

DESIGN AND FABRICATION OF A SOLAR POWER SYSTEM FOR AN ACTIVE RFID TAG

Nji Raden Poespawati^{1*}, Muhammad Rifki Nugroho¹

¹ *Department of Electrical Engineering, Faculty of Engineering, Universitas Indonesia, Kampus UI Depok, Depok 16424, Indonesia*

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ABSTRACT

An active Radio-Frequency Identification (RFID) tag is a low-power device, which is often used as a tracking device, where operation of this tag will be in remote areas from an electrical power source. Therefore, this device requires an independent power source. To meet these needs, solar power may be used, which can be accessed anywhere there is sunlight. Supercapacitors (SC) are used as an energy source to support a solar power system. The advantage of supercapacitors, as an energy storage device, is their long life cycle that means more charging and discharging processes compared to a conventional battery. The design and fabrication of a solar power system for an active RFID tag with supercapacitors as the energy storage will be covered in this paper.

Keywords: Active RFID tag; Battery charging/discharging; Load regulator; Solar panel; Supercapacitor

1. INTRODUCTION

An active RFID Tag is a low-power device that operates in remote regions. Active RFID tags can be used as tracking devices, for example, as tracking devices for wild animals. Therefore, we need an independent power device, which does not depend on electricity (Liu et al., 2008; Nath et al., 2006). Suitable power for this application can be taken from solar panels. Solar panels use solar energy, as a renewable energy alternative. Available anywhere as long as there is sunlight, solar energy does not depend on electricity from a wall plug.

Common use of solar power is followed by using batteries as the energy storage media. Sunlight is not constant due to the weather and the day/night cycle. The use of solar power accompanied by batteries can solve the problem of energy supply for devices that are in remote regions. However, the use of batteries still has obstacles, namely in terms of the life cycle of the battery charging and discharging process. On the other hand, the use of batteries in remote areas is very difficult due to battery replacement because the location of the device is often out of the operator's reach.

To overcome such problems, supercapacitors can be used as substitutes for batteries. Supercapacitors can store energy in the form of electric charge, which is the same as a conventional capacitor, but the capacity of a supercapacitor is much larger than that of a conventional one (Sikha & Popov, 2004; IEC, 2010). In addition, supercapacitors have a longer life cycle than that of batteries (Shukla et al., 2000). Therefore, in this work, we designed and fabricated a solar power system for an active RFID tag with supercapacitors that were used as

*Corresponding author's email: pupu@eng.ui.ac.id, Tel. +62-21-7270078, Fax. +62-21-7270077
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the energy storage media.

2. RESEARCH METHODOLOGY

In the design, the solar power system for an active RFID tag consisted of a solar cell panel, regulators and supercapacitors. Figure 1 depicts the block diagram of the designed solar power system for the active RFID tag.



Figure 1 Block diagram of the solar panel with supercapacitor as the energy storage media

The solar panel was equipped with two voltage regulators, namely the supercapacitor regulator and the load regulator. The supercapacitor serves to keep the incoming voltage stable so it does not exceed the voltage rating of supercapacitor. The load regulator functions to regulate the DC voltage of supercapacitor output to fit the active RFID tag specifications. In this system the voltage regulation process occurs twice. First, the 9V voltage, which enters the solar panel, is regulated to adjust the rating specifications of supercapacitors on 4.6V. Second, before entering into the load, the voltage was adjusted back to 3V to suit the voltage of the active RFID tag.

2.1. Active RFID Tag

The characteristics of the active RFID Tag determine the design of the other parts. The active RFID tag used a RF Code with a M100 code type (RF Code, 2015). This tag works with the power supply, which comes from a CR2032 Lithium battery with a voltage output of 3V (Energizer, 2015). In this paper, the function of the CR2032 Lithium batteries would be replaced with a resource system based on solar power. By experiment, we measured the voltage and current, which were consumed by this tag, namely 2.8 V and 0.16 mA, respectively. Hence, we designed the solar power system based on those current and voltage data.

2.2. Load Regulator

The voltage regulator was used to regulate the output voltage to match the characteristics required by the M100 Tag. The output voltage target of this regulator was the same as the output voltage of CR2032 Lithium batteries, that is, equal to 3V. The used voltage regulator uses a Bipolar Junction Transistor (BJT) with an emitter follower configuration and connected in series. Figure 2 shows the load regulator circuit.

