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# The Characteristic of Supercapacitors Circuit as a Future Electrical Energy Storage Media

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**Abstract.** Battery or accumulator is a general electrical energy storage media. The main disadvantage of the battery is the long duration during charging process, short lifetime and less environment friendly. This is one of the obstacles in the development of electric vehicles. Recently, it has been found an electrical energy storage media that uses capacitor technology. The basic principle of capacitors is similar to a battery, which can store electrical charges. The charging process of capacitor is relatively faster than battery, but the discharging process is also very fast. The advantages of capacitor are not using chemical process, cheap maintenance and longer lifetime than battery. Therefore, the researcher developed supercapacitor. The supercapacitor has bigger and larger capacity than common capacitor. This study aims to find out the performance of some types of supercapacitor circuits during the charging and discharging process.

## 1. Introduction

In the case of electrical energy storage system, electrochemical capacitor and lithium-ion battery are most excavated [1]. The basic functions of capacitors are similar to battery, because capacitors are used to store and discharge electrical energy. But the working principle of capacitor is very different from battery [8]. Disadvantage of the battery is long charging process duration. The process of charging and discharging the battery using a chemical reaction, the waste is very harmful to humans and less environmentally friendly. The battery life is short ranging from 2-3 years. Another weakness of battery is estimated residual energy is not appropriate and need periodic maintenance. This is one of the factors inhibiting future vehicle development which requires environmentally friendly, i.e. electric vehicle. Electric vehicle, such as bike and car which use battery need long time for charging.

Based on the problem above, the researcher developed supercapacitor. Supercapacitor is same with capacitor but has bigger size and higher capacity than usual capacitor. The advantage of supercapacitor is fast charging process and a little chemical reactions occurs during charging process. The supercapacitor life is long time about 20 years although its power decreased by 80%. Supercapacitor require low maintenance and has operational resilience [9]. However, the supercapacitor voltage is running out faster than battery. Chemical reaction of supercapacitor for charging process need short time but discharging process in a very fast time [8].



Fahad et al. [9] studied that supercapacitor has possibility as solar energy storage as a replacement battery. Supercapacitor more easier in maintenance, more resilient in operations, and more environmentally friendly than battery. Supercapacitor designed and developed using circuit to manage the energy. Yifeng [10] and Hu et al. [11] designed control and monitoring device to measure capacitors voltage of charging and discharging process. Their experimental successfully measure the voltage and state of charge (SOC) estimation.

The previous research is the usage of capacitor for small energy storage. Capacitor did not use for high energy as home energy system such as pump, lamp, refrigerator, and washing machine. Present research, the supercapacitor arranged series supported by electronics control in charging and discharging process.

This research is how to develop and to know the performance of supercapacitors circuit type. The characteristic of circuit type of supercapacitor will founded. The best circuit type can use to main component as energy storage system (ESS).

The general purpose of this research is to know the performance of supercapacitor using control circuit for charging and discharging process. The specific purpose are (1) to know the best supercapacitor circuit for energy saving (2) to design electronics control for charging and discharging (3) to know charging and discharging time of supercapacitor circuit.

## 2. Research Method

The method of this research divided into several steps, which are (1) selection and procurement the supercapacitor; (2) designing and assembling supercapacitors in series; (3) designing and assembling the balancer circuit for charging and discharging; (4) assembling in series of supercapacitor, charging control, discharging (balancer) and lamp; (5) retrieve data by video recoding to know the performance of supercapacitor circuit.

Performance test of supercapacitor using resistive load of incandescent lamp. Firstly procurement of supercapacitor more than 100F. If the supercapacitor less than 12V, so the supercapacitor arranged series until 12 Volt. The test equipment in present research is digital power supply, amperemeter, voltmeter and video recorder. The digital power supply should has voltage and current indicator. The incandescent lamp 24V/50watt used for load to know the performance of supercapacitor circuit. The digital power supply unit used to provide power supply to the supercapacitor circuit accurately in charging process. The digital power supply unit strongly needed in this research because show the voltage and current flowing to the load in real time. Video recorder used to record charging and discharging supercapacitor process, so every detail of the charging and discharging process can be observed and analyzed.

## 3. Results and Discussion

The supercapacitor available in the online market is 120 Farad/2.7volt and 500Farad/2.7volt. Because of the voltage every single supercapacitor is 2.7 volt, while the output voltage from solar panel is 18 volt, so six supercapacitors arranged in series. Based on the calculation result six supercapacitors has total voltage  $2.7\text{volt} * 6 = 16.2 \text{ volt}$ . The physical of six

supercapacitor 120F in series arrangement shows in Figure 1, and six supercapacitor 500F in series arrangement shows in Figure 1.

