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Analysis of Supercapacitor Banks Applied for Smart Cities

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Abstract Normally batteries are chosen for energy storage systems (ESS) because of their high energy density and low maintenance. However, batteries harm the environment, due to their disposal problem, since they are mostly made up of lithium ions. Thus, new clean alternatives energy storage systems are important. There are other devices for storing energy with some advantages and disadvantages as well. One of them is the supercapacitor. A set of supercapacitors is used to create a bank, and this bank may provide energy for a specific application. To explore this further option is crucial, because it might reduce the use of batteries in some situations, and as consequence, reduce the environmental damage. Even though supercapacitors do not have high energy density as batteries, perhaps in one situation with low consumption, a bank of supercapacitors are suitable. As to create devices for smart cities are necessary sensors and supply energy, maybe a bank of supercapacitors works well, due low consumption of some sensors. To confirm this hypothesis without further expenses, modeling tools are powerful to validated it. This simulation intends to obtain the curve of charging and discharging of two sorts of supercapacitor banks connected to photovoltaic (PV) source. In the final it was possible to prove that one sort of bank fits well for this certain application for smart cities providing energy around 2,7 hours.

Keywords: Supercapacitor Banks, Energy Storage System, Energy Supply;

1 Introduction

Usually, batteries are chosen for energy storage. This happens because they have high energy density and low maintenance. However, batteries have some disadvantages as well. Depending on their demand curve, and being used in a stand-alone solar system, batteries must be replaced each 3-5 years. Furthermore, using PV cells for supplying energy batteries reduces their lifetime. As PV sources are intermittent there are fluctuations of electric current in the output, providing unstable and unpredictable power, that could cause damage to the batteries. In addition, when a load requires a high amount of

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current in a short time, batteries also can be damaged, because they do not have high power density (Malek, Mustafa and Asry, 2019; Fahmi et al, 2015).

Besides, batteries cause environmental damage. For instance, the rechargeable lithium-based batteries are substituting nickel-cadmium and nickel metal hydride and have become the dominant energy supply in some electronics products due to Li-ion's superior energy density and slow discharge in idle mode. But lithium batteries contain potentially toxic materials such as copper, nickel and among others. And their high rate of disposal may contribute substantially to environmental pollution and adverse human health impacts (Silva, Afonso and Mahler, 2018).

However, there are some studies being made using hybrid energy storage systems (HESS) combining batteries and supercapacitors with the purpose of using the great features of each. As known, supercapacitors have huge power storage capabilities and batteries high energy density (Malek, Mustafa and Asry, 2019; Fahmi et al, 2015).

Then, it means that supercapacitors may not provide energy as batteries do. But, for any situation with low consumption, supercapacitors might be suitable. In this context, many Smart Cities applications could be considered in this scenario.

Smart Cities request Information Technology and Communication (IT&C). The intelligence of the city is created by interconnecting digital telecommunication networks, integrating into systems, sensors, physical components and software (Eremia, Toma and Sanduleac, 2017). In this context, these dispersed devices need energy supply.

There is a scenario for smart city already thought. A device that might be used either in urban zones or remote areas, more precisely at energy sector, collecting data and allowing correction of any eventual problem in the area faster and efficiently. This device, as mentioned above, constitutes of sensors and some physical components that needs energy supply for working.

Batteries could be the first option, however, considering all information presented in the previous paragraphs, it was wondering if other possibilities might be suitable and less harmful to the environment. Supercapacitors seem very interesting, but should require more information about them, for further analysis of their use as energy system storage for this application thought for smart cities.

Thus, this paper presents some PSCAD simulation results involving supercapacitor banks as ESS for Smart Cities, focused on to study when supercapacitors are enough to supply Smart Cities devices, without the need of batteries.

2 Methodology

The methodology used basically was, collecting information about ESS, such as pros and cons. After that, it was made a cost comparison on Brazilian websites between li-ion batteries and supercapacitors, whereby is possible to see one of the main reasons for using batteries on a larger scale is due to their low cost compared to supercapacitors (See table 1).

