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Application of Supercapacitors for Short term Energy Storage Requirements

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ABSTRACT

Distributed power generation networks and Autonomous Renewable Energy Systems (ARES) are gaining much popularity as renewable energy sources for a vital part in such systems. The reliability and the efficiency of such systems can be greatly increased by connecting energy storage devices. Supercapacitor based energy storage system is used to mitigate the power quality problems as they are capable of providing necessary energy bursts for a very short period. Sizing of supercapacitor bank is an important step towards design of such systems. This study presents a simple methodology to be adopted for sizing the supercapacitor bank based on basic parameters. Proposed method is verified by experimental results to demonstrate the use of the suggested methodology and also the use of such energy storage devices for its application in short term energy storage requirements.

Key words: ARES, DPGS, supercapacitor

INTRODUCTION

Use of non conventional energy sources is gaining popularity in a widespread manner. Deregulation of the electricity market has opened up many opportunities in the area of distributed generation. The advantage of distributed generation is that it can be located close to the load and issues related to land management are minimal (Barker and de Mello, 2000; IEA., 2002). Moreover it is best suited for remote places which cannot be connected to the grid. Such systems are referred Distributed Power Generation Sources (DPGS) which takes care of the local load. But the main problem associated with them is that they are heavily dependent on climatic conditions. Power quality issues like voltage sags, voltage flicker, sustained interruptions etc are bound to exist and must be limited according to the IEEE standards (El-Samahy and El-Saadany, 2005; Dugan *et al.*, 2003; Khatri *et al.*, 2005). Be it WECS or PV based systems energy storage devices are highly essential in order to take care of the fluctuations. Supercapacitors or ultracapacitors can be used as energy storage devices in order to take care of these fluctuations thereby maintaining the output voltage at a constant value (Sels *et al.*, 2001). They are effectively capable of providing solutions to the voltage sags thereby acting as perfect ride through systems. Active research has proved that SECS based reactive power compensation is effective in releasing the stored energy to load thereby improving the power quality significantly (Zhang, 2005; Lu and Zhang, 2006). They are effectively capable of providing solutions to the fluctuations power in a hybrid system (Degobert *et al.*, 2006).

The design of a super capacitor based storage system it is important to get the equivalent circuit model as it forms the basis for determining the size of the bank or in other words the number of cells to be connected. The model also helps to proper voltage balancing circuit due to the capacitance difference between the cells. This indifference in the capacitance value will eventually lead to voltage imbalance which finally may have a risk of overvoltage. Thus the need for a voltage balancing circuit is highly essential here for taking care of the voltage imbalances across the string of capacitors (Rizoug *et al.*, 2004). Van Voorden *et al.* (2007) suggested a Lead-acid battery-Super capacitor system as a solution for energy storage in Autonomous Renewable Energy Systems (ARES). They concluded that batteries are not appropriate to follow the sharp fluctuations, since their life-time is negatively affected. Therefore, the application of only Lead-acid batteries is inadequate for ARES of this power scale. Xue *et al.* (2009) suggested a novel method well by using the supercapacitors which can also balance the power for the load mutant as the energy storage device. Additionally, it also verified by simulation that the Ultracapacitor can absorb or release instant high-power. Chan *et al.* (2006) suggested the usage of supercapacitors as energy storage devices as peak power unit in a DVR ensures increased power quality by smoothing out the voltage fluctuations. Abbey and Joos (2007) proposed the integration of a short term energy storage device in the form of supercapacitor to a doubly fed induction generator to smooth out the fast wind induced power variation and enhancing its LVRT capability. Choosing the right size of the supercapacitor bank is always a challenging task and the present study discusses a methodology to sizing the bank.