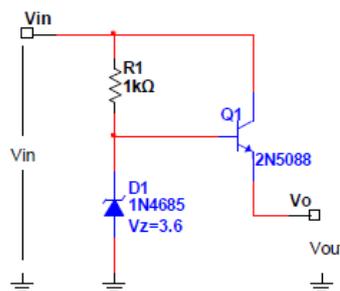


Figure 2 Load regulator circuit

To achieve the output voltage target of 3V, we need to calculate the Zener voltage. From Figure 2 the output voltage target could be achieved by decreasing the Zener voltage with the base-emitter voltage, as described in Equation 1, i.e.

$$V_0 = V_z - V_{be} \quad (1)$$

Since we used silicon devices, this design needed the Zener diode, which had a Zener voltage of ~3.7V, namely the Zener diode type 1N4685 ($V_z = 3.6V$) (On Semiconductor, 2015). The transistor was a BJT transistor type 2N5088. This type is the General Purpose NPN BJT and operates at low power (Fairchild Semiconductor, 2015). In Figure 2 the value of a Zener diode current (I_z) could be derived from R_1 , as follows in Equation 2:

$$R_1 = \frac{V_{in} - V_z}{I_z + I_b} \quad (2)$$

In this case, the magnitude of I_b is very small within a micro-amperes scale and can be ignored, so the number of I_b is ~ 0 Ampere. Thus, the Equation 2 becomes Equation 3a:

$$I_z = \frac{V_{in} - V_z}{R_1} \quad (3a)$$

By using Equation 3a we could calculate a Zener diode current, which was necessary. We found that a Zener diode current would produce 1 mA, when an input voltage was 4.6 V, Zener voltage 3.6V, and R_1 1k Ω .

In this system, V_{in} was the input voltage, which was derived from the supercapacitor with a voltage magnitude of 4.6V in a fully charged condition and it would decrease linearly in the disposal process. By setting the value of R_1 at 1 k Ω , it will get a Zener diode current (I_z) of 1mA. In a datasheet, the minimum value of I_z is 50 μ A (On Semiconductor, 2015), then the I_z value, which was obtained with the R_1 value on 1 k Ω , can enable the Zener diode. From the datasheet, the Zener diode will not be able to provide a reference voltage when the value of I_z is $< 50\mu$ A (the cut-off condition), so the Equation 3a was modified as follows in Equations 3b and 3c:

$$I_{z\min} = \frac{V_{cut-off} - V_z}{R_1} \quad (3b)$$

$$V_{cut-off} = I_{z\min} R_1 + V_z \quad (3c)$$

From Equations 3c, the Zener diode with the magnitude of minimum Zener current ($I_{z\min}$) of 50 μ A, R_1 1k Ω , V_z 3.6V produced the cut-off voltage ($V_{cut-off}$) of 3.65V. Therefore, the minimum value of the voltage regulator was equal to 3.65V. It means when the voltage was under 3.65V, the regulator was no longer able to provide the output voltage of 3V.

2.3. Supercapacitor

In this work, the energy storage medium with the EDLHW306D2R3R was used. This type is made from CDE Cornell Dubilier, (2015). The magnitude of the supercapacitor capacitance of this system was 30F with a voltage rating of 2.3V. For this system, the capacitor was assembled in two series for increasing the voltage rating of a supercapacitor, so the total voltage, which

can be accommodated by a supercapacitor, was doubled by 4.6V. The value of supercapacitor follows the common formula, shown in Equation 4, i.e.:

$$\frac{1}{C_t} = \frac{1}{C_1} + \frac{1}{C_2} + \dots + \frac{1}{C_n} \tag{4}$$

From Equation 4, the magnitude of capacitance total (C_t) was calculated to be 15F. Thus, the capacitance total in this system was 15F. The length of time of the backup supercapacitor (t) can be determined using Equation 5, namely (CDE Cornell Dubilier, 2015)

$$t = C \frac{\Delta V}{I} \tag{5}$$

where, $C = 15\text{F}$; $\Delta V = 4.6\text{V} - 3.65\text{V} = 0.95\text{V}$; $I = 1 \text{ mA}$, thereby the resulting t was 14,250 seconds (3.9 hours).