Table 1 Cost Comparison between li-ion battery and supercapacitor

Energy storage	Voltage(Volts)	Price(R$)
Li-ion battery model 18650 2600mAh	3.7	13,41
Supercapacitor 500F	2.7	49,00

At this point it was possible to obtain the technical specifications of the researched items such as, the battery has capacity dropped up 80% after 300 cycles (Eem3, 2010), and the supercapacitor supports up to 500000 cycles (Green-Cap, no date), under the circumstances tested by the manufacturer . However, with these definitions alone, it is not possible to affirm or refute the financial and technical viability of the supercapacitor in the long run, only the need for further study was confirmed.

It is important to highlight that there are two different ESS, and regardless some different properties, it is possible to do some comparison because the model of battery chose has information at the datasheet provided by the manufacturer about charge characteristics, using approximately the value of current used in the simulation of supercapacitor bank.

But, before simulating, there is a modeling part. For doing that, it was researched some materials in order of find some works already done and help building the project. More details will be shown afterwards in next section.

After modeling it was made the simulation. The last step was to compare the results.

3 Architecture and Simulation

The modeling developed in this paper is focused on specific application for Smart Cities, that involves supercapacitors bank as the only ESS, considering PV as the primary energy source. This way, the intermittence feature of PV is reduced. In the simulation context, this paper aims to obtain the charge and discharge curves of the supercapacitor banks and analyze the fit of this behavior in terms of the application considered.

The system simulated consists basically of a solar panel, supercapacitor bank, buck-boost converter and the load. Using resources provided by PSCAD, it was possible to represented solar panel, the supercapacitor banks, and the load, that at first should have a consume of 100mA and with a demanded voltage between 7-12V voltages. For the buck-boost converter and its controller it was used an already done model of a buck converter (PSCAD Q&A, 2014), making few adjusts in the architecture and in the controller for suiting in the application as a buck-boost converter (Sharma and Jain, 2014).

As the simulation should represent the real world, it was necessary to find properties of those components mentioned. After some research in the market and collected information about them, it was built the circuit to simulate. The solar panel chose has a size suitable and with reasonable value of current of 0.53A (SinoSola, no date). The bank consisted of six supercapacitors in series according to the properties found (Green-Cap, no date).

Thus, two sorts of supercapacitors bank were simulated. One bank has six supercapacitors of 120F each, second one six of 500F each. Each simulation was made separately, but, following the same architecture, just changing the part that represents the bank.

The single difference between both simulations is the bank of supercapacitors. As each supercapacitor has a capacitance, when connecting the 6 supercapacitors in series, will result in an equivalent capacitance. The formula used is:

$$(C_{eq})^{-1} = (C_1)^{-1} + (C_2)^{-1} + \ldots + (C_n)^{-1} \quad (1)$$

Where C_n represents capacitance of each supercapacitor and C_{eq} represents equivalent capacitance. As there are 6 supercapacitors and every supercapacitor in the bank has same capacitance, the formula is reduced to:

$$C_{eq} = C \div n \quad (2)$$

Where "C" is the capacitance and "n" is the total numbers of supercapacitors.

This means, according to formula 2, the capacitance equivalent of the bank of supercapacitors of 120F and 500F are respectively 20F and approximately 83.3F.

The schematic of the system that contains a bank of 20F is represented in figure 1, that was detached in four parts, and figure 2 shows the controller of buck-boost converter. In figure 1, the part 1 is related to solar panel, where parameters such as temperature and solar radiation are configured and whereby the process started. Part 2 represents the bank of supercapacitors, using a single capacitor with equivalent capacitance that has function of to store energy. It is important to mention that for the second simulation made, it was just necessary to change part 2 to the value 83.3F. Part 3 is between the bank and load , it is a representation of the architecture of the buck-boost converter, that increases or decreases output voltage depending on its input and demanded voltage of load. And finally, part 4 is the representation of a load, in this case, it is a device for Smart Cities.

As mentioned, for the solar panel there are some parameters such as temperature and solar radiation, and it was chosen low variation of these values. Thus, the behavior of the solar panel will be constant during the simulation. And another point is, the real bank of supercapacitors has a limited voltage of 16.2V. But for safety, the supercapacitors will be charged until approximately 15.5V.

Besides, the bank only will provide energy for load after reaching approximately 15.5V. For doing that, it was added 4 keys: key1, key2, key3 and key 4. During the charging process, the keys 2 and 4 stay opened, not allowing any current to the load. When a value in the bank reaches approximately 15.5V the keys 1 and 3 become opened, this way, stopping charging the bank of supercapacitors. Then, key2 and key4 close and begins the process of discharge.