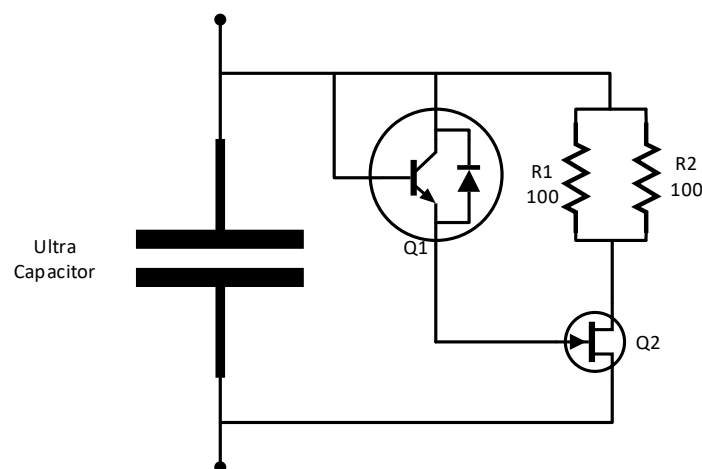


**Figure 1.** Series arrangement of six supercapacitor 120F/2.7voltage



**Figure 2.** Series arrangement of six supercapacitor 500F/2.7voltage

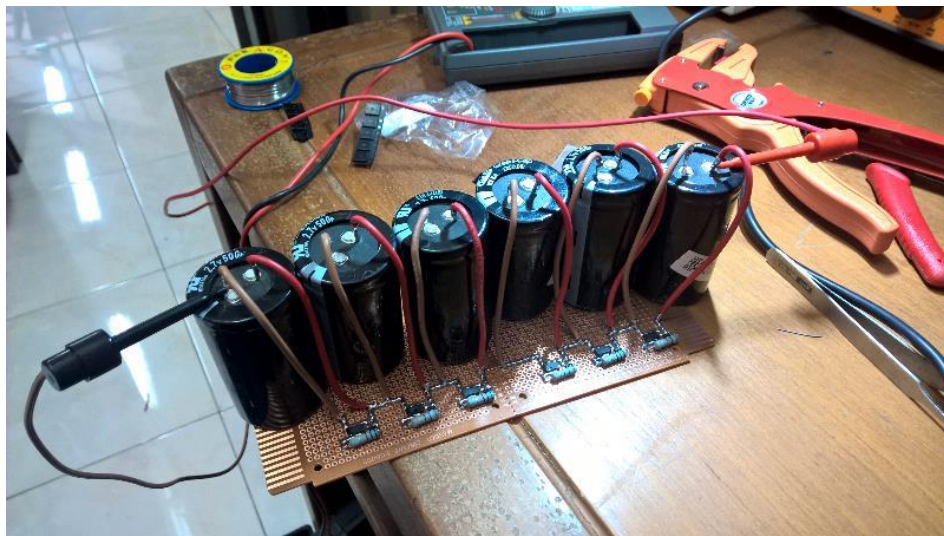
After research, observation and analysis to the output of series six supercapacitor, we concluded that it need balancer circuit in every supercapacitor. The main function of balancer is to ensure that each supercapacitor arrange in series will filled accordance with voltage and current. Figure 3 shows the balancer based on the design.



**Figure 3.** Balancer circuit for supercapacitor

The number of balancer circuit is same as the number of supercapacitor. Figure 4 shows the assembling of supercapacitor and balancer. Next step is trials, i.e. the circuit is loaded an incandescent lamp 24volt/25watt. Supercapacitor charging process used digital variable power supply to set the output voltage. The data of voltage and current are very fast change of voltage and current values. The video recorder used to record voltage and current values from the lamp illuminated until stop. The final step is the video data analyzed until the performance of supercapacitor obtained.

The supercapacitor is usual capacitor which has big dimension and capacity (in order hundred farad). The charging characteristic analyzed is same the usual capacitor. Equation (1) used to analyzed voltage of capacitor in t second.



**Figure 4.** Six arrangement of supercapacitor and balancer

$$V_c(t) = V_{in} + \left\{ \{V_c(0) - V_{in}\} e^{-t/RC} \right\} \quad (1)$$

where  $V_{in}$  : input voltage from the source,  $V_c(0)$ : initial voltage of capacitor, R: resistor arrangement series with capacitor for set filling time constant, and t: filling time from 0 secon.

