# Power Management of a Hybrid Energy Storage System in a Domestic Microgrid

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## Abstract

**This paper presents a power control strategy for a grid connected domestic PV system included hybrid energy storage devices. The strategy aims to minimize utility grid dependency of the users in addition to considering safe working conditions of the storage devices. Battery and ultracapacitor were used respectively for providing high energy density and high power density in hybrid storage system. The proposed model was tested in Matlab/Simulink simulation environment by using measurement values which are presented in literature for PV electric generation and domestic energy consumption. Simulation results reveal that domestic demand is exactly supplied by the hybrid storage system as long as ultracapacitor has stored energy. After the energy stored in ultracapacitor is consumed, battery blanks sustain to support utility grid for meeting the demand.**

## 1. Introduction

Micro Grids (MGs) can be defined as secondary electric grids composed of renewable and distributed energy sources. MGs have various advantages for utility grid and consumers. First of all, MGs are the renewable, economic and clean energy sources [1-2]. With this aspect, it is the most significant alternative for oil products that they are environmentally hazardous and on the point of exhausting. Secondly, MGs can be used to solve existing grid problems such as energy gap and power deficit [3-4]. Thereby, MGs increase reliability and flexibility of the grids. Thirdly, main grid dependency of the consumers who use grid connected MG is decreased [5-6]. By this means, consumers take active roles both on energy policies and solutions of the energy problems. These desirable features accelerate penetration of the MGs.

Renewable energy sources have an intermittent electric generation characteristic. At the same time, electricity consumption amounts of the houses differ from day to day. Energy storage devices are used to provide the balance between consumption and generation in MGs. These devices store the surplus energy when the generation is higher than demand. In the other times, the devices meet the demand of the MGs by using the stored energy. Thus, the energy generated in RESs can be managed, hence cost benefit of the MGs increases. The rate of cost benefit can be changed in accordance with energy storage technologies and energy control methods [7-8].

Various storage devices are employed in energy backup systems. The devices mostly used in MGs are battery, ultracapacitor, flywheel and magnetic energy storage units. Each of the devices has some advantage and disadvantage in terms of their storage characteristics. In Table 1, the characteristics of the battery and ultracapacitor are compared with each other. Power density of the battery per kg is low whereas their energy density is high. Moreover, power density per kg in ultracapacitor is high while its energy density is low [9]. Hybrid storage systems are designed for gathering all of the advantages of the storage technologies together [10-12]. Thus, the disadvantages of an energy storage system can be eliminated by using the advantage of another storage system.

**Table 1.** Comparison of battery and ultracapacitor

| Features | Battery | UltraCap. |
|---|---|---|
| Efficiency (%) | 60–80 | 95 |
| Energy density (Wh/kg) | 20–200 | <50 |
| Power density (W/kg) | 25–1000 | 4000 |
| Response time (ms) | 30 | 5 |
| Cycle life (time) | 200–2000 | >50,000 |
| Cost ($/kWh) | 150–1300 | 250–350 |

Hybrid energy storage systems can be composed of different energy storage devices according to their design features. Li et al. combined lead-acid battery and superconducting magnetic energy storage in a residential context in order to improve battery life time [13]. Abbassi et al. utilized hybrid supercapacitor-battery system in a PV/Wind power system [14]. The study aims to limit power peaks caused by energy consumption and to keep SOCs in a suitable range. Lee et al. considered battery and flywheel hybrid storage systems to reduce power fluctuation in a large scale wind farm [15]. The results show that instead of only using battery; hybrid storage system is a more efficient and effective to provide power stability of wind farms.

This paper presents a power management method for hybrid energy storage systems using in domestic MGs. The hybrid storage system is composed of battery banks and ultracapacitor. The batteries are employed to increase energy density and ultracapacitor is used to enhance power density of the storage system. An analytic program was designed to control the system that it aims to meet the demand from the battery when the demand is low; and meet the demand from the ultracapacitor and battery when the demand is high. The data of PV generation and energy demand are taken from the literature to catch actual data. Simulation results reveal that hybrid storage systems meet high power demands as long as there is stored energy in ultracapacitor. Furthermore, the storage system has worked in healthy working conditions during the simulation time.