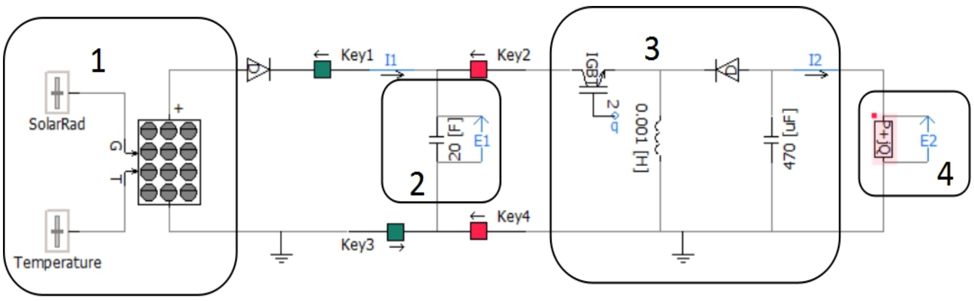

Fig. 1 First circuit that was simulated, with the main component detached

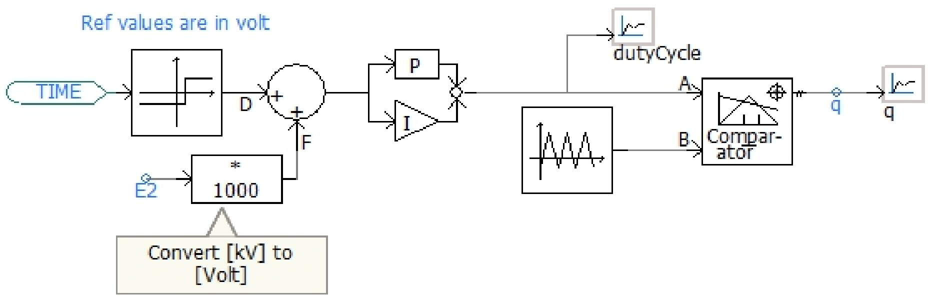

Fig. 2 Controller of buck-boost converter

4 Simulation Results

Figure 3 shows results obtained simulating a bank of 20F and figure 4 a bank of 83.3F presented voltage by time in seconds. According to the results it is possible to notice that the supercapacitors bank with equivalent capacitance of 20F reach full charge faster than the 83.3F. However, discharge quicker as well.

In figures 3 and 4 do not present the time that exactly a process started or finished, but, PSCAD provides those values. The bank that has 20F of equivalent capacitance reached around 15.6V in 600 seconds, or, 10 minutes, presenting a quick charging curve. But its discharging process has a duration of 1800 seconds (30 minutes) until full discharging. The whole process took 2400 seconds.

The bank of 83.3F has an interesting curve. Whole process took 9600 seconds, which means, approximately 2,7 hours. The charging process took 2400 seconds, around 40 minutes, until achieving the value of 15,07V and discharged process had duration of 2 hours. Then, comparing both banks, the second one presents a better property for the application.

The bank of supercapacitors with equivalent capacitance of 83.3F presents a better property due the autonomy that it may provide. This means, in case any problem with solar panel and grid, the system will continue work and obtaining data necessary during more time than the other bank. This may be an opportunity for fixing the system before fully discharge the bank.

