Development of a Hybrid Energy Storage System Composed Battery and Ultracapacitor Supplied from Photovoltaic Power Source for 3-phase 4-wire Smart Micro Grid Structure

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Abstract:
Solar, wind and other renewable energy sources are becoming an important part of energy supply to the power grid. Integrating a Hybrid Energy Storage Systems (HESS) with renewable energy sources can make these intermittent renewable energy sources more dispatchable. The HESS will play a vital and large role in renewable energy based 3-phase 4-wire grid connected electrical power infrastructure. Because renewable energy is not constant (aside from hydroelectricity) and intermittent, the energy produced from the renewable energy needs to be conserved and used at appropriate times. The proposed HESS made from an ultracapacitor bank and a lead-acid battery bank connected to the 3-phase 4-wire electrical power grid. This process acts as a pilot project for future large scale smart grid applications. The proposed system will be investigated with a capacity sizing estimation of the energy storage system supported by PV based renewable energy source. The energy state modes of the HESS are given demonstrated by simulation results in this study.

Keywords: Solar energy, hybrid energy storage, 3-phase 4-wire network, smart grid.

1. Introduction

Nowadays, renewable energy has been more and more attractive due to the severe environmental protection regulations and the shortage of conventional energy sources. Photovoltaic (PV) generation is the technique which uses photovoltaic cell to convert solar energy to electric energy. Photovoltaic energy is assuming increasingly important as a renewable energy source because of its distinctive advantages, such as simple configuration, easy allocation, free of pollution, low maintenance cost, etc.

However, the disadvantage is that photovoltaic generation is intermittent, depending upon weather conditions. Thus, energy storage element is necessary to help get stable and reliable power from PV system for loads or utility grid, and thus improve both steady and dynamic behaviors of the whole generation system [1-4].

This paper studies the hybrid energy storage system that combines the solar energy source and a rechargeable battery and ultracapacitor. In a typical configuration of the direct current (DC) coupled battery and ultracapacitor hybrid energy storage system, solar power source and the battery are connected to a DC bus through an DC/DC boost converter and a bidirectional converter, respectively.

To increase reliability, energy storage systems within a microgrid are essential. Energy is stored while in gridconnected mode, when the microgrid's distributed generation (DG) systems produce excess power, to be used later to supply critical loads during power outages [5-7].

2. Hybrid Energy Storage Systems (HESS) and 3-phase 4-wire Smart Micro Grid Structure

Many kinds of storage devices can be used in the micro grid and each device has its own character, which has been showed in Figure 1. Flywheels and fuel cells are expensive and they are also not available in harsh environments which will exist in different kinds of microgrids.

Conventional capacitors energy density is too low to be used to adjust a micro grid system. Battery and ultracapacitor have been finally chosen in this paper to form the energy storage system, taking advantage of the batterys high energy density and the ultracapacitors high power density, which has been displayed in Figure 1 [8-9].

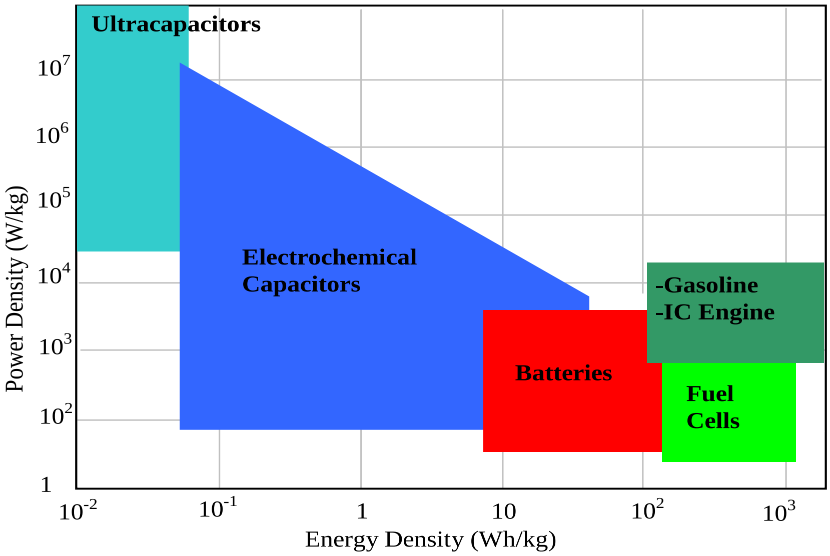

Figure 1. Comparison of different storage devices [7]