ΔV is the difference between the maximum voltage to the cut-off supercapacitor voltage, where a cut-off voltage was set at 3.65V and a maximum voltage of supercapacitor for 4.6V, which matched the settings on the block of the supercapacitor regulator. The Value of I is the magnitude of a supercapacitor discharge current. The current of I would be assumed, based on the consumption of 1mA of current required by the block of a load regulator. Thus, the length of time of a backup supercapacitor in this system was around 3.9 hours.

2.4. Supercapacitor Regulator

The voltage regulator was used to keep the voltage on the supercapacitor charging current, which does not exceed the voltage rating of the supercapacitor. The voltage regulator has the same composition as the load regulator in Section 2.2, the difference is only the output voltage. The output voltage of this regulator was 4.6 V (refers to the voltage rating of the supercapacitor). Figure 3 shows the circuit of a supercapacitor regulator.

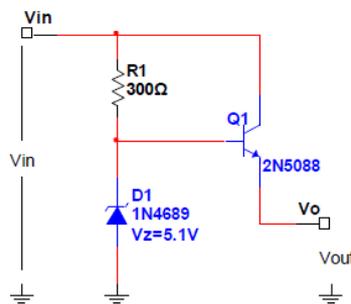


Figure 3 Supercapacitor voltage regulator

To obtain the output voltage of 4.6 V, then the Zener diode with a Zener voltage type 1N4689 was used at 5.1 V. This regulator voltage input was derived from the solar panels and output of the regulator voltage entered into the supercapacitor.

2.5. Solar Panel

This system used solar panels as a source of power. Solar panels, which were used, consisted of a composition of several solar cells. Solar cells were arranged in series to get enough voltage to run the system.

By experiment, the average open-circuit voltage and short-circuit current of the solar cell were obtained at 2.6 V and 44 mA, respectively. For getting the supercapacitor voltage 4.6 V it

needed an input voltage greater than the value of the supercapacitor voltage. This excess voltage will reduce the influence of solar panel voltage fluctuations due to variations in solar radiation. For this system, an input voltage from the solar panels was selected at 8V. In accordance with Equation 6, we can calculate the number of solar cells, which are needed in series (Singh, 1995), as follows:

$$N_{series} = \frac{V_{output}}{0.9V_{OC}} \quad (6)$$

$$N_{series} = 4.44$$

Thus, the required number of solar cells was four pieces with series drawn. The amount of current from the solar panels will only affect the length of charging time and a current of 44 mA was sufficient to perform the charging process.

2.6. The Power System of Active RFID Tag based on Solar Power

Figure 4 shows an overall resource system of the active RFID tag based on solar power. Generally, this system began with the generation of voltage and current by solar panels. Current and voltage was then used to charge the supercapacitor with a maximum charging voltage, which was limited in accordance with a voltage rating supercapacitor. After the supercapacitor was fully charged, the voltage from the solar panels would directly supply the load with the first voltage through the process of adjusting the voltage regulator circuit through the load. When in the absence of sunlight, the solar panel was unable to provide a power supply then a supercapacitor would discharge and begin the process of becoming a backup power source to solar panels. The supercapacitor is capable of providing power supply again. Solar panels were installed on a BAT85 Schottky diode to prevent backflows of current into the solar panel. Figure 5 depicts the solar power system for the active RFID Tag.

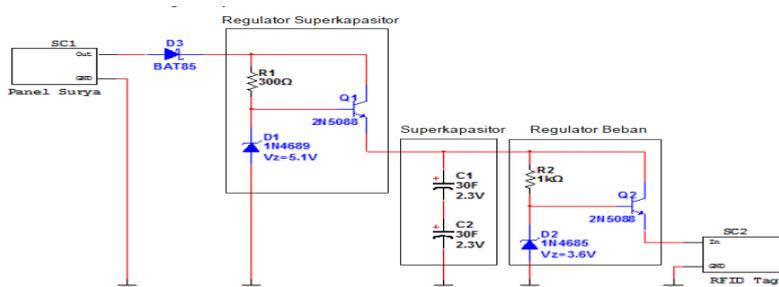


Figure 4 Overall resource system of active RFID tag based on solar power



Figure 5 The solar power system of active RFID tag

3. OPTIMAL TUNING OF THE IPF

3.1. The Experiment without Load

The first experiment was the charging process. During the measurement, parameters observed were light intensity, voltage, current, and time. Data, which were taken at intervals of 5 minutes, are the voltage of solar panels, supercapacitor voltage and output voltage, while the current data, which would be taken, are the current from the solar panel and charging current of the supercapacitor. This data collection was done at an average light intensity of 56,637.5 Lux, with solar panels positioned perpendicular to the earth. Figure 6 shows the graph of the current on solar panels, which are connected to the charging current of the supercapacitor with respect to time.

