Influence of supercapacitor size on battery life and selection of optimal parameter for control strategies in hybrid energy storage system

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The problem with renewable energy sources exists with the efficiency in monitoring the required amount of electricity, on the one hand due to frequent load fluctuations, and on the other due to frequent changes in the amount of energy produced from renewable energy sources. Therefore, it is necessary to store the energy and that is the most critical part of the system and represents the focus of considerable scientific research. The nature of the energy obtained from the sun is intermittent which causes frequent oscillations in the energy produced. A battery exposed to this process has a reduced lifespan, so the investment becomes unprofitable. Therefore, hybrid systems have been developed that mitigate the effects of the nature of solar energy.

Structure of simulation system

System configuration

The simulation system consists of photovoltaic energy system (PVES) which have solar PV arrays, a maximum power point tracking (MPPT) controller, DC/DC Boost converter, DC link, hybrid energy storage system (HESS) and changeable DC load. The hybrid energy storage system consist of lithium-Ion battery bank, supercapacitor bank, and a bi-directional DC/DC converter associated with each bank. Solar PV arrays, HESS and changeable load are connected on DC link. Figure 1. shows the schematic diagram of the simulated system.

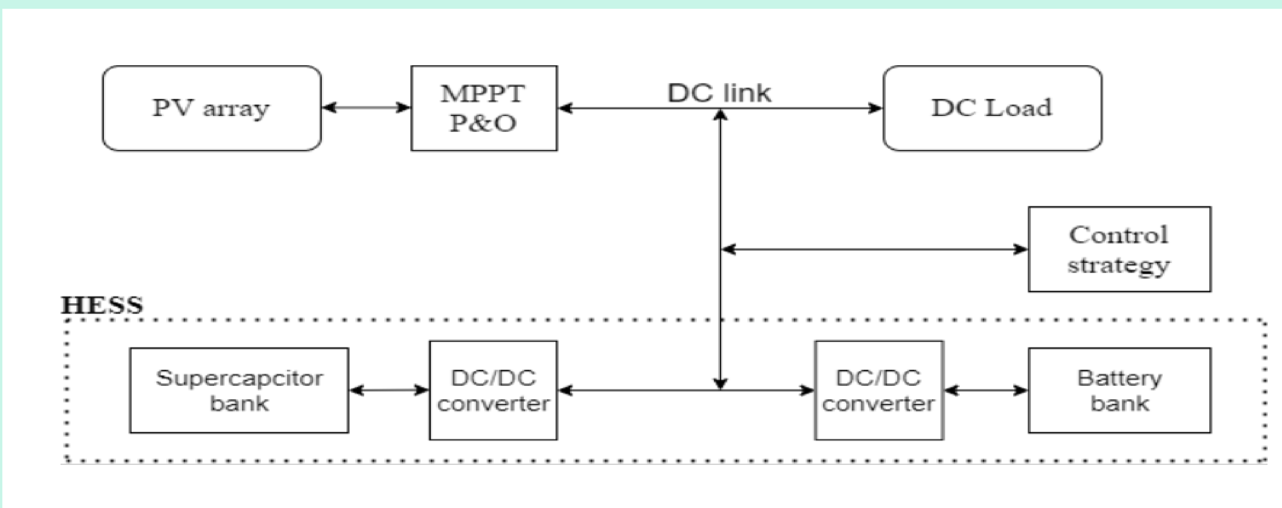

Figure 1. Schematic diagram of a simulated system.

Control of Photovoltaic energy system (PVES)

The output power of solar PV array depends on solar irradiation and cell temperature. The change in irradiation and temperature over time during the simulation is given in Figure 2. The photovoltaic (PV) array provides power to the unidirectional boost converter that is controlled by the Perturb and Observe (P&O) MPPT algorithm. Also, The Incremental Conductance (IC) MPPT algorithm is often used in practice. Both algorithms have some drawbacks but are good enough to extract the maximum power from PVES.