Energy storage is mainly intended to balance the fluctuations in the demand and supply of electricity. Though it cannot completely replace generation such devices can complement them. As power quality issues are gaining more importance the provision of energy storage facilitates the shaving of peak demands. This improves the quality of the supply. Several energy storage devices are developed over the years as produced in Table 1. Super capacitors are ideal for applications requiring high peak power discharge for a few milliseconds to a few minutes. They possess power density and they can be charged much faster which makes them ideal for applications which require short energy bursts (Chen *et al.*, 2008). It is generally used as strings of series connections put across the DC bus. Depending upon the requirement of the application this DC voltage can be directly used or can be inverted to get the suitable AC. They can be effectively used with non conventional energy sources especially WECS and PV array based systems to take momentary loads.

Table 1: Comparison of energy storage devices (Conway, 1999; Becker, 1957; Yan and Zhao, 2006; Binduhewa *et al.*, 2008)

Property	Supercapacitor	Battery	Flywheel
Discharge time	1-30 sec	0.3-3 h	0.5-2 h
Charge time	1-30 sec	1-5 h	0.5-2 h
Energy density	1-10	2-100	5-50
Power density	7000-18000	50-200	180-1800
Cycle life	>10 ⁶ times	10 ³ times	10 ³ times
Efficiency	>95%	85-95%	90-95%
Safety	Good	Good	Not good
Maintenance	Very good	Good	Medium
Cost	20	1	8

This is possible because of the very high power density it posses. In addition to that they have super high capacity ranging from several farads to tens of thousands of farads They can be charged and discharged at a much lesser time which again makes them a better choice for high power applications and also be cycled several hundred times without much maintenance.

MATERIALS AND METHODS

The proper selection of the size of the supercapacitor bank is imperative to reap the benefits it offers. The timing for which the voltage has to maintained forms a decisive factor in the determination of the size. The super capacitor bank for the given specifications is determined by following the procedure given in the flowchart http://www.mouser.com/pdfDocs/Maxwell_whitepaper_designinguide.pdf (Fig. 1).

Following the procedure elaborated in the flow chart the total capacitance needed for the given application is calculated to be 4.4 F and it is achieved by connecting five cells in series to form one parallel string. The super capacitors chosen for the application is from Tecate group TPL-22/12X35F.

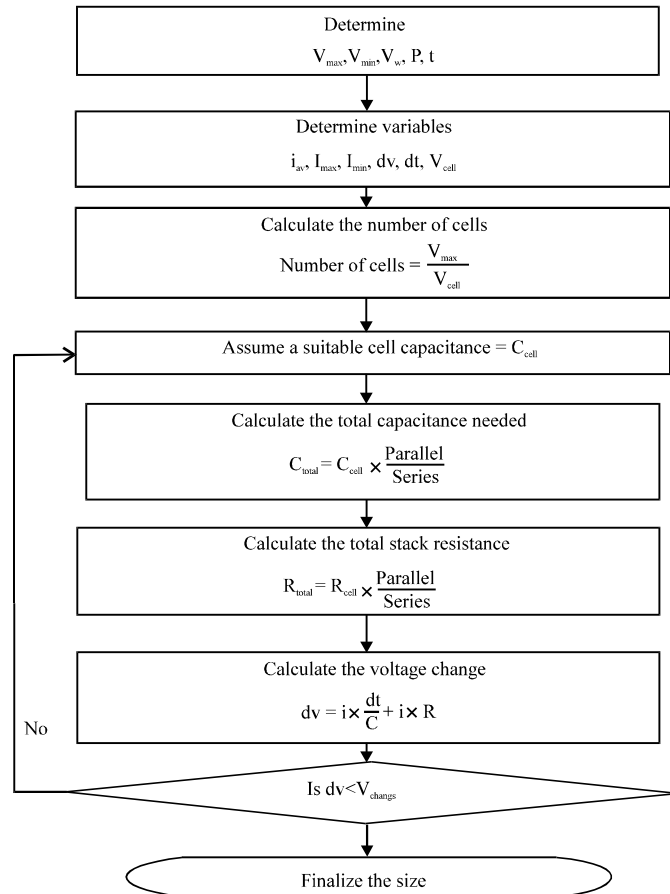


Fig. 1: Flowchart for determining the size of the supercapacitor bank, V_{max} : Maximum Voltage, V_{min} : Minimum allowable voltage, V_w : Working operating voltage, P: Power requirement, t: Time of discharge, dv: Change in voltage, i_{av} : Average current, I_{max} : Maximum current, I_{min} : Minimum current, C_{cell} : Cell capacitance, C_{total} : Total capacitance of the bank, R_{cell} : Resistance of cell, R_{total} : Total resistance of the bank

The hardware setup is constructed using an AT 89c51 ATMEL microcontroller based system and the data pertaining to the experimental set up is given in Table 2.

