen to connect the battery and supercapacitor in one combination. It has the advantage of combining their advantages and solving the disadvantages of supercapacitor voltage variation and matching by placing DC-DC converter between the supercapacitor and the DC bus. The power requested $P_{storage\_ref}$ by the supervisory is met by supply base power from the battery P_{bat} and the transient power from the supercapacitor P_{sc}, the references of the both powers are obtained from low pass filter as shown in Figure 5.

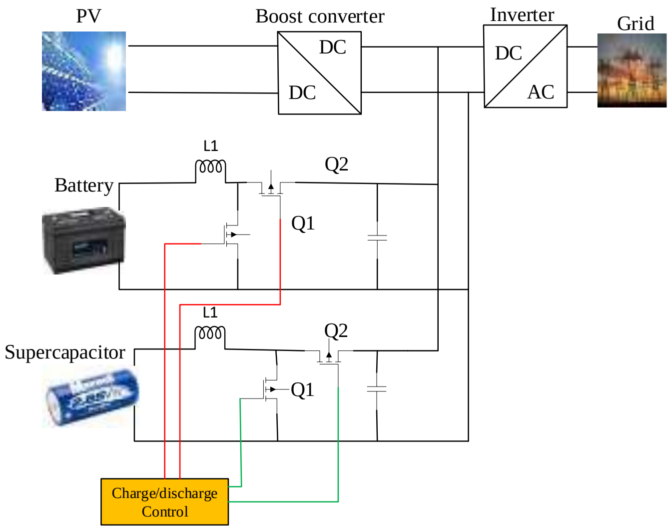


Figure 5. Hybrid Energy Storage System Configuration

A. Charge and discharge control of HESS

The bidirectional converter is controlled by a PI current controller, which adjusts the duty ratio of the IGBT switching at a fixed 5-kHz. Depending on the mode of operation, only one IGBT is needed to be switched at a predefined frequency. In order to select the proper IGBT, the reference current is compared to zero. If the reference current is negative, the controlled PWM signal is sent to S1, activating the buck mode of operation. On the other hand, if the current reference is positive, the signal is sent to S2 to transfer energy from the LV side to the HV side, activating the boost mode of operation [2]. The proposed charge and discharge control of batery in this work is shown in Figure 7. Control of SC is also the same with the battery.

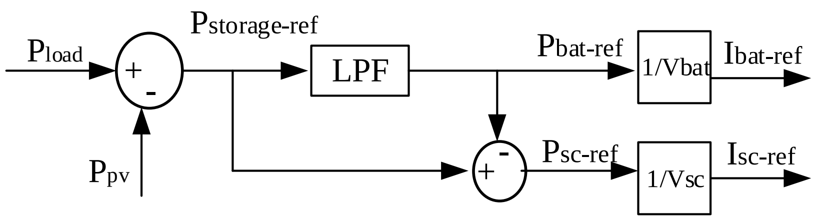


Figure 6: Power balance control of HESS

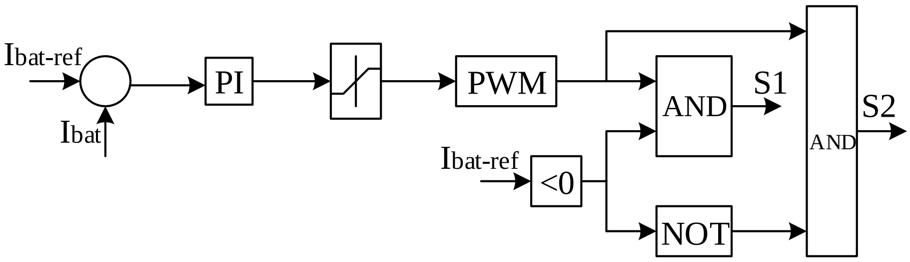


Figure 7 .Charge and discharge control diagram

5. SIMULATION RESULTS:

In order to validate the performance of the proposed system, to check the behavior of all components that are working together, and to verify the control strategies under all the possible cases and two different load condition, the simulation is run for 1 second.

