International Journal of Research
Available at https://edupediapublications.org/journals
e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 05 Issue-01
January 2018

Three-Phase Grid Connected Solar Powered Battery- Super Capacitor Based Hybrid Energy Storage System

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Abstract:

The power generation from renewable power sources is variable in nature, and may contain unacceptable fluctuations, alleviated by using energy storage technique. The cost of batteries and their limited lifetime are serious disadvantages. Solve these problems; improvement consisting in the collaborative association of super capacitors and batteries has been studied. The Super capacitor-Battery based hybrid energy storage systems are a popular choice for the battery lifetime extension and system power enhancement. The Battery ESS is characterized by high energy density, low power density, degradation due to frequent and partial charge/discharge cycles. By incorporating SC ESS which has high charge/discharge rates, a system having both high energy and power capabilities can be designed. The proposed scheme is validated by detailed simulation and experimental results.

Keywords

Super capacitor, Battery, Photovoltaic Cell, Hybrid Energy Storage Systems, Inverters, Energy Storage system, etc

1. Introduction

In order to deal with the projected energy requirements, and address the environmental concerns through the integration of more renewable energy sources, the current electric power grid is required to undergo essential modernization. In order to help meet 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. Moreover, energy storage systems, as backup power, can be essential for system stabilization services and emergency preparedness. Pursuit of a renewable energy future is inspiring significantly increased efforts for global energy storage installations.

Among all the renewable energy sources, solar energy and wind energy are environmentally friendly and the fastest growing green energy sources, but main drawback of PV system is that power produced by these systems are highly dependent on climatic conditions. PV system intermittently produces power so PV system may not satisfy load demand at each instant. However above problem can be solved by combining PV system with other renewable energy sources and/or energy storage systems like wind, wave, fuel cell, battery bank, ultra capacitor bank, and hydrogen storage tank in a suitable hybrid framework.

In this project we have used combination of two energy storage systems, one of them is used to fulfill high power demand, fluctuating loads demand. Hence we are using super capacitor for this purpose which has high efficiency, large cycle life and rapid response time. The second energy storage system is used to fulfill high energy demand and we are using battery for this purpose which have low self discharge rate and installation is inexpensive. Primary benefits of HESS are: Reduces expenditure in comparison to single storage system, Higher system efficiency than single ESS, Storage is increased and lifetime is raised. Battery and super capacitor are integrated to form a basic structure of HESS. Here super capacitor provides peak power for small duration and battery provides average power for longer duration.

2. Solar Cell

Solar energy is one of the widely used renewable energy source. Large group of peoples are using solar energy in now days and this energy is used by most peoples in older days also with different methods. There are many renewable energy sources are available on earth such as solar energy, wave and wind power, biomass, and hydroelectricity etc.

Solar photovoltaic system converts solar energy into electrical energy. Solar energy is only used in very definite applications through human creativity. To harvest the solar energy the most common way is to use a photovoltaic panel which converts the energy obtained from the sun in the shape of photons into electrical energy. Photovoltaic system can work as either passive solar or active solar cell depending on allocation of solar energy or the technique of conversion.

Solar panels and solar thermal collectors are used for collecting energy in case of active solar system. The selecting materials with favorable thermal mass or light

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dispersing properties and space architecture with natural air circulation are used for passive solar system.

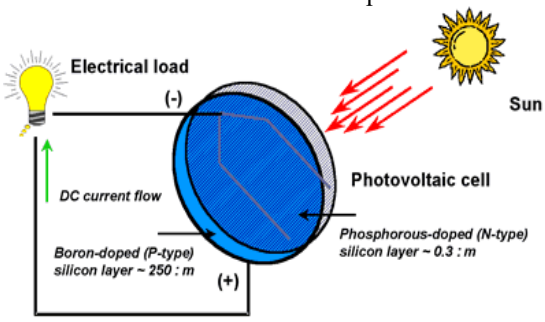

Figure 1, Photovoltaic Cell System

3. Battery Storage

In HV applications, the total energy stored and the weight of the battery unit is considered to be important technological aspects, another important factor is the cost of the batteries. The total storage of energy in a battery usually follows the weight and volume more or less linearly. The linear factors are called 'energy density' [Wh/L]. The highest power a battery can deliver is also limited and is, similar to energy, measured in 'power density' [W/L].There are a number of different battery types on the market today, some of them more established and some more new and modern. For high power application there are two major technologies of interest, namely the NiMH and the Li-Ion.