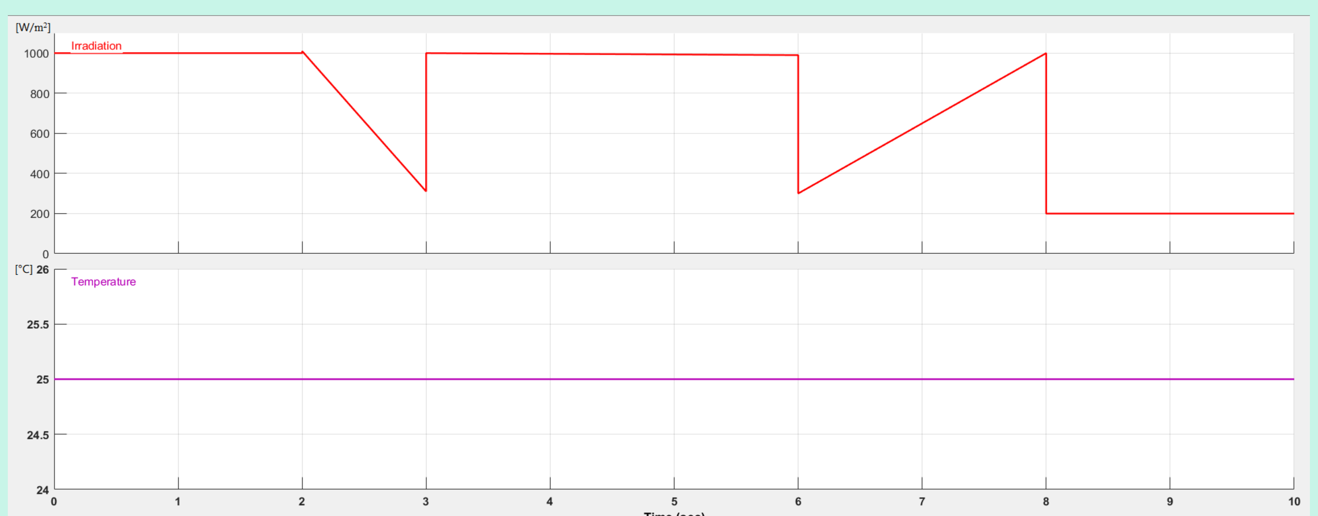

Figure 2. Irradiation and temperature diagram.

On the other side, the power delivered by the system is defined by a DC load that is variable and has two levels. The change in load over time is shown in Figure 3.

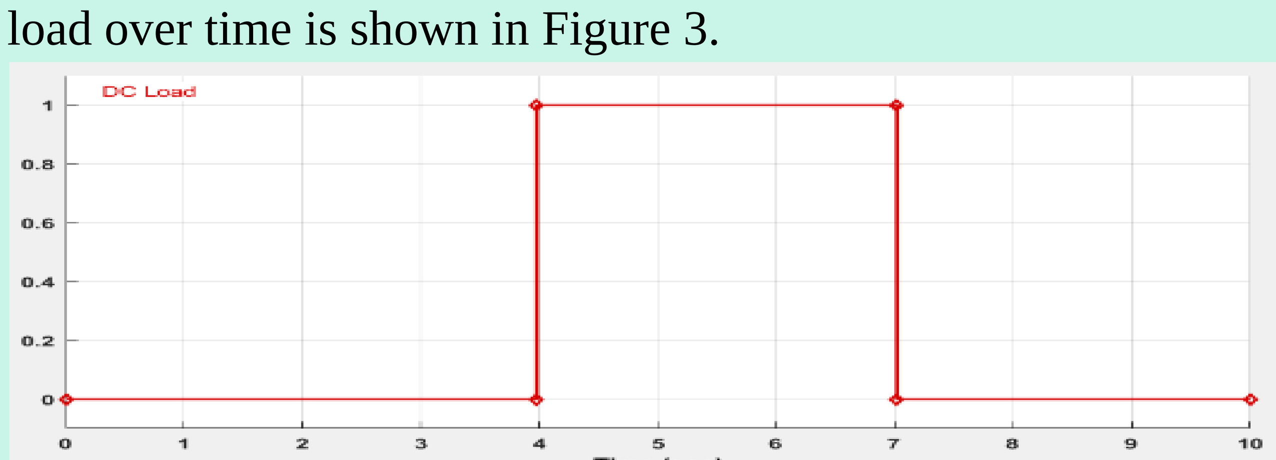

Figure 3. Change of DC load.