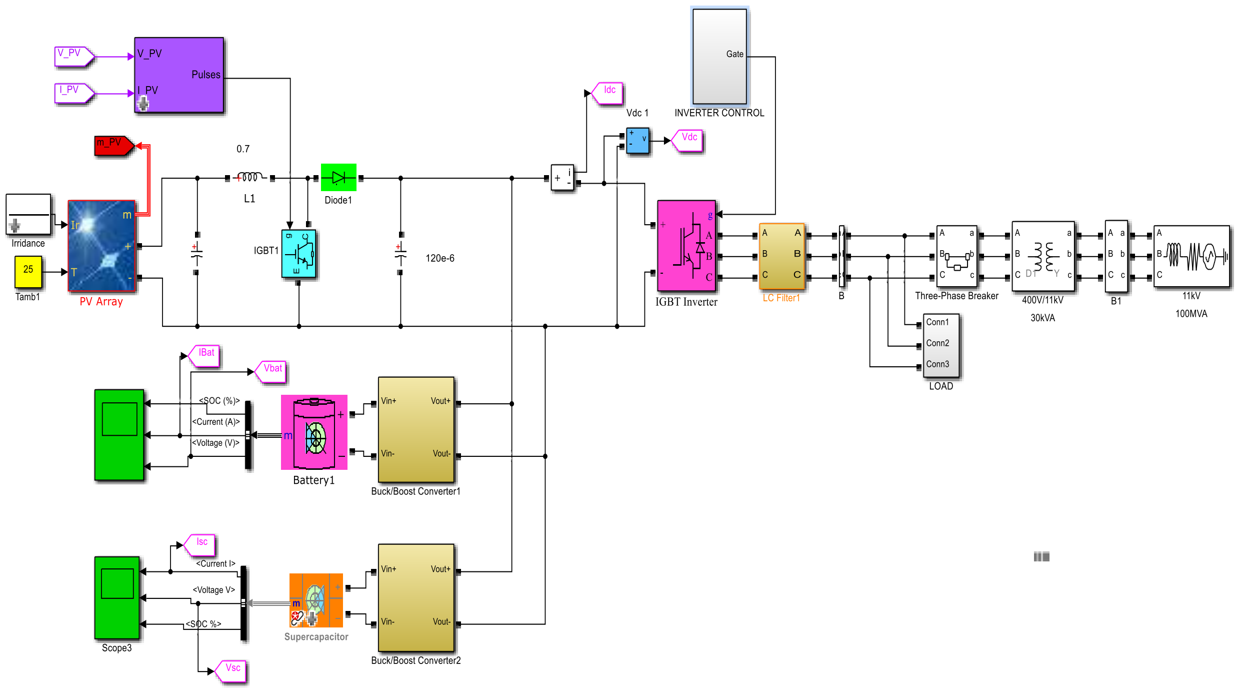


Figure 8. Simulink Model of Proposed System

TABLE 1. Parameters of the proposed system

PV	Maximum Peak Power (P_{MPP}) Open circuit Voltage (V_{oc}) Maximum Voltage (V_{MPP}) Short Circuit Current Series Modules(N_s) Parallel Modules (N_p)	100 kW 64 V 54.7 V 5.87 A 8 42
Battery	Rated capacity Rated voltage Series batteries	1157Ah 720 V 56
Supercap-acitor	Rated capacitance Rated voltage Equivalent series resistance Series modules	2.439 F 780 V 18 mΩ 239
DC bus voltage Load 1 Load 2 AC load side voltage		780 V 70 kW 120 kW 400 V

Case I: In this case, the generated power from PV is 100kW constant. The load is changed from 70kW to 120kW as shown in Fig.11 (b). DC bus voltage is maintained at 780V as reference voltage shown in Fig.11 (a). Under a light load, the storage discharge power is 50kW, and the DC bus power is 150kW. The reference power of storage system, battery and SC is shown in Fig.8.