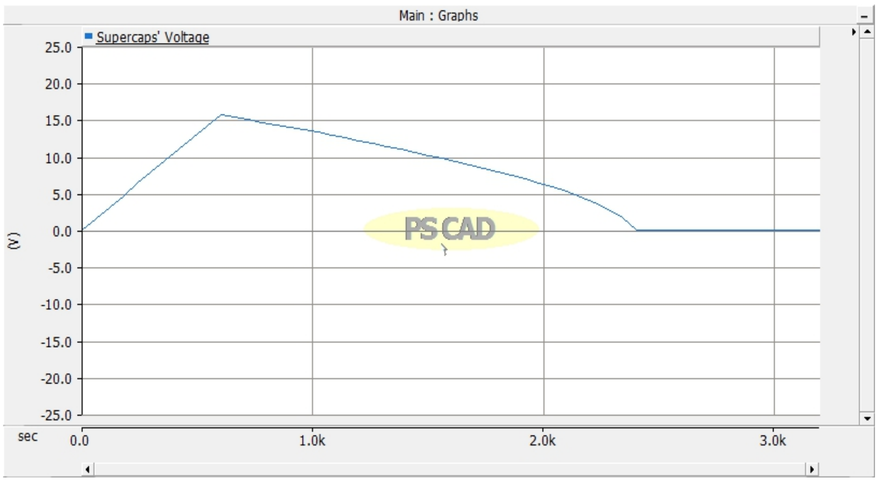

Fig. 3 20F bank charge and discharge curve

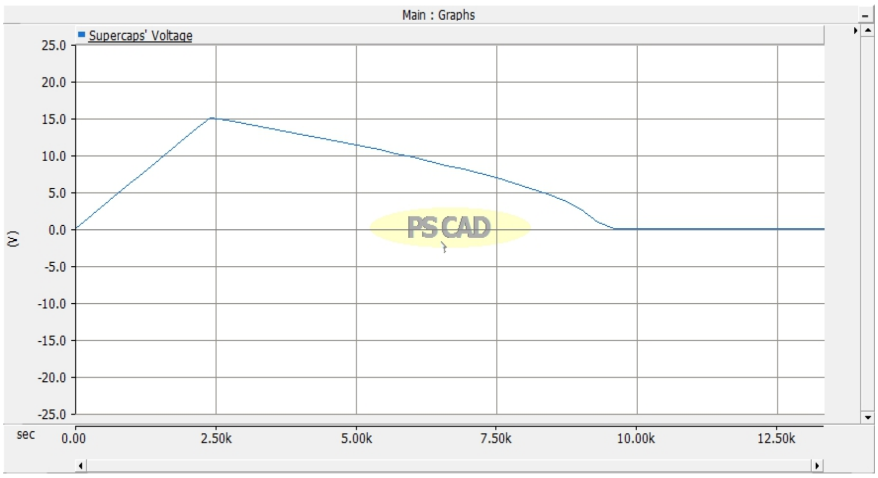

Fig. 4 83.3F bank charge and discharge curve

Furthermore, it is important to mention that there are some differences in the real case and simulation, such as: in the simulation the solar panel has a constant power and it is known this does not happen in real case. Furthermore, the process of charging just happens in the beginning of the simulation, but this process may be continuous in real case.

There are other points for considering, as, the simulation provided graphics of full charging and discharging. However, there are limitations. The buck-boost converter requires a certain threshold of voltage for working properly. This means the time may be reduced slightly.

Secondly, when comparing batteries to the bank of supercapacitors, the main barriers are: the price of the bank is more expensive and the duration is less than the battery. However, batteries cause environmental damage when their lifetime is over, making this the reason for trying alternative storage systems.

Another issue is, for solar energy is crucial sunlight, but the sun is not always available. Thus, occasionally the energy feed will be low, doing the device work improperly.

Fortunately, there are solutions for some problems. When solar energy is not enough for maintaining the bank of supercapacitors, it will be used energy from the grid, guaranteeing continuously energy to the system. Besides, for increasing time of duration of supercapacitors, may be used the idle mode of microprocessor, each 15 minutes turn on the system for collecting data, and after returning for idle mode. This might decrease the energy demand.

5 Conclusions

This paper aimed to presents some PSCAD simulation results involving supercapacitor banks as ESS for Smart Cities, focused on to study when supercapacitors are enough to supply Smart Cities devices, without the need of batteries.

After simulating 2 sorts of the bank of supercapacitors, it was possible to obtain and understand their behavior. The bank of supercapacitors with equivalent capacitance 20F, charges faster, however, discharges as well. Thus, the bank 83.3F presents better properties to this wished application, because it may provide more time of autonomy.

Some problems for this application were considered too. However, some solutions have been already thought. For reducing energy demand, might be used idle mode, and connect the bank on grid just in case of insufficient solar supply.

It is possible to conclude that an application with low consumption a bank of supercapacitors may be suitable with a reasonable time of autonomy. This way, supercapacitors might substitute batteries, and then reducing environmental damage caused by using batteries.

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