Traditionally, the lead acid battery is the most popular energy storage device due to its low cost and wide availability. However, DG system is not an ideal source for battery charging as the output is unreliable and heavily dependent on weather conditions. The charging/recharging frequency of the batteries is increased and the batteries are often deep discharged, which damages the battery and shortens its service life. In addition, the battery stores energy by electrochemical reaction and it has a lower power density, which makes it cannot compensate a large power for the load over a short period of time. The ultracapacitors, which stores energy by physically separating positive and negative charges, becomes a good candidate to provide a convenient and reliable power source for DG systems. Its service life is much longer than the battery and it can tolerate voltages up to the devices maximum voltage rating. Another advantage that the ultracapacitor has over a battery is its fast charge/discharge time and its ability to be stored at any state of charge. The ultracapacitors can work better than the battery in extreme conditions [10].

PV panels work as a current source to provide appropriate energy. When the micro grid is interconnected to the main grid, PV panels also works under MPPT mode as a current source. DC/DC bidirectional converter becomes a rectifier to provide energy for the DC bus and the energy storage system from the main grid. The battery bank is controlled to discharge properly, until they are totaly discharge [11]. By utilizing battery and ultracapacitor in a hybrid energy storage system as shown in Figure 2 the battery size can be reduced and a higher State of Charge (SOC) can be maintained. The ultracapacitor has a greater power density than the battery, which allows the ultracapacitor to provide more power over a short period of time. Conversely, the battery has a much higher energy density when compared to a ultracapacitor allowing the battery to store more energy and release it over a long period of time. In the hybrid system the peak power requirements of the load are supplied by the supercapacitor and the battery supplies the lower continuous power requirements [12-14].

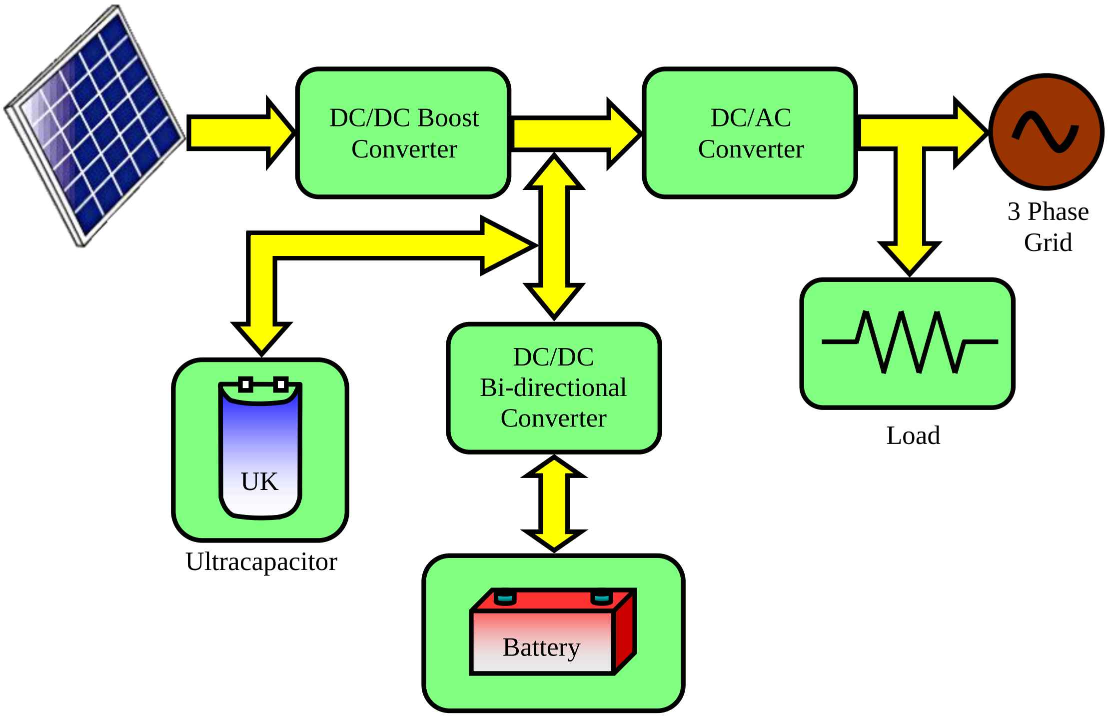

Figure 2. Hybrid energy storage system in micro grid

PV array, grid, battery, ultracapacitor and load parameters used in the simulation model are given in Table 1.