The charging circuit which forms the main section of the hardware is as shown in the Fig. 2. The balancing resistors of 6 K are used across each super capacitor in order to minimize the effect of unequal voltage distribution and hence preventing the cells from any high voltage. The time for which the storage is necessary is an important factor which decides the size of the bank. For the given problem it is assumed to be 10 sec.

The load on the system is taken to be 20 W and the working voltage is 12 V. The super capacitor bank is being charged during normal working conditions. The bank is charged during normal working voltage and when the voltage suddenly drops to then control circuitry will switch on the bank thereby maintaining the rated voltage at the bus terminals. The control procedure is also illustrated in the flow chart and its charging and discharging are plotted as shown in the Fig. 3a-b.

Table 2: Data for the experimental setup (Conway, 1999; Becker, 1957; Yan and Zhao, 2006; Binduhewa *et al.*, 2008)

Parameters	Values
V_{max}	12 V
V_{min}	04 V
V_w	12 V
P	20 W
t	10 S
dv	8 V
I_{max}	5 A
I_{min}	1.33 A
R_{total}	1.75e-3

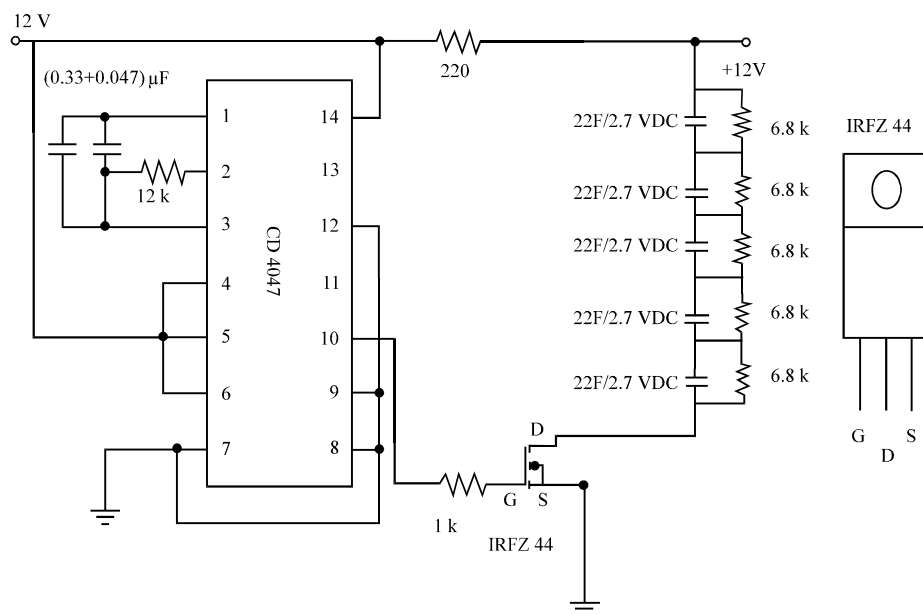


Fig. 2: Charging circuit for the supercapacitor bank

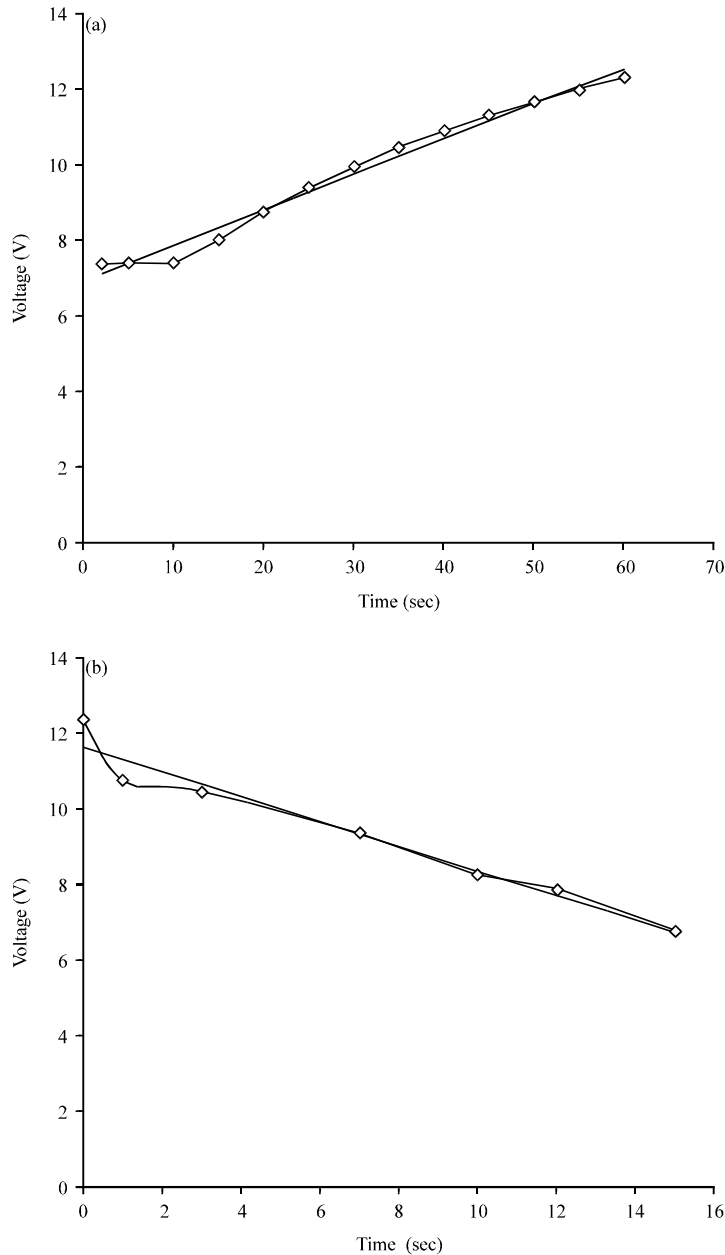


Fig. 3(a-b): (a) Charging and (b) Discharging characteristics of supercapacitor bank

RESULTS

Experimental results show that the charging of the supercapacitor bank is rapid and it can provide momentary power bursts for the required load and for the specified time period. The proposed methodology of sizing the bank is simple and uses the basic parameters for determination of the size. The design proposed is sufficient to maintain the terminal voltage of 12 V across the load terminals for a load of 10 W and for a time period of 10 sec. As the rating of the load and the backup time increases the size of the bank also increases which necessitates a much higher rating of the bank. Such banks may have a combination of series and parallel strings of supercapacitors effective to ride through the disturbances and maintain a healthy voltage profile.

DISCUSSION

A comparison of energy storage devices is shown in Table 1. Use of Supercapacitors for the purpose of storing energy for short term applications is explored in many publications, however determining the exact size of the bank is always a challenging task and a suitable methodology should be adopted to select the right size. This study elaborated the procedure to be followed for sizing the supercapacitor bank which forms the critical part of the design as the cost of supercapacitors is still on the higher side. Experimental results are also used to verify the charging and discharging characteristics of the bank. Small DGPS are subjected to such kind of fluctuations and the proposed system will be effective and handy for such applications. However as supercapacitors are capable of providing only short term power bursts to improve the power quality it cannot store energy for a sustained longer period. Moreover as the backup time period increases the cost of the bank becomes extremely higher which will eventually lead towards higher capital expenditure. The proposed system can be used in conjunction with a long term energy storage devices like CAES or flywheel so that they can complement each other in case of energy requirement for sustained periods.

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