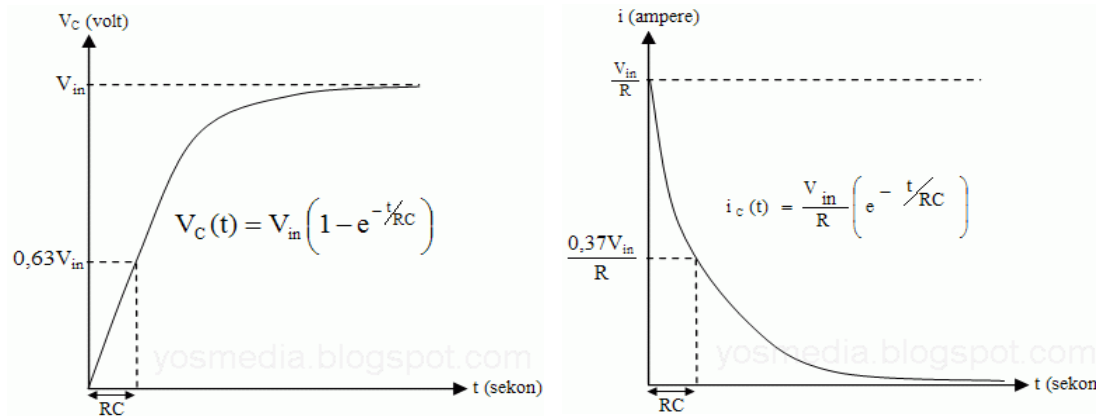
If the initial time, there is zero voltage,  $V_c(0) = 0$  volt, so the equation (1) to be equation (2).

$$V_c(t) = V_{in} \left\{ 1 - e^{-t/RC} \right\} \quad (2)$$

The charging current in after t secon shown in equation (3).

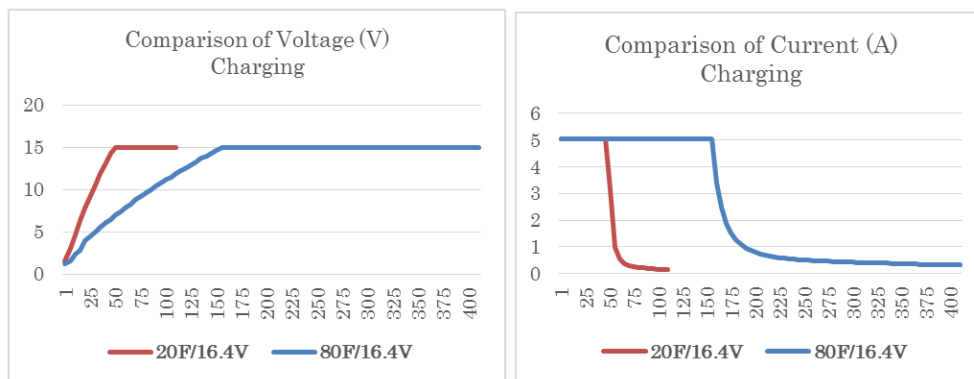
$$i_c(t) = \left( \frac{V_{in}}{R} \right) e^{-t/RC} \quad (3)$$

Based on equation (2) and (3) the graph relationship between voltage and current of capacitor charging can be obtained, see Figure 5.



**Figure 5.** Graph of the characteristic voltage and current of supercapacitor charging

There are two type testing to obtained the supercapacitors performance, which are the characteristic of charging and discharging process. Figure 6 shows the characteristic of charging process. Both voltage and current chart in Figure 6 is similar with the caharcteristic of supercapacitor charging theoretically in Figure 5. Electrical resistance (R) in series with supercapacitor from cable, solder connection and connectors is 1 ohm. So, time constant value is  $RC = 1\text{ohm} \times 20\text{F} = 20$  for supercapacitor 20F and  $RC = 1\text{ohm} \times 83\text{F} = 83$  for supercapacitor 83F.



**Figure 6.** Characteristic graph for charging supercapacitor

**Table 1.** Relationship between charging time and prosentage of capacitors voltage

t	Vc	t	Vc
0	0	2 RC	86.5%
0.7 RC	50%	3 RC	95%
RC	63%	5 RC	99%

Table 2 shows the relationship between charging time and prosentage of capacitors voltage. The full supercapacitors voltage about 99% of supercapacitor 20F/16.2V need 5RC for charging time. The meaning of 5RC is  $5 \times 20 = 100$  secon. For supercapacitor 83F/16.2V need time  $5 \times 80 = 400$  secon. Based on research result and theoretical calculations result, there is a good agreement between research and calculation result.