Table 1. System parameters

Parameters		
PV Array	Open Circuit Voltage (V_{oc})	228.9 V
	Short Circuit Current (I_{sc})	23 A
	Voltage at MPP (V_{max})	185.25 A
	Current at MPP (I_{max})	21.6 A
Grid	Voltage (V_{gabc})	110 V_{rms} /L-N
	Frequency (*f*)	50 Hz
	Impedance (R_f, L_f)	10mΩ, 59µH
Battery	Battery Type	Lead-Acid
	Nominal Voltage (V_{bat})	120 V
	Rated Capacity (Ah)	105 Ah
Ultracapacitor	Ultracapacitor Voltage (V_{uc})	405 V
	Ultracapacitor Capaticy (*F*)	2.14 *F*
Load	Resistance	19.37 Ω

3. Simulation Results

In this paper, to build an effective energy buffer to compensate for the mismatch between generated and required power in a DG system, a hybrid energy storage system is built. It is composed of batteries and ultracapacitors, which connected in parallel the DC bus. It could make the best use of the high energy density of battery and the high power density of ultracapacitor. Furthermore, the capacity of the batteries could be decreased nearly a half so the charging/recharging cycle of the batteries could be reduced. Figure 3 shows the energy flow diagram $P_{pv} > P_{load}$ status. In this case, PV generated power is greater than the load power. So the PV power are fed all the load and charges the battery. If there is a remaining power which is transferred to the grid. When a sudden increase occurs in load power, ultracapacitor starts to provide the load contributively the battery.

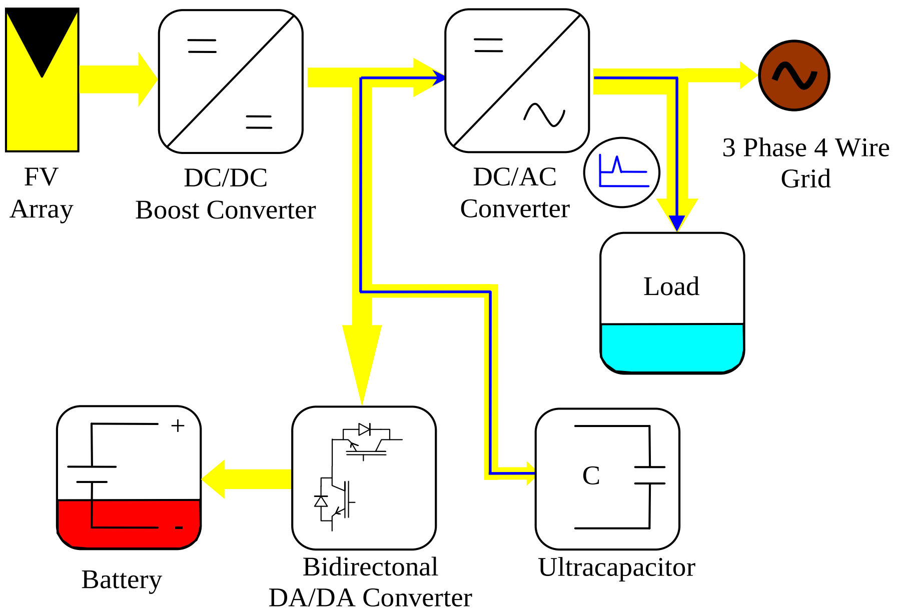

Figure 3. The energy flow diyagram for $P_{pv} > P_{load}$ status

In Figure 4, PV panel, battery, sum of PV and battery current can be seen respectively. PV panel current is 15 A approximately. This current rate is enough to supply load demand and battery charging. Battery charges with 4.5 A and remaining current which is nearly 10.5 A supply the inverter unit.

In Figure 5, alternative current (AC) part of the hybrid system is discussed. Peak current of the load is 8 A can be seen in Figure 5(a). Peak current of the inverter unit is 10.5 A shown in Figure 5(b). Inverter unit supplies the all load and provides power to the grid. Providing current value to the grid is 2.5 A approximately. In this simulation study, because of using the hysteresis current control, in low current condition, distortions are pronounced as grid current figure.