		0 – 0.5s	0.5 – 1s
$P_{PV} \pm P_{storage} = P_{DC}$ $P_{dc} = P_{ac}$ $P_{ac} = P_{load} + P_{grid}$	P_{load}	70 kW	120 kW
	P_{dc}	82 kW	120kW
	$P_{storage}$	18 kW	-20 kW
	P_{ac}	83 kW	120 kW
	P_{grid}	11 kW	8 kW

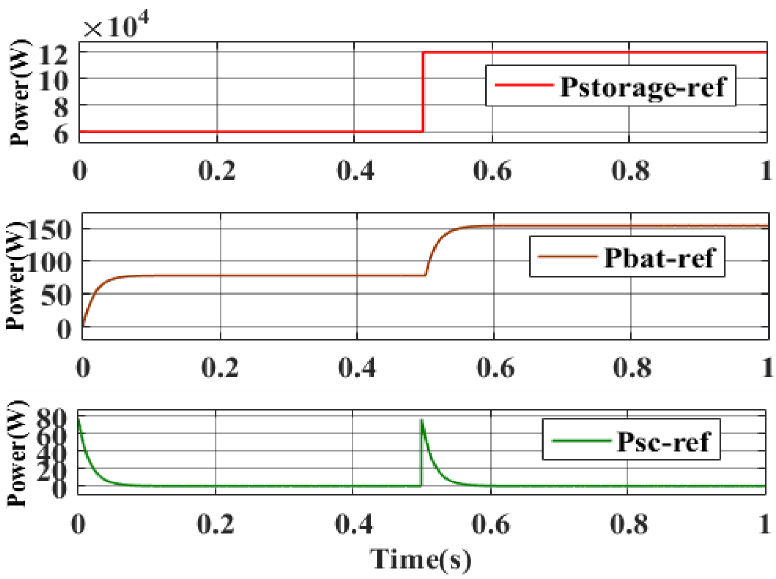


Figure 9. Reference power of storage system, battery and SC

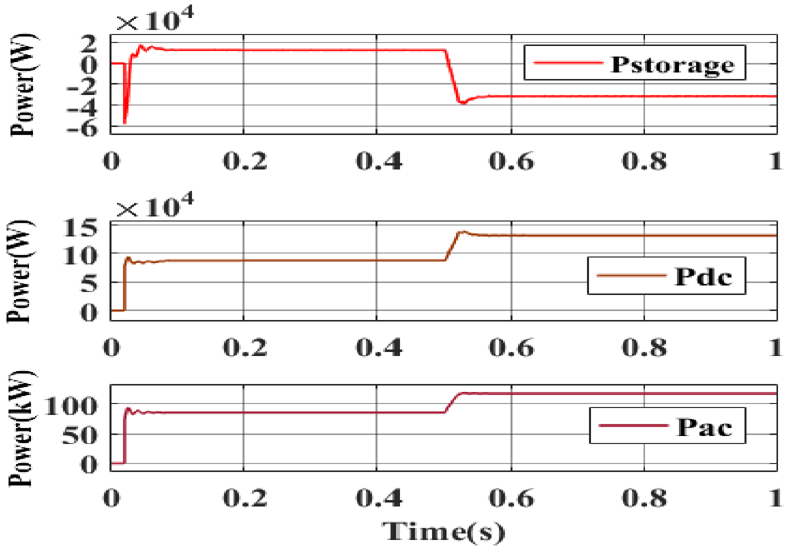


Figure 10. Storage, DC power and AC side power in Standalone mode

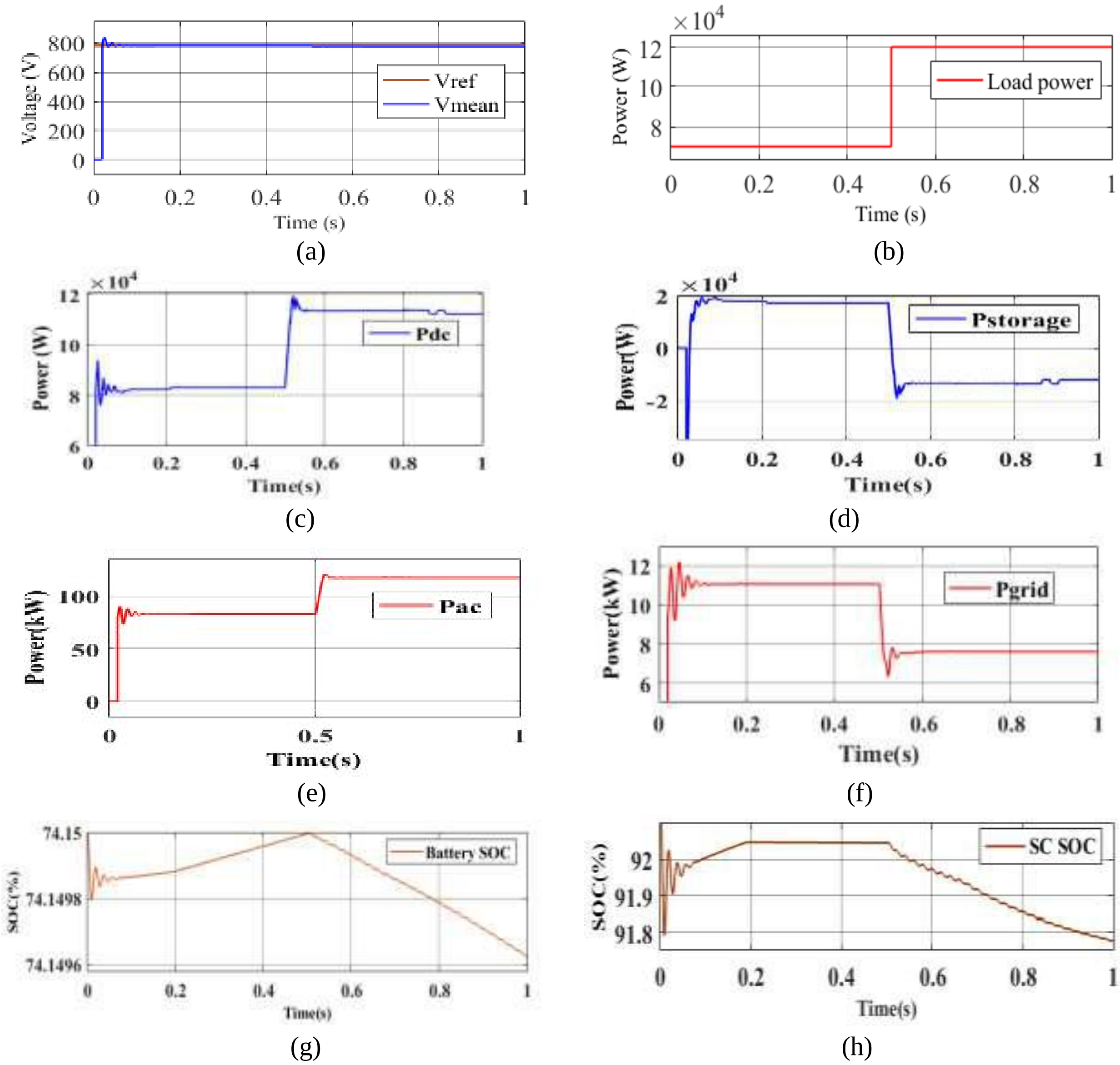


Figure 11. (a) DC Bus Voltage, (b) Load Power, (c) DC Bus Power (d) Storage Power,(e)AC side Power, (f) Grid Power(g) State of charge of battery and (h) State of charge of SC (Case I)

Case II. Variable solar irradiance and constant load is simulated in this case, shown in Fig.12.As the results, the HESS support to maintain the constant power on the DC bus. Furthermore, Fig.14(a) shows how the HESS kept the DC bus voltage constant despite the irradiation changes for some period.