It is interesting to note the two graphs presented in Figure 6. Fistly, an exponential curve, meaning to charge the 83F/16.2V supercapacitor from a voltage approaching 0 volt until 16,2 volt only takes about 400 secons. Secondly, the length of charging time is directly proportional to the capacity of the supercapacitor. The larger capacity of supercapacitor need the longer charging time. If the capacity of supercapacitor increased n times, by assembling more and more parralel supercapacitor, the the length of charging time will be longer n times from the original. Third, the length of charging time is not dependent on the magnitude of the capacitors voltage but depend on capacity and physical resistant of supercapacitor.

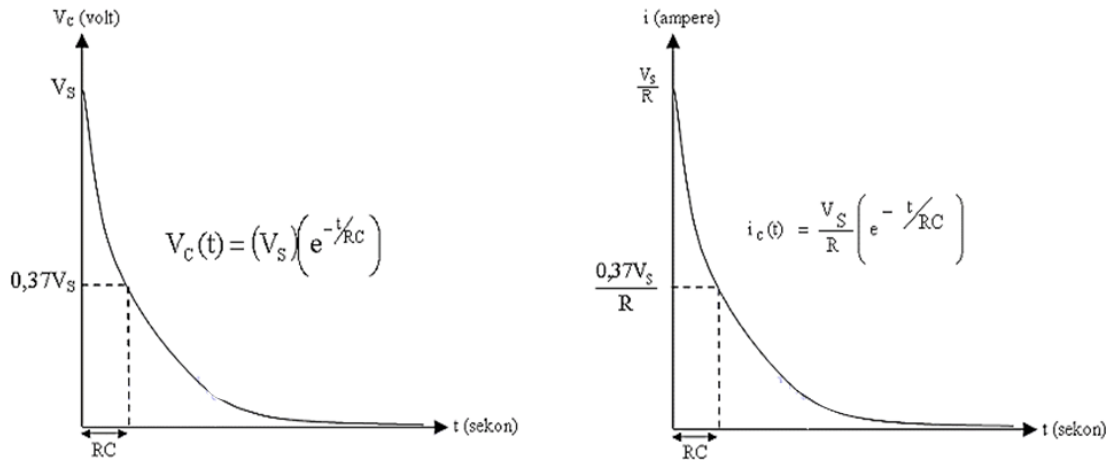
Discharging test of supercapacitor by mechanism and formula of discharge supercapacitor. Resistant R is load from incandescent lamps 24V/25W in ohm. The  $Q_o$  is initial charge of super-capacirtor both 20F and 83F.  $V_o$  is initial voltage of supercapacitor. Based on the basic theory of electricity, supercapacitors voltage in discharging process at time t can describe in equation (4).

$$V_c(t) = (V_s) \left( e^{-\frac{t}{RC}} \right) \quad (4)$$

The current of discharging at time t can describe in equation (5).

$$i_c(t) = \left( \frac{V_s}{R} \right) e^{-\frac{t}{RC}} \quad (5)$$

$V_s$  is initial voltage of supercapacitor. Both equation of discharging voltage and current are exponential equation, so the graph of the equation are exponential too. Based on equation (4) and (5) can be made graph Figure 7. Based on the Figure 7 can be derived the relationship between discharging time and percentage of supercapacitor voltage, see Table 2.



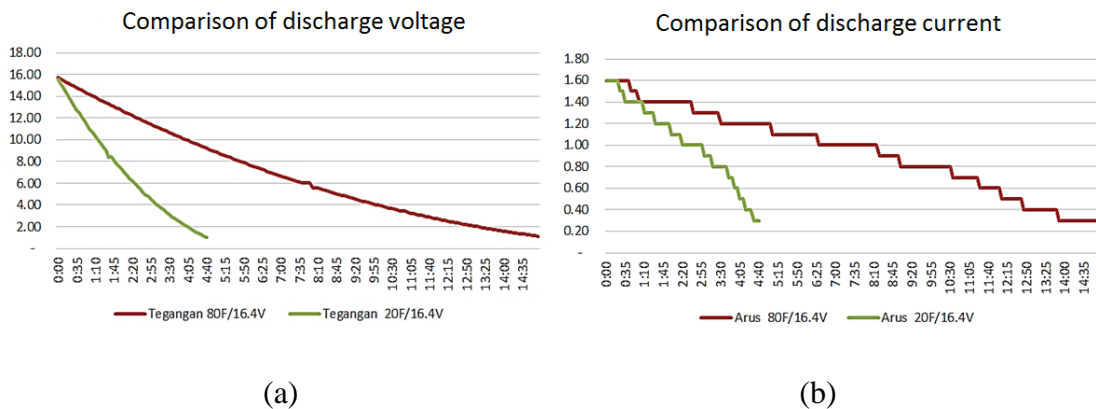
**Figure 7.** Relationship between voltage or current and time in discharging process