Control of HESS

According to the previously explained structure, HESS consists of a battery bank and a supercapacitor bank connected via bi-directional converters to a dc link. As HESS is used to control the power injection in grid. It is necessary to use DC/DC buck/boost converters here because DC/DC converter acts as a boost converter during HESS discharge mode and as a buck converter during HESS charge mode.

Power distribution according to the proposed strategy is based on the use of low pass filters (LPF). LPF divides the total current reference into low-frequency and high-frequency components. The applied strategy differs from the others in the way of calculating the current reference for SESS. The reference supercapacitor current is compared with the actual SC current and the error is given to the PI controller.

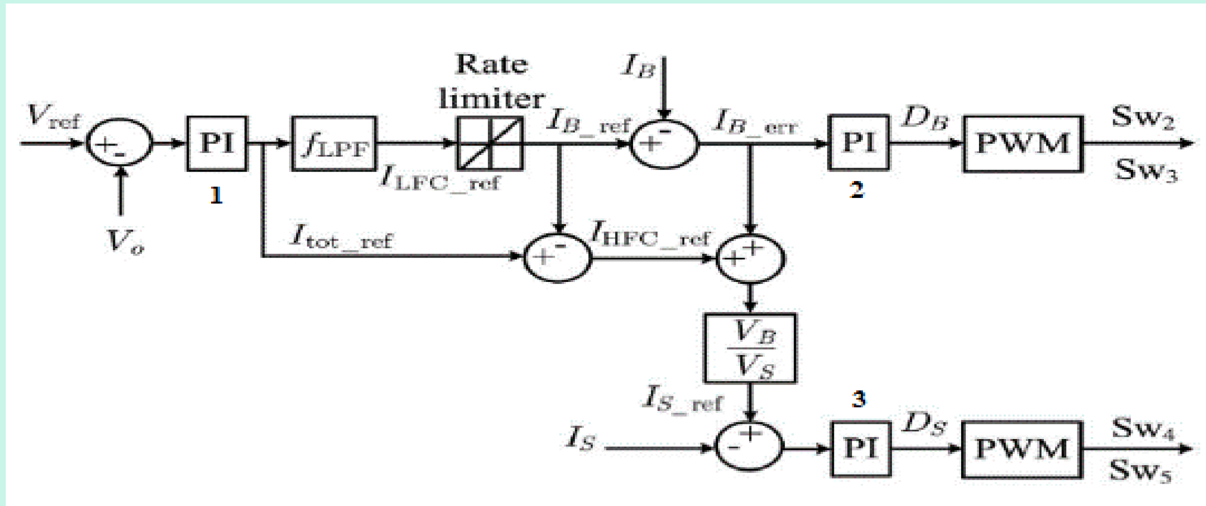

Figure 4. Control scheme of HESS.

The system is set up to simulate the intermittent nature of solar energy through variable irradiance, with a constant cell temperature. Also, load fluctuations are simulated by changing the load level as explained earlier. The parameters of the supercapacitor and the parameters of the control strategy were changed through 4 cases as shown in the next chapter.

Simulation results

The parameters of the elements of the Hybrid Energy Storage System (HESS) used in the simulation are: battery bank 14Ah, 24V and supercapacitor bank 30F, 32V. The simulation lasts 10s, because the goal was to monitor the output parameters of the system (primarily batteries as the most sensitive part) on a small sample of time, with frequent changes in energy production and consumption. The initial value of the time constant low pass filter was taken as T = 0.05.

Figure 5 shows a diagram of power flows through the elements of the system. In this example from case 1 it can be clearly seen how the elements of the HESS behave in relation to the produced and required energy.

The simulation results for the battery bank for case 1 are shown in Figures 6. The diagram shows the values of voltage, current, battery charge (SOC) and power during the simulation.