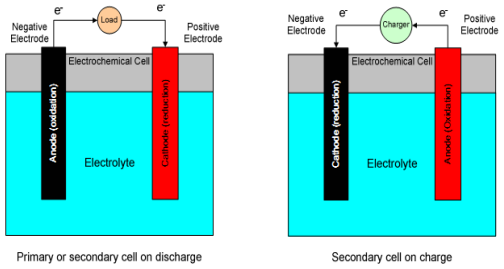

Figure 2, Functioning of an electrochemical cell on charge and discharge

4. Super Capacitor Storage

Basic construction of super capacitor consists of two electrodes, an electrolyte and a separator. Due to transition of charge between electrode and electrolyte, energy is stored in the super capacitors. Energy storage in super capacitor depends on the following factors, (a) surface area of electrode and electrolyte, (b) ion size, (c) decomposition voltage of electrolyte. In super capacitor electrodes are made of activated carbon and it provides large surface area. Super capacitors characteristics lies between battery and capacitors, it have high energy density than capacitors but it is lower than battery also it have high power density than battery. Therefore it is used in the application where heavy power demand is required for small duration because it have high power density but fast self discharge rate.

The lifetime of super capacitors is virtually indefinite and their energy efficiency rarely falls below 90% when they are kept within their design limits. Their power density is higher than that of batteries while their energy density is generally lower. However, unlike batteries, almost all of this energy is available in a reversible process. Typical construction of a super capacitor: 1. Supply 2. Plates of collector 3. Electrodes 4. Double layer 5. Solution of positive and negative ions called electrolyte 6. Separator

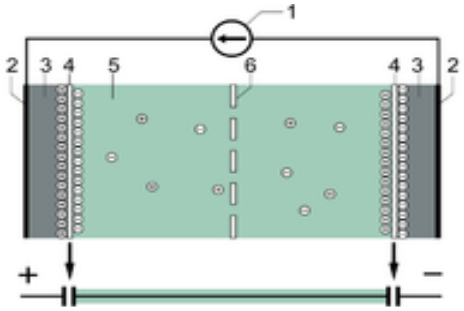

Figure 3, Super capacitor storage

The capacitance of a capacitor is closely related to the surface area of the electrodes and the distance between them, the capacitance can physically be described as.

$$C = \frac{\varepsilon A}{d}$$

Where ε is the permeability of the dielectric between the electrodes

5. Simulation And Results

The proposed method has been simulated with a MATLAB/Simulink model. The Simscape toolbox contains power electronics symbols that include semiconductor parameters for simulating switching losses, conduction losses and transients. The experimental results of solar based storage system using battery and super-capacitor given blow,

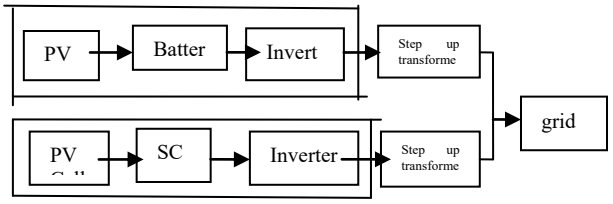

Figure 4, Block diagram of Three Phase Grid Connected Solar Powered Super Capacitor-Battery Based Hybrid Energy Storage System.

In this block diagram, Super capacitor storage system and battery storage system is used to form hybrid energy

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storage system. Here battery and super capacitors are charged with the help of solar energy and connected in parallel with each other. Super capacitor and battery based hybrid energy storage system is used as back up or emergency power supply and it is connected to the three phase grid through three phase feeders lines. This storage system can supply power to the loads connected to the grid in case of emergency when grid is unable to fulfill the load demands. Step up transformer is used enhance the power of the storage system to make it compatible with the three phase grid.