## 2. Hybrid storage system

Energy storage devices can be integrated with MGs by using different ways. The simplest way is direct integration method which includes no DC/DC converter. This method is economic but has no power control unit thence; power flexibility of the method is lowest. Another storage device integration method is to use a DC/DC converter for only one storage device. In this method, a storage device which has high power or energy density can be controlled via the DC/DC converter. The third method includes DC/DC converters for each energy storage device. This method improves power controllability of hybrid storage system but it is the most expensive method due to the extra power converters. In this study, only one DC/DC converter is used as a charger to control battery charge-discharge power. Thus, hybrid storage system can be controlled with an economical way.

Fig. 1 shows the configuration of a domestic micro grid for the proposed hybrid storage system. Grid connected PV system has a hybrid storage unit composed of battery and ultracapacitor. The energy generated in PV panels is managed by an inverter and a charger. The charger sets the charge-discharge power of the battery depending on the input variables of the controllers. Ultracapacitor is directly connected to the inverter with the intent of minimizing response time. Power difference between inverter and charger is met or stored by ultracapacitor. The object of the micro grid is to decrease the grid dependency of the house. However, the generated excess energy can be given to utility grid after storage devices are charged fully.

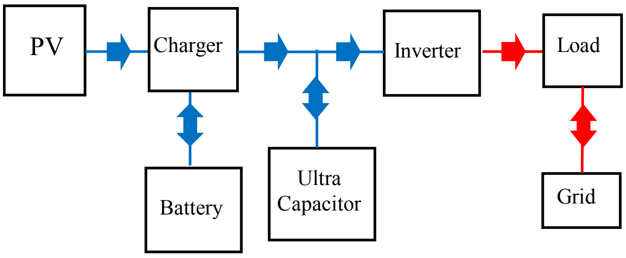


**Fig. 1.** Configuration of a domestic microgrid using hybrid storage system

Domestic loads are supplied by grid and inverter, as shown in Equation 1. Because inverter is unidirectional, inverter power ($P_{Inv}$) does not carry a negative value, but grid power ($P_{grid}$) turns into negative when the MG gives energy to the grid. In Equation 2, the charge/discharge power of the ultracapacitor ($P_{UC}$) is defined. Since $P_{charger}$ and $P_{Inv}$ are controllable variables, and $P_{UC}$ is also can be controlled. The charge/discharge power of the battery ($P_{Bat}$) is determined by the help of Equation 3. If the generated excess energy is stored in battery, $P_{charger}$ equals to $P_{Load}$. Besides, if it is stored in ultracapacitor, $P_{charger}$ equals to $P_{PV}$. The same power flow equation is ruled, also, during discharging period of the hybrid storage system.

$$P_{Load} = P_{Grid} + P_{Inv} \quad (1)$$

$$P_{UC} = P_{Charger} - P_{Inv} \quad (2)$$

$$P_{Charger} = P_{PV} - P_{Bat} \quad (3)$$

Fig. 2 shows input and output variables of the controller. All of the power flows appeared in hybrid storage system can be controlled through $P_{Inv}$ and $P_{charger}$. Hence, outputs of the controllers are formed by these variables. $P_{PV}$ and $P_{Load}$ rank among input variables as hybrid storage system stabilizes the balance between the generated energy and load. The other input variables that are decisive in power control are SOC values of ultracapacitor and battery.

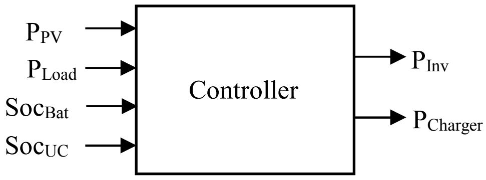


**Fig. 2.** Input and output variables of the micro grid controller

Charge/discharge power is a remarkable matter for the controlling of the energy storage devices. High power charge shortens the life of the storage devices by causing overheating [16]. Therefore, maximum charge/discharge power has to be determined for each storage devices. In this study, it was determined as follows: $P_{Bat\text{-}max} = - P_{Bat\text{-}min} = 1000$ W and $P_{UC\text{-}max} = -P_{UC\text{-}min} = 4000$ W. Another factor that shortens the life of the battery is very high and low SOC values. In order to increase the effectiveness of the storage devices and prolong their lives, SOC values are usually kept between %15 and %85 [17]. The limit values used in proposed hybrid energy storage are as follows:

$$P_{Bat\text{-}min} < P_{Bat} < P_{Bat\text{-}max}$$

$$P_{UC\text{-}min} < P_{UC} < P_{UC\text{-}max}$$

$$SOC_{Low} < SOC_{BAT} < SOC_{High}$$

$$SOC_{Low} < SOC_{UC} < SOC_{High}$$

The difference between PV generation and house consumption is used as a main variable to control hybrid energy storage system. When PV generation is more than demand, capacitor and battery are charged respectively. In times of high consumption, the battery and the capacity are discharged respectively. The main purpose of this control strategy is to use ultracapacitor in case the consumption is high. The basic control steps of the hybrid storage system are as follows:

1) If $P_{Demand} - P_{PV} \leq 0$ is the state that the generated power is more than the consumed power. At this stage, firstly the ultracapacitor and then the battery are charged. If the batteries are full, the generated excess energy is given to the grid.

**if** $SOC_{UC} < SOC_{High}$

$P_{Charger} = P_{PV}$

$P_{Inv} = P_{Demand}$

**elseif** $SOC_{UC} \geq SOC_{High}$

$P_{Charger} = P_{Demand}$

$P_{Inv} = P_{Demand}$

**elseif** $SOC_{Bat} \geq SOC_{High}$

$P_{Charge} = P_{PV}$

$P_{Inv} = P_{PV}$

2) If $0 < P_{Demand-PPV} < P_{Bat-max}$, is the power range that the demand is more than generation, and the surplus demand is supplied only by the battery. In case the battery charge is insufficient, ultracapacitor meets the demand. If the SOC of the ultracapacitor is insufficient, only the generated energy is given to the load, and the remaining part is supplied from the grid.

$P_{Inv} = P_{Demand}$

**if** $SOC_{Bat} > SOC_{Low}$

$P_{Charge} = P_{Demand}$

**elseif** $SOC_{Bat} \leq SOC_{Low}$ && $SOC_{UC} > SOC_{Low}$

$P_{Charge} = P_{PV}$

**elseif** $SOC_{UC} \leq SOC_{Low}$

$P_{Charge} = P_{PV}$

$P_{Inv} = P_{PV}$

3) If $P_{Bat-max} \leq P_{Demand-PPV} < P_{Bat-max} + P_{SC-max}$, is the state that battery is insufficient for meeting the surplus consumption. In this situation, battery is charged in high limit value, and the remaining energy is supplied through ultracapacitor. In case the charge of the battery is exhausted, the consumption surplus is met completely by ultracapacitor. If the charge of the ultracapacitor is insufficient, then only the generated energy is given to the grid.

$P_{Inv} = P_{Demand}$

**if** $SOC_{Bat} \geq SOC_{Low}$ && $SOC_{UC} > SOC_{Low}$

$P_{Charge} = P_{PV} + P_{Bat-max}$

**if** $SOC_{Bat} \leq SOC_{Low}$ && $SOC_{UC} > SOC_{Low}$

$P_{Charge} = P_{PV}$

**elseif** $SOC_{UC} < SOC_{Low}$

$P_{Inv} = P_{PV}$

Ultracapacitor is utilized to meet high power demand in short term periods and battery is employed to meet low power demand long term periods as well as their stored energies are available. Because PV generation and house consumption have unpredictable characteristic, ultracapacitor has a priority in charge process and has a collateral role in discharge process. Thus, the hybrid storage system can meet high power demand in any time. Battery has high energy and low power density. Therefore, battery is employed to meet low power demand up to PBat-max. When the energy stored in the hybrid storage system is insufficient, utility grid support the MG to meet the remaining power.

## 3. Simulation results

The proposed model was tested in the Matlab/Simulink simulation program. The measurement values in the references [18] and [19] were used for daily PV electricity generation and domestic consumption respectively. The capacities of the PV system were determined as 1.5 kWp, the battery as 8 kWh, and the ultracapacitor as 3 kWh. The two-day PV generation and electricity consumption values are showed in Figure 3. Considering the bad weather conditions, solar generation of the second day is determined as the half of the first day. Due to the standby mode, household consumption never becomes zero. Consumption lives up to the maximum values at the times of working hours of the clothes dryer or oven.