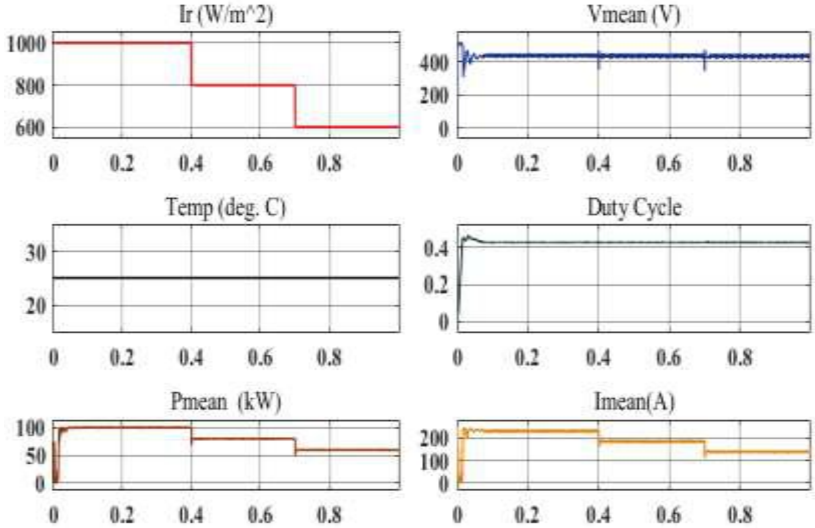


Figure 12. PV irradiation, temperature,PV output power, current, duty ratio and voltage

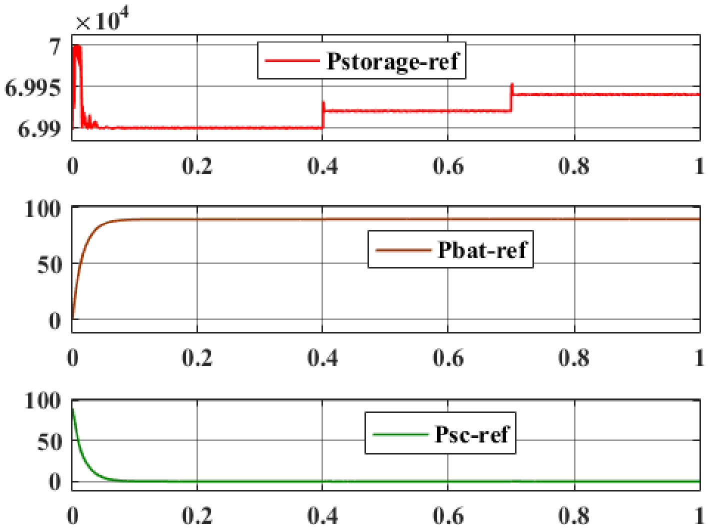
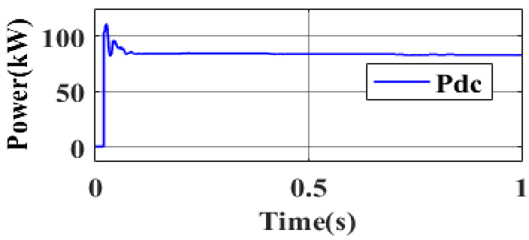
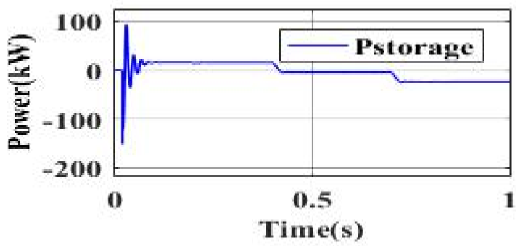