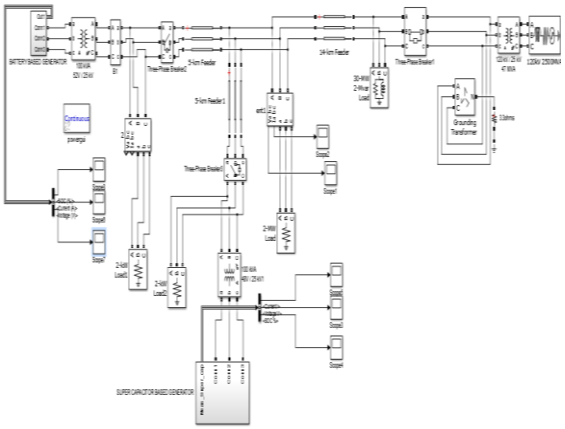

Figure 5, Complete Simulation Model of Three Phase Grid Connected Solar Powered Super Capacitor-Battery Based Hybrid Energy Storage System.

Figure 5 shows the complete simulation diagram of the three phase grid connected HESS, here solar powered battery storage block and solar powered Super capacitor storage block are connected in parallel to form an hybrid energy storage system (HESS). These blocks are connected to the three phase grid through step up transformer and used as back up power supply.

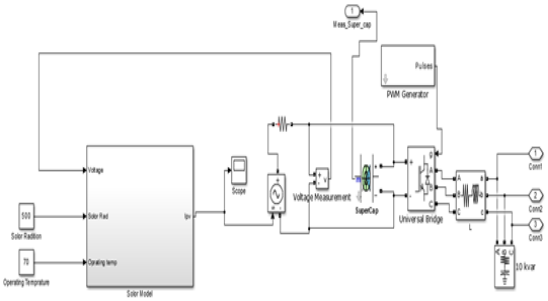

Figure 6, Solar based super capacitor sub system

Figure 6 shows the simulation diagram of the solar based Super capacitor storage, here super capacitor is charged by DC voltage equivalent of the output photovoltaic current of the solar cell with the help of current equivalent voltage source block and output of Super capacitor is converted into AC quantity by using three phase inverter and supplied to the three phase load.

Table 1, Super Capacitor Parameters

S.No.	Parameter	Value
1	Rated Capacitance (F)	99.5
2	Equivalent DC Series Resistance (Ohms)	8.9 *10-3
3	Rated Voltage (V)	48
4	Number Of Series Capacitors	18
5	Number Of Parallel Capacitors	4
6	Initial Voltage (V)	48
7	Operating Temperature (Celsius)	25

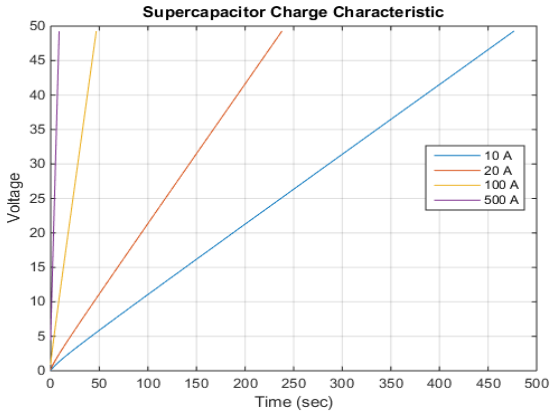

Figure 7, Super capacitor charging characteristics

- **Super capacitor Simulation Results:**

Figure 8 and 9 shows the simulation results of the super capacitor current and voltage waveform with respect to time. In below diagrams it is shown that Super capacitor current and voltage are zero from time interval 0- 0.049 secs because at that time three phase breaker at super capacitor side disconnects the solar powered super capacitor generator from rest of the circuit and three phase grid supply the loads connected to it. At time 0.049 sec Super capacitor is connected with the rest of the circuit and supply peak current requirement of the load.