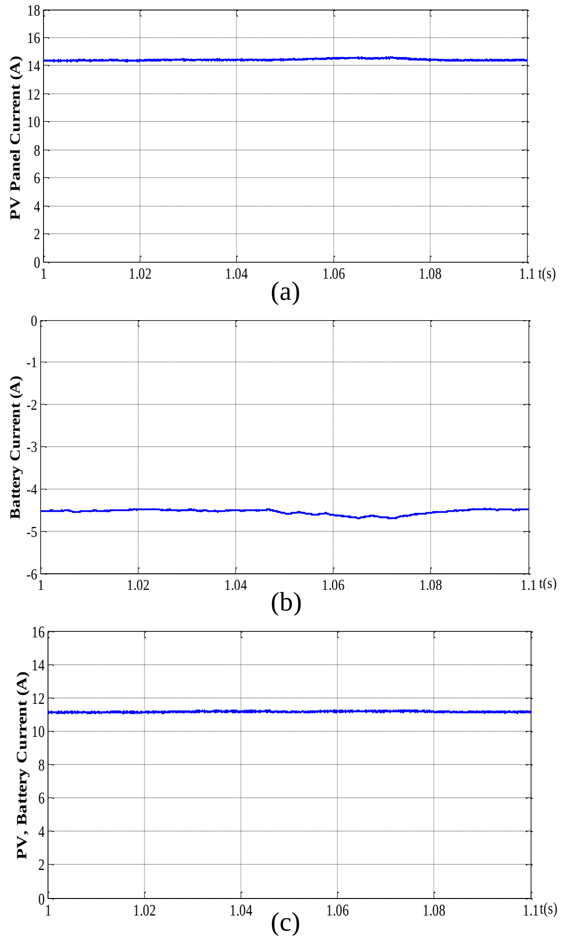

Figure 4. $P_{pv} > P_{load}$ in case, a) PV panel, b) battery and c) PV+battery currents respectively

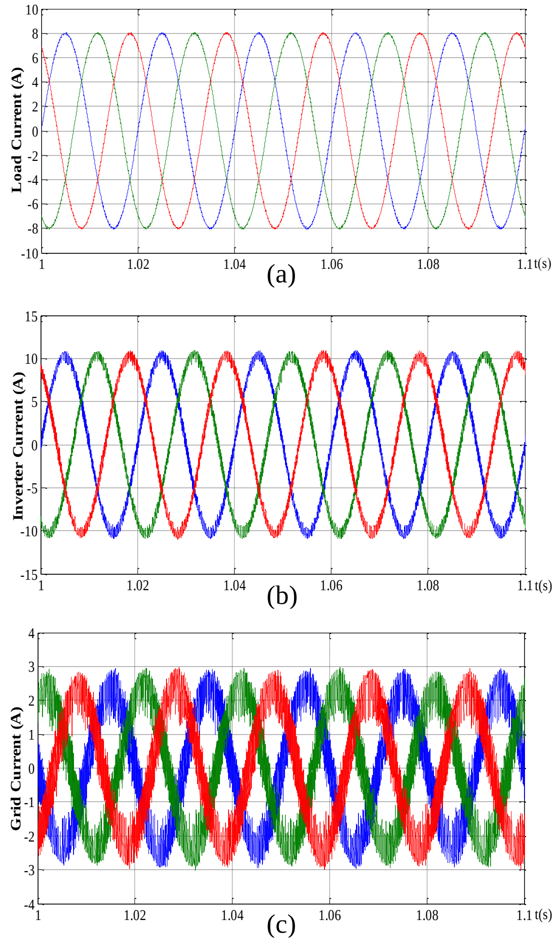

Figure 5. $P_{pv} > P_{load}$ in case, a) load, b) inverter and c) grid currents respectively

In Figure 6(a), PV panel current is about 14.5 A. In this situation, load current suddenly rises in 1.5 second. This rises couldn't provide by PV panel alone. So battery condition changes from charging mode to decharging mode. Accrual of the load is very fast so response time of the battery unit is slow, can be seen in Figure 6(b). But ultracapacitor can be supply the load current quickly as recommended HESS drawn in Figure 6(c). This situation prevents the drop of the DC bus voltage in the system. Besides, battery cycle life is increased. Load current demand, inverter and grid currents can be seen in Figure 7 respectively.

Demand current of the load increases as well as inverter current drawn in Figure 7(b). Because of the long response time of the inverter, it is hard to supply the load which requires high power demand. In this case, the part of the increasing load current is supplied by the grid. Referring to Figure 7(c), the power flow is from inverter to grid in the first case between 1.47 to 1.5 second. After 1.5 second, while increasing the load current demand, inverter and grid supply the load together.