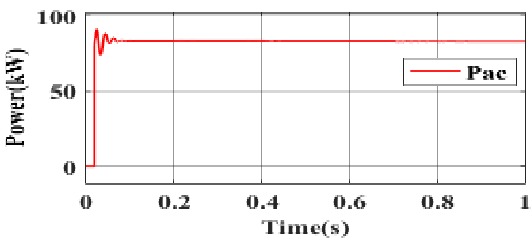
Figure 13. Reference power of storage system, battery and SC



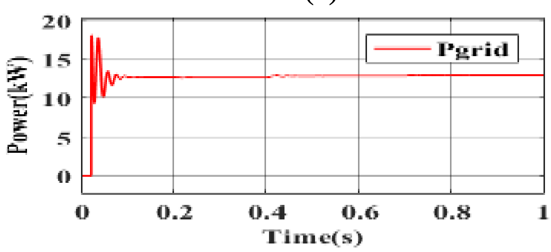
(a)



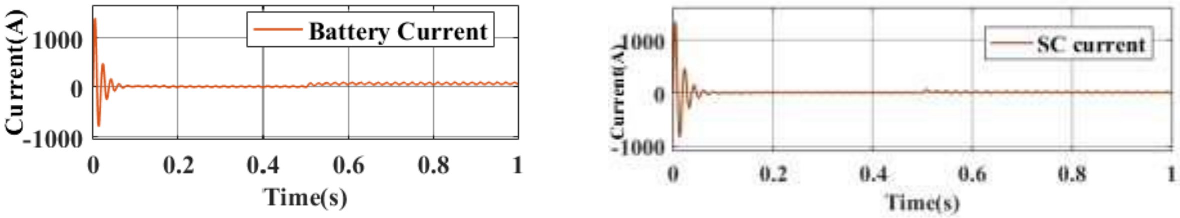
(b)



(c)



(d)



(e) (f)

Figure 14. (a) DC Bus Power, (b) Storage Power, (c) AC side Power (d) Grid Power,(e)Battery Current, (f) SC Current (Case II)

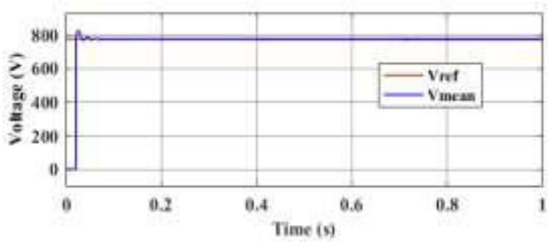


Figure 15. DC bus voltage

6. CONCLUSION:

The simulation results confirm the high efficiency of the proposed control algorithm, as well as the benefits of using hybrid energy storage system. The PV system has been simulated in the different loads and irradiation changes, where the load requested a peak current, even though, the hybrid storage system responded to this demand without destabilizing the system performance. And under irradiation changes conditions, the HESS support to maintain the constant power on the DC bus.

REFERENCES:

1. Jordan Chaires, (2016), Solar farm hourly dispatching using a supercapacitor and battery energy storage system, Master diss., Western Carolina University, Department of Engineering and Technology.
2. Mustafa Farhadi, (2016), Hybrid Energy Storage Implementation in DC and AC Power System for Efficiency, Power Quality and Reliability Improvements, doctoral diss., Florida International University, FIU Digital Commons.
3. Pranoy Kumar Singha Roy, (2018), Design of a cost effective battery-supercapacitor hybrid energy storage system for hourly dispatching solar pv power, Master diss., Western Carolina University.
4. Víctor Manuel Miñambres-Marcos, Miguel Ángel Guerrero-Martínez, Fermín Barrero-González and María Isabel Milanés-Montero,(2017): A Grid Connected Photovoltaic Inverter with Battery-Supercapacitor Hybrid Energy Storage: Journal of Sensors, 2017, 17, 1856; doi: 10.3390/s17081856.
5. A Guichi1, A Talha1, El Berkouk2, and N Sabeur (2018): Control and energy management of grid-connected pv system with battery-supercapacitor hybrid energy storage: IOP Conf. Series: Earth and Environmental Science 164 (2018) 012014 doi: 10.1088/1755-1315/164/1/012014.