**Table 2.** Relationship between discharging time and supercapacitor voltage

$t$	$V_c$	$t$	$V_c$
0	99%	3RC	5%
RC	37%	4RC	2%
2RC	14%	5RC	1%

To calculate the time constant of discharge  $\tau = R.C$ , must be known first load R. Here, the load from incandescent lamps, measured directly using digital. The load of incandescent lamps are  $R_d=1.1$  ohm, so  $R=2.1$  ohm. The time constant of discharge ( $\tau$ ) of both supercapacitor can be obtained. Supercapacitor 20F:  $\tau =R.C= 2.1$  ohm \* 20F = 42 and supercapacitor 83F:  $\tau =R.C = 2.1$  ohm \* 83F = 174.

Discharging time until 0.16 volt (1%) using Tabel 2 above. Supercapacitor 20F need discharging time  $t = 5RC = 5*2.1*20 = 210$  secon, while supercapacitor 83F need discharging time  $t=5RC=5*174= 871$  secon.



**Figure 8.** The characteristic of supercapacitor discharging



Figure 8 (a) shows the graph of supercapacitor voltage 20F/16.2V and 83F/16.2V versus discharging time. The load used in this supercapacitor is 24volt/25W. In initial test, when the lamp start to connected, the supercapacitor voltage measured was 16V. After 35 secon, the 20 F supercapacitor voltage was 12-13 volt and 80F supercapacitor voltage was 15 volt. After 35 secon, the 20 F supercapacitor voltage was 10 volt and 80F supercapacitor voltage was 14 volt. Differentiation of supercapacitor voltage 20F and 80F at t secon tend to be increases with time until the lamp off. The lamp off when the capacitor voltage 1 volt after 4 minute 40 secon for supercapacitor 20F and 14 minute 35 secon for supercapacitor 83F.

Figure 8(b) shows the graph of supercapacitor current 20F/16.2V and 83F/16.2V. Current and voltage DC apply Ohms law  $V = I.R$ , which R is electrical resistant. If voltage decrease so the current also decrease because the resistant is constant. Based on Figure 7, the voltage and current are directly proportional with capacity of supercapacitor, see equation (6).

$$C = \frac{Q}{V} \quad (6)$$

where: C is capacity of suer-capacitor (F), V is capacitors voltage (V) and Q = capacitors charge (Qoulomb). The capacity of capacitor is not depend on V and Q but influence of V and Q. The capacity depend on size and form of supercapacitor. From equation (6) shows if there are two capacitor having  $C_1 = 4 \times C_2$  and having same voltage, so the capacitor voltage is  $Q_1 = 4 C_2$ . Its mean that capaciotrs voltage  $Q_1$  is four times  $Q_4$  Mean.

From the basic theory of electricity, electricity current (I) in ampere is shown in equation (7).

$$I = \frac{Q}{t} \quad (7)$$

where t is time in secon.

From the equation (7) shows that the electric charge increase in supercapacitor so the the electric current will increase. If the ability of the load to absorb electricity in contasnt, so the higher Q is need longer time for discharging process.

## Conclusion

Based on discussion and research result, we can conclude as follows.

1. The performance of six supercapacitors in series 120F/2.7V (total 20F/16.2V) need the charging time approximately 100 secon while supercapacitors 500F/2.7V (total 80F/16.2V) need the charging time approximately 400 secon.
2. Supercapacitors charging time is directly proportional with supercapacitor capacity. The greater capacity need longer charging time. If the capacity of supercapacitor raised n times so the cahrging time become longer n time.
3. Electronics balancer could be developed to keeping the voltage of each suparcapacitor not change during charging process.
4. Dischaging time of supercapacitor 20F/16.2V for load 24V/25W need 200 secon approximately while supercapacitor 83F/16.2V need 400 secon.

5. Discharging time of supercapacitor for same load is directly proportional with the capacity of supercapacitor. The greater capacity need longer discharging time. If the capacity of supercapacitor raised  $n$  times so the discharging time become longer  $n$  time.

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