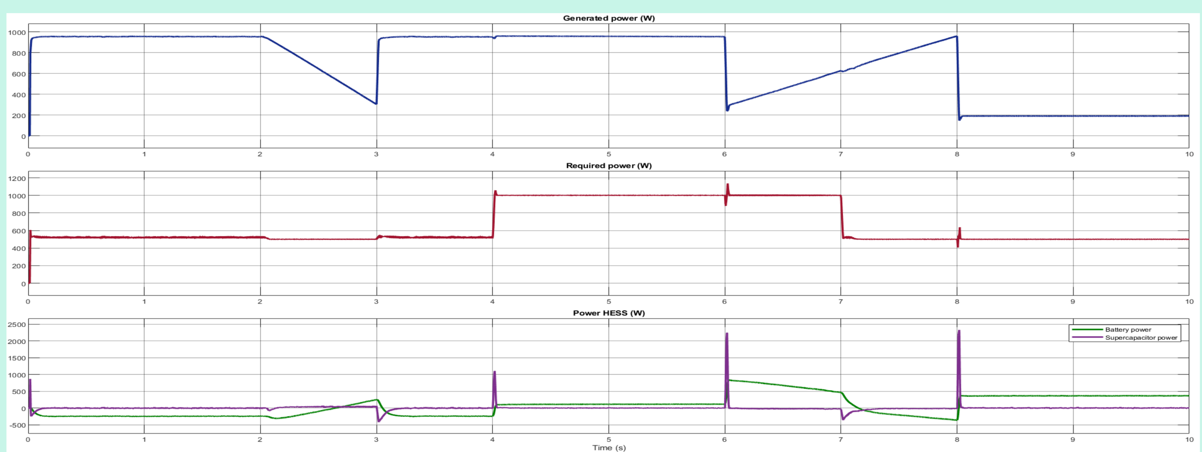

Figure 5. Simulation results for power flow in case 1

It is possible to notice that depending on the change of production and consumption, the battery bank adds energy to the system or charges its capacities in order to maintain a constant supply of energy.

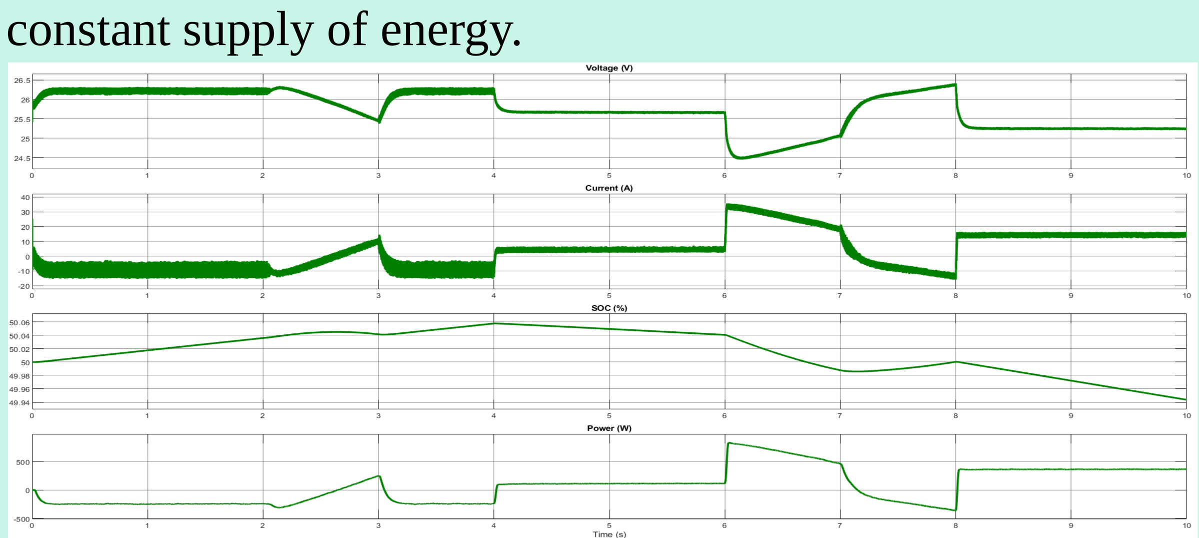

Figure 6. Simulation results for battery bank in case 1

Hybrid energy storage systems are designed to provide a longer life of the battery bank with the help of a supercapsitor bank due to the ability of the supercapacitor to charge and discharge quickly. In order to show the influence of the size of the supercapacitor bank on the observed parameters of the battery bank, several simulations were done with different sizes of the supercapacitor bank, and the characteristic one is shown in Figure 7 marked as case 2. The size of the supercapasitor bank, in this case, is 1500 F.