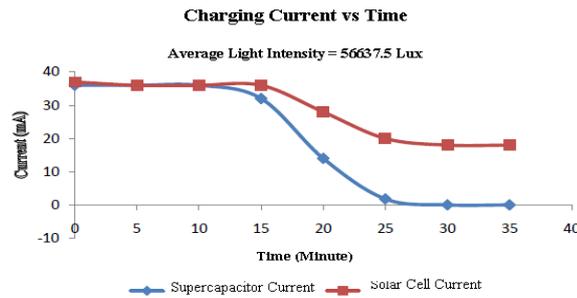


Figure 6 Graph of charging current versus time

In this experiment the current characteristics of the supercapacitor will be obtained during the charging process. From the graph, at the beginning of the charging process it can be seen that the input current value of supercapacitors will be close to the generated current value by the solar panels. However, when the supercapacitor is approaching a fully charged condition, the supercapacitor current will decrease and produce the current difference between the current on solar panels with the current of supercapacitor. When the supercapacitor is fully charged, the input current of supercapacitor will be zero. This value indicates that the supercapacitor can no longer hold a charge. Figure 7 shows a graph of the voltage on solar panels, supercapacitor voltage and output voltage of the system versus time.

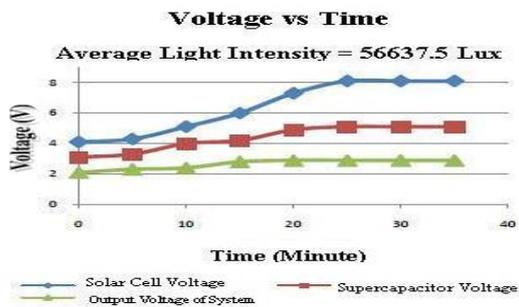


Figure 7 Graph of charging voltage versus time

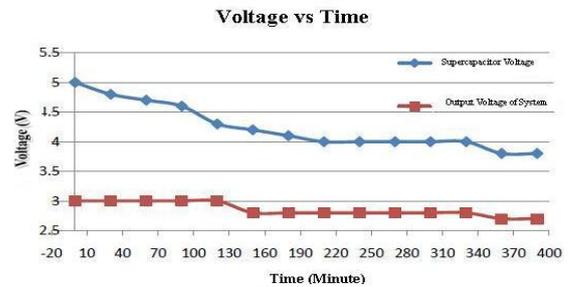


Figure 8 Graph of discharging voltage versus time

The next experiment was the testing of the discharging process. During the discharging process, we observed the system parameters, namely, the supercapacitor voltage and system output voltage. The discharging process was done without load on the system output terminal. Figure 8 shows a graph of the discharging process for the supercapacitor. From the graph it can be seen that the voltage of the supercapacitor will decrease when there is no input voltage from the solar panels. This voltage drop indicates that there was power consumption by the voltage regulator, even though it was not connected to a load. In addition, the leakage of electric charge on the supercapacitor also was one of the factors, which is causing voltage drop. These tests indicated that the conditions were not overburdened, and the output voltage of system could be maintained in the range of 2.7V–3V over a period of 360 minutes or 6 hours.

3.2. The Experiment with Load

In this section the solar power system was tested in an overburdened system condition. The used loads were resistors with a resistance value of 16 kΩ to replace the active RFID tag. Measurements would be devoted to two processes, namely the process of charging and discharging. In the first part, it was tested on the supercapacitor charging for three average values of light intensity, i.e. 51087.50 Lux; 55828.87 Lux; and 59614.29 Lux. The parameters, which have been tested, were the charging current of supercapacitor, supercapacitor voltage,

and output voltage. Figure 9 shows the experimental results of the charging process with a 16 k Ω load.