The charge/discharge powers of the battery and ultracapacitor, and the changes of the SOC values are showed in Figures 4 and 5. When PV generation is more than the demand, firstly ultracapacitor is charged. The battery begins to be charged after the SOC values of the ultracapacitor reach at the maximum value. If the energy demanded from the hybrid storage system during the discharge process is less than 1000 W, only the battery is used. If it is more than 1000 W, ultracapacitor achieves to meet the demand. Since the energy density of the ultracapacitor is low, the SOC level lives a rapid decrease. However, the ultracapacitor is able to meet high power demands because of its high power density. The opposite situation is a matter of the battery. The fall speed in SOC is slow since it supplies a lower power of the load. This result indicates that the battery and the ultracapacitor make up for each other's weaknesses in a hybrid storage system.

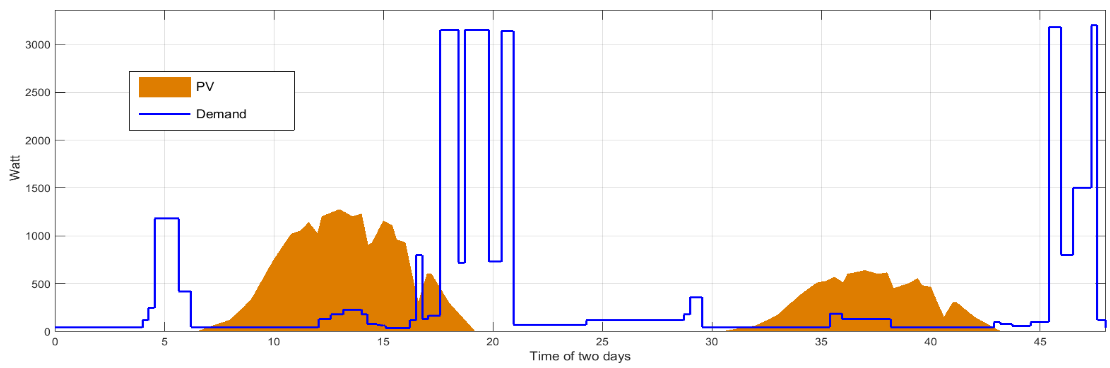


**Fig. 3.** PV generation and power demand for two days

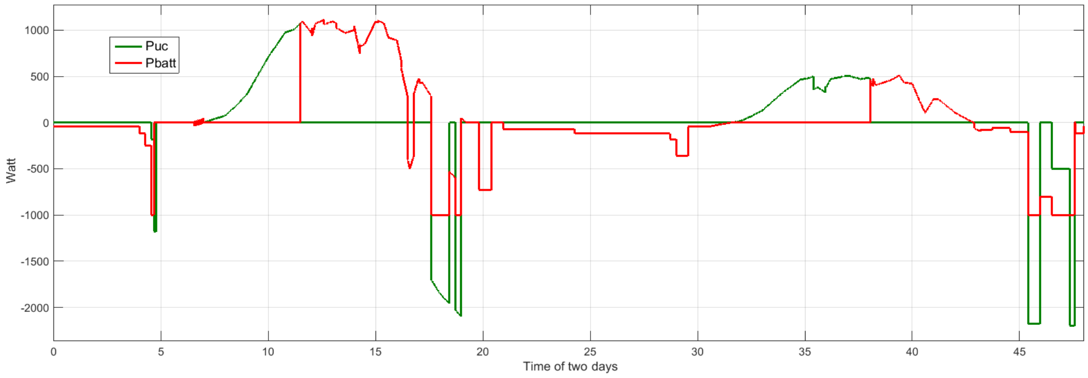


**Fig. 4.** Instant powers of battery and ultracapacitor during the two days

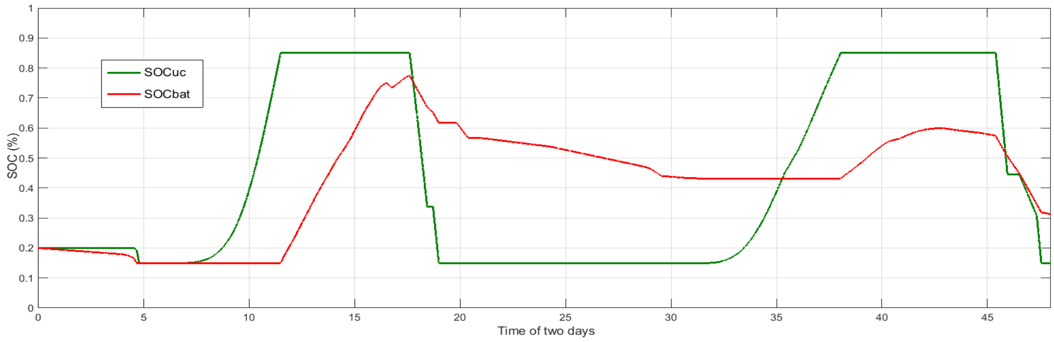


**Fig. 5.** SOCs of battery and ultracapacitor during the two days

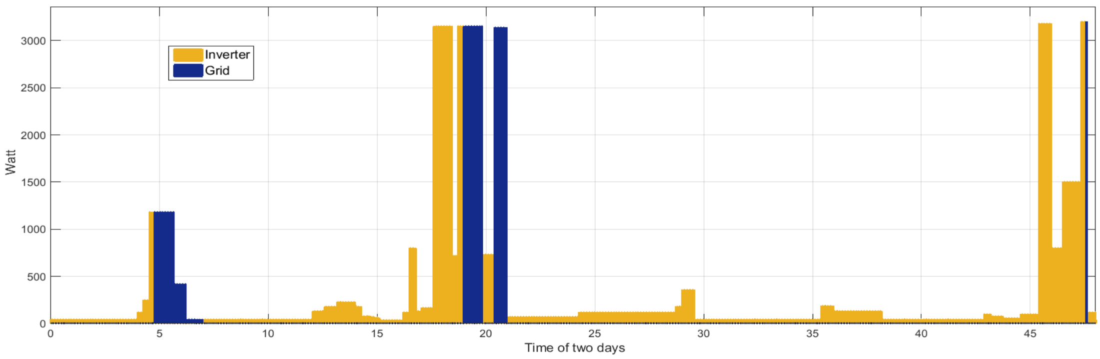


**Fig. 6.** The powers of MG (inverter) and utility grid during the two days

Figure 6 shows the powers of the PV system and the utility grid. On the first day when there is no PV generation, utility grid supplies the load because the stored energy is insufficient for meeting the demand. After the initiation of the PV generation, the demand is met completely from the PV system being stored of the generated excess energy. The stored energy falls short in the evening