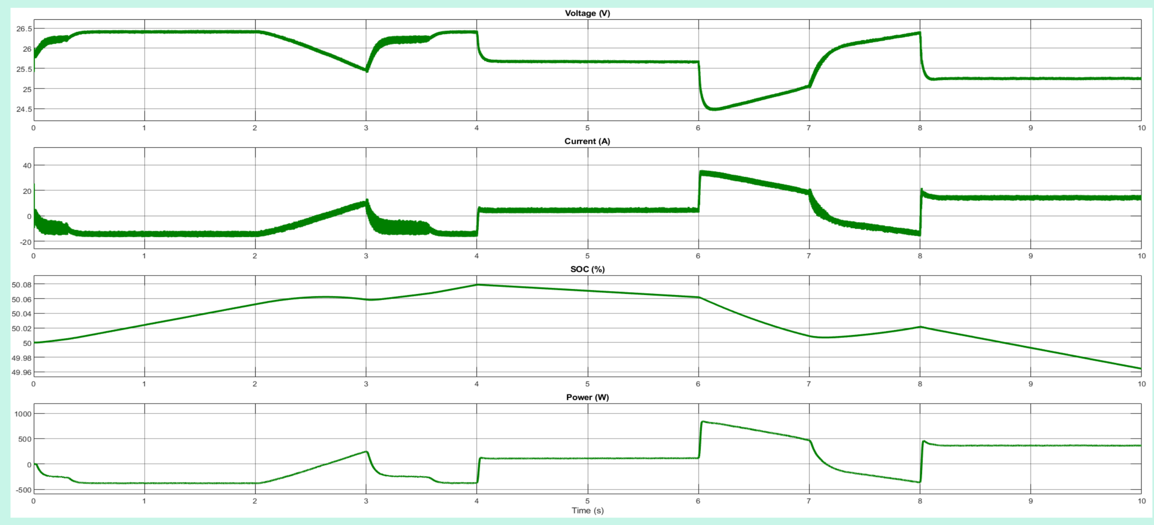

Figure 7. Simulation results for battery bank in case 2

The values of current in the moments of change (peaks) are lower by 10% and therefore there is a significant impact on the state of charge (SOC) of the battery, which would be 5% more charged in an hour of simulated activity than in the first case.. Also, in the period of 0-3 seconds and 3-4 seconds, the oscillations of the current are reduced. The values of current in the moments of change (peaks) are lower by 10% and therefore there is a significant impact on the state of charge (SOC) of the battery, which would be 5% more charged in an hour of simulated activity than in the first case. Also, in the period of 0-3 seconds and 3-4 seconds, the oscillations of the current are reduced.

The value of the time constant of the low pass filter crucially affects how much energy will flow through the battery and which through the supercapsulator Increasing the value of this parameter reduces the amount of energy that passes through the battery, and this allows the use of a battery that has a smaller capacity, without affecting the conditions in the system.