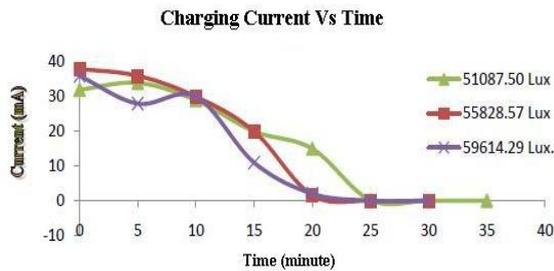


Figure 9 Graph of supercapacitor current versus time at charging process with load

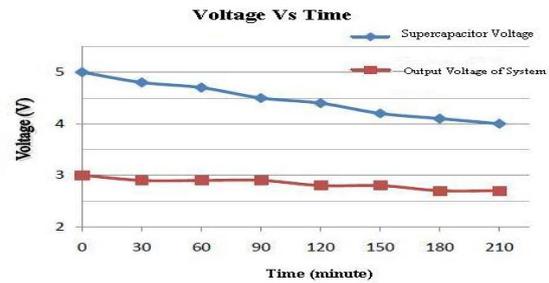


Figure 10 Graph of supercapacitor voltage versus time at discharging process with load

The graph in Figure 9 shows that the greater the value of the light intensity, the faster charging process of supercapacitor. The fluctuations and magnitude of current into supercapacitor were caused by light intensity fluctuations, which have an impact on the value of the generated solar panel currents. The charging time for each value of the average light intensity was 35 minutes for an average intensity of 51,087.50 Lux; 30 minutes for 55,828.87 Lux; and 30 minutes for 59,614.29 Lux. The length of charging time of the intensity average, 59,614.29 Lux was not faster than the 55,828.87 Lux. It happens because of the high temperatures, so that the performance of solar panels will be reduced.

Figure 10 shows a graph of the discharging process with a 16k Ω load. From the data, the findings were that the output voltage of the system decreased from 3V to 2.7V in 150 minutes or 2.5 hours. This shows that the supercapacitor is only able to provide the backup power for 2.5 hours.

3.3. The Experiment with RFID Tag

In this section, the system with given load, i.e. Active RFID Tag will be measured. Figure 11 shows the process of the RFID tag testing.

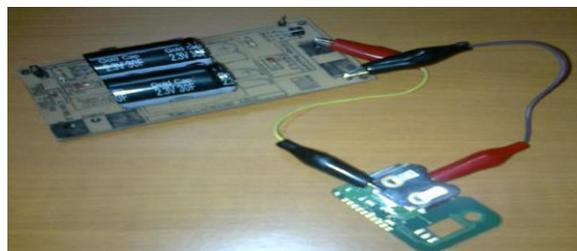


Figure 11 An experiment with RFID tag load

The experimental results, presented in Table 1, are a supercapacitor voltage (V_{CAP}) and the output voltage of the system (V_{out}). Table 1 shows that RFID tags can operate when the voltage of supercapacitors has 5.1V and it can still continue to operate normally until the supercapacitor voltage goes down to 4.8V within 60 minutes. At the 65th minute, the reading on the reader indicates a message, namely “Low Battery Warning”. The warning appears when the supercapacitor voltage is 4.8V and the output voltage of systems 2.8 V. From this test it can be concluded that supercapacitor can back up the RFID tag for 60 minutes, but it can also be concluded that the required minimum voltage of RFID tags is 2.8 V.

Table 1 Discharging Process with RFID Tag Load

t (minute)	V _{cap} (V)	V _{out} (V)	Event
0	5.1	3	no Event
5	5.1	3	no Event
10	5.1	3	no Event
15	5.1	3	no Event
20	5.1	3	no Event
25	5.1	3	no Event
30	5	2.9	no Event
35	5	2.9	no Event
40	5	2.9	no Event
45	5	2.9	no Event
50	5	2.9	no Event
55	5	2.9	no Event
60	5	2.9	no Event
65	4.8	2.8	Low Battery Warning
70	4.8	2.8	Low Battery Warning
75	4.8	2.8	Low Battery Warning

4. CONCLUSION

The conclusion of this paper is the solar panel system with supercapacitors as energy storage can be used as a resource for active RFID tags. The use of the supercapacitor can provide backup power for the system at the 3V output voltage for 360 minutes with a no-load condition, 150 minutes with the use of 16k Ω resistor as a load, and 60 minutes with the use of an active RFID tag as a load. The charging speed of the supercapacitor is directly proportional to the amount of light intensity obtained by the solar panel. The charging time using a 16k Ω resistor load is 35 minutes for the average light intensity at 51,087.50 Lux; 30 minutes for the average light intensity at 55,828.87 Lux and 30 minutes for the average light intensity at 59,614.29 Lux.

5. ACKNOWLEDGEMENT

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