hours of the first day due to the fact that the demand is too high on that day. After the energy stored in the ultracapacitor is exhausted completely, the load is completely benefited from the grid as the battery is insufficient to supply it. At the hours when the demand is less than 1000 W, the grids are inactivated, and the load is benefited from the battery. On the second day, the demand and PV generation decrease according to first day. The battery has more stored energy at the beginning of the second day. The charge-discharge process of the hybrid storage system is similar to the first day. The energy taken from the grid on the second day is less than the one on the first day. During the simulation time, if the ultracapacitor has the stored energy, MG can achieve to meet all power demand of the house.

## 4. Conclusions

In this study, an analytic power control method is presented for a hybrid storage system consisted of battery banks and ultracapacitor unit. A grid connected domestic MG was utilized to design and test this method. The simulation results show that the ultracapacitor increases the power density in the hybrid storage system, and by this means, the stored energy is sufficient to meet the demand even at the hours when the demand is too high. It has been observed that after the energy stored in the ultracapacitor is discharged, the load is supplied from the grid at times when the demand is high and the load is supplied from the battery when the demand is smaller than $P_{Bat-max}$. If the sizes of the battery and ultracapacitor are optimized in accordance with to the load, hybrid storage systems can improve the effectiveness of the PV systems in terms of the meeting house demands.

## 5. References


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