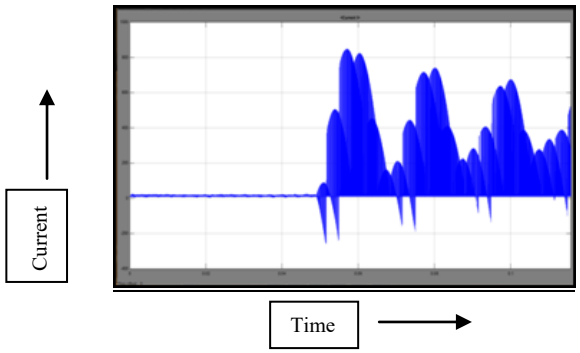

Figure 8, Super capacitor Current (amp) Vs. Time (sec)

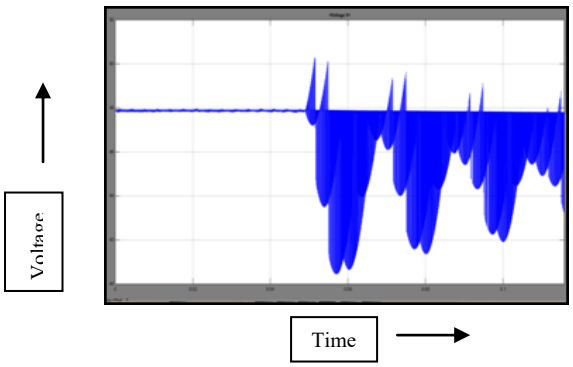

Figure 9, Super capacitor Voltage (volt) Vs. Time(sec)

- **Simulation Results Of Three Phase Load Voltage And Current wrt Time**

In Figure 10 and 11 Load Voltage and Current waveforms are shown below, where load is supplied by grid side generator from time 0 – 0.05 sec and from 0.05 -0.2 sec grid side generator is turned off with the help of Three-Phase Breaker at grid side and at time 0.049 sec solar based super capacitor and battery storage is turned on with the help of three phase breaker connected at Super capacitor and Battery end respectively so at time 0.05- 0.2 sec load is driven by these storages.

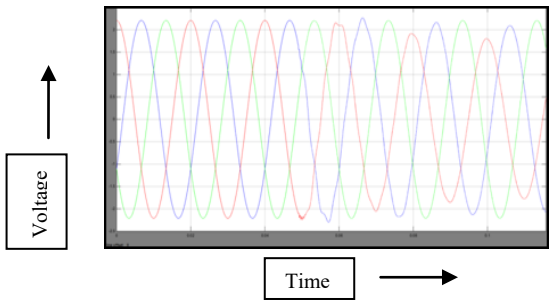

Figure 10, Performance Of Load Voltage (KV) Versus Time(sec)

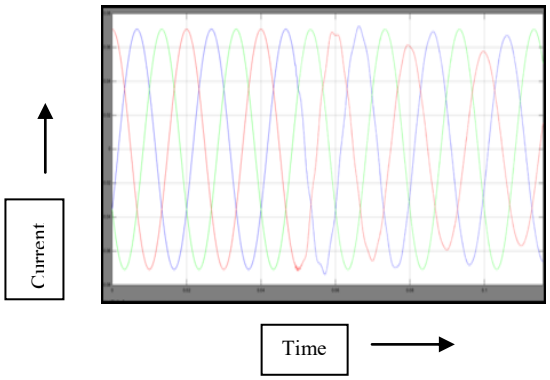

Figure 11, Performance Of Load Current (Kamp) Versus Time(sec)

6. Conclusion

Batteries and super capacitors are electrochemical energy storage media, but they are as different as night and day. Both are capable of energy storage and targeted energy release and yet there are major differences between the two. Batteries store very large amounts of energy that is released slowly but constantly. By contrast, super capacitors can only store small amounts of energy, but they release this energy much faster and more powerfully with large short-term peak currents. Battery cycle-life is increased that can be achieved using a power-filtering control strategy to the distribution of power between the super capacitor and the battery.

The low frequency power component was managed by battery storage system while the high frequency component was managed by super capacitor. Results show to maintain the constant DC output voltage during change in PV generation and load demand. Hence, power balance between the generation and demand is achieved.

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