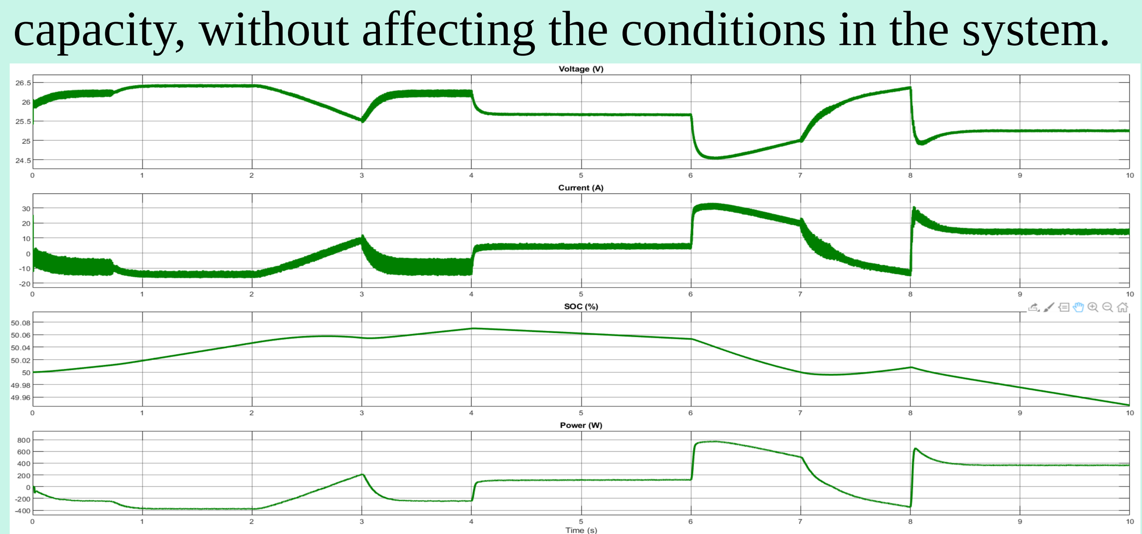

Figure 8. Simulation results for battery bank in case 3

Figures 8 and 9 show diagrams with system parameters from case 1 but with changed time constants of the low pass filter. First, case 3 is shown where the time constant is T=0.1, then case 4 and T=0.015. An increase in the time constant contributes to a decrease in the oscillation of the current in the initial period and there is a decrease in the value of the current in moments of sudden changes (peaks) of the current. The time constant set in this way provides better conditions than in case 1, but not in relation to case 2.

In the diagram shown in Figure 9, it can be seen that in case 4 there are no large current oscillations in the initial period, as well as that the SOC is at the level as in case 2. The downside of this parameter setting is the current values in the peaks, which are higher than in the case of 2 and up to 20 percent. This is due to the reduction of the time constant of the low pass filter, which results in more of the energy passing through the battery bank

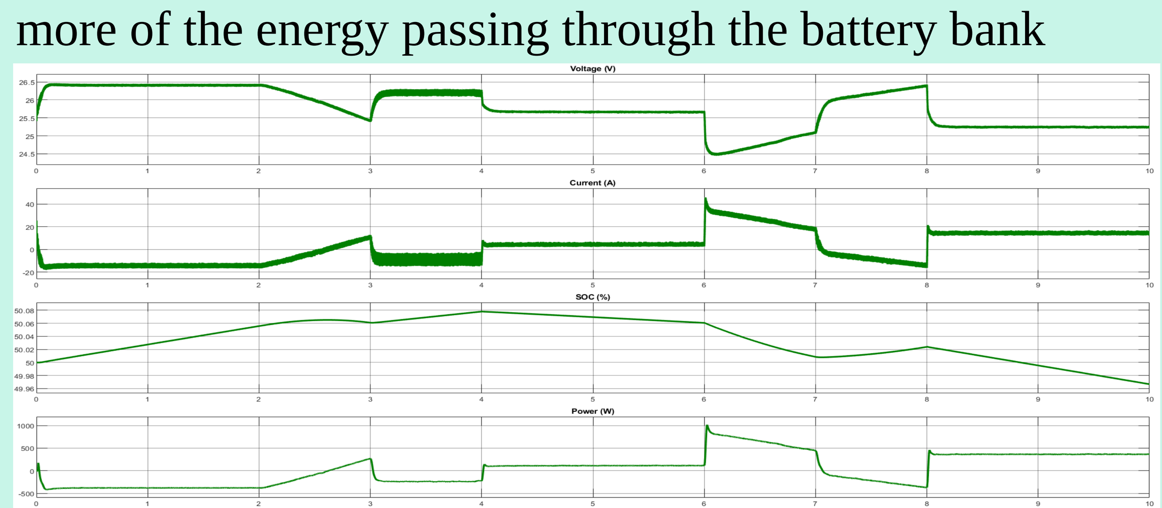

Figure 9. Simulation results for battery bank in case 4

Conclusion

Using the optimal size of battery and supercapacitor, as well as the optimal system parameters contributes to making the investment in the RES more profitable. As shown, increasing the capacity of the SC significantly improves the conditions in the battery bank, but due to the high price of the supercapacitor there are profitability limits up to which it is profitable to increase the size of the supercapacitor. The time constant of the low pass filter allows the allocation of power between battery and supercapacitor, which contributes to increasing the battery life, but only within certain limits.