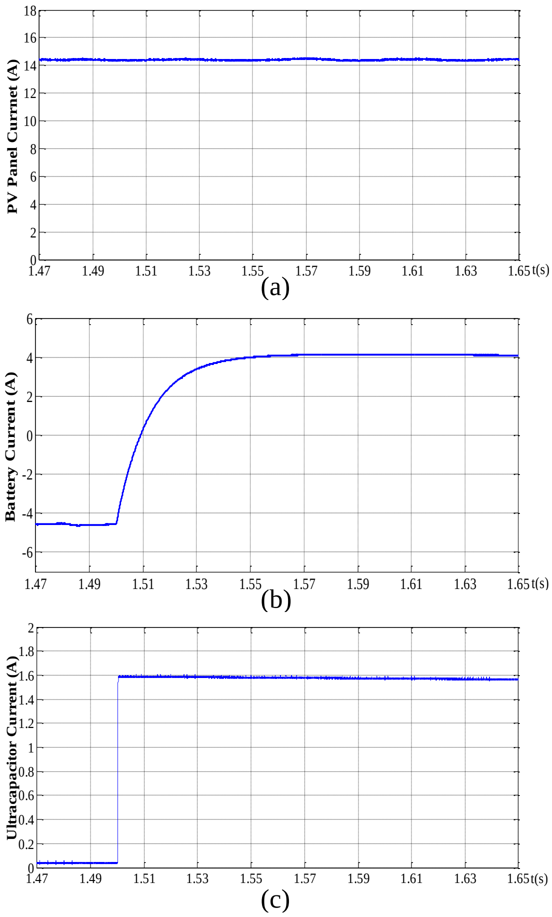

Figure 6. $P_{pv} > P_{load}$ changing load in case, a) PV panel, b) battery and c) ultracapacitor currents respectively

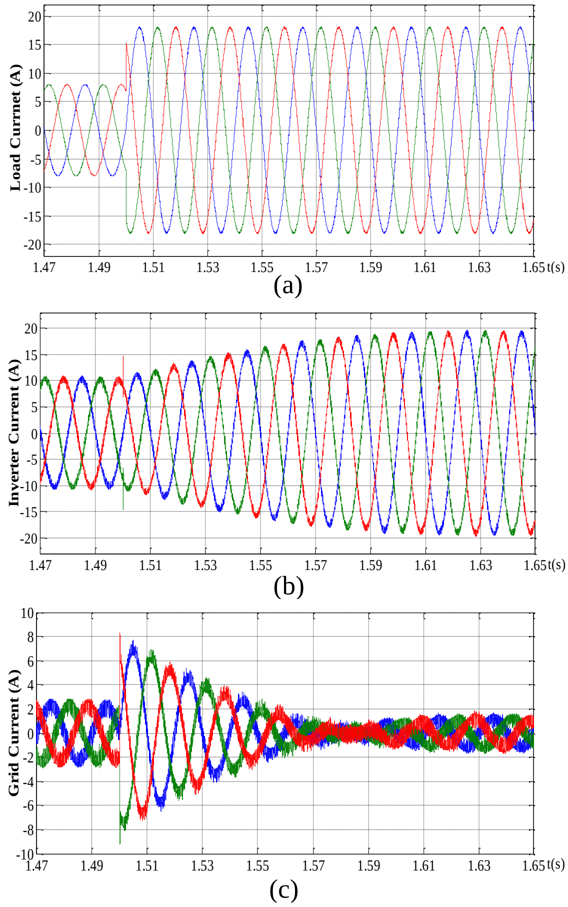

Figure 7. $P_{pv} > P_{load}$ changing load in case, a) load, b) inverter and c) grid currents respectively

4. Conclusion

In this study, a 3-phase 4-wire grid connected HESS composed from battery and ultracapacitor banks simulation study were performed. First, the battery's and ultracapacitor's working together condition was investigated. According to the results, it was observed that ultracapacitor is faster then the battery while high power demands occur. Also, increasing of the battery life predicted in this case. From grid side, inverter couldn't be response quickly. But, when including the ultracapacitor and battery to the system, drop of voltage in the grid start to decrease. The lack of distortion in grid voltage affects power quality positively.

The black out situation is the big problem in electrical network. If the energy demand is bigger than the energy supply, black out occurs. As a result of black out, a part of the electrical network becomes unusable. Smart micro grid structure could prevent this event. When stability of the grid break down, system can be restabilized by commissioning a large number of smart micro grids.

5. Acknowledgements

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6. References

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