# Different Ways to Charging Supercapacitor in WSN Using Solar Cells

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***Abstract*—The supercapacitors are widely used as a primary or secondary energy source in WSN. In this paper, different ways to charge the supercapacitor using solar cells are presented. The charging time for different connection of solar cells at different levels of light intensity is shown. Also, the advantages and disadvantages of using voltage booster are discussed and explained with appropriate results.**

***Index Terms*—Supercapacitor, Solar cell, Charging time, WSN, Voltage booster.**

## I. Introduction

Wireless Sensor Network (WSN) is one of the most popular technologies today. This network is composed of nodes, and every node has one or more sensors, a microcontroller, and a radio module for communication with the base station. Powering of the WSN nodes is the main problem in all application because the nodes are usually located in some places where is difficult to carry out their maintenance.

The period during which the WSN node can work completely autonomous (without intervention) represents a lifetime of the WSN node. The initial solution for the power supply of WSN nodes was a battery. It is a good solution from the aspect of energy density and self-discharge current. However, batteries have a finite lifecycle (number of charge and discharge) and therefore their frequent replacement is necessary, and it is a significant limitation for their using in these power supply units. But batteries are necessary in applications that include hundreds of WSN nodes and high rates because of high energy consumption.

If the WSN node is powered by a battery, then its lifetime is determined by the capacity of the battery and energy consumption. Obviously, the lifetime of the WSN node can be extended in two ways, increasing the capacity of the battery or reducing the energy consumption of active elements. The first option can be achieved by energy harvester and the supercapacitor.

## II. Increasing capacity of storage unit in WSN

The supercapacitors have been used to increase the power capabilities in WSN nodes. They also have a significant role in other electronics areas even more in commercial products and devices. In some application, which consumes low energy, the battery can be removed and the supercapacitor can be used as the primary energy storage element. The second option is using hybrid systems, storage energy units that have both the battery and the supercapacitor [1]. The supercapacitors are a good solution for storing energy in energy harvesting wireless sensor network nodes (EH-WSNs).

In paper [2] is described power supply unit with the supercapacitor used in combination with a renewable energy source. The paper [3] shows a node with a power supply based on solar cell and the supercapacitor. The estimated lifetime without maintenance, how it is presented in this paper, is 20 years. The other improvements are MPPT (Maximum Power Point Tracking) and PFM (Pulse Frequency Modulation).

The most significant drawback of the supercapacitor is leakage current and self-discharging process described in [4] and [5]. A part of the supercapacitor energy is dissipated on a series resistance which is present because of imperfections in its structure [6]. Also, a power management circuit is needed to provide a balance between harvested and consumed energy over a long period [7]. If the harvested energy is greater than the consumed energy, the power management circuit will charge the supercapacitor. Energy will be used from the supercapacitor if harvested energy is not sufficient.

## III. Experimental setup

The idea of this research is a comparison of different ways to charge the supercapacitor with a solar cell at different levels of light intensity.

The main goal is finding the most effective solution to charge the supercapacitor (470 mF) up to 3.3 V with the different configurations of solar cells whereby all configurations produce the same output power. This voltage level is chosen because this is a working voltage for the numerous microcontrollers, sensors, and radio modules in WSN nodes.

The structure of the supercapacitor implicates that it can not be said with certainty at this moment if the supercapacitor fully charged. Because of that, the time where voltage of the supercapacitor comes up to 3.3 V (charging time) is measured instead of fully charging time.

Two identical solar cells, IXYS 17-04x3 (Fig. 1), were used. The basic parameters of these cells are open circuit voltage, $V_{OC}$=1.89 V, and short circuit current, $I_{SC}$=42 mA. It should be noted that these values were obtained with measurements at standard test conditions environment

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(1000 W/m$^2$), and their values will be significantly different in real conditions.

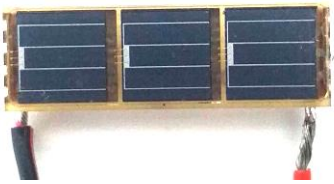

Fig. 1. Solar cell IXYS 17-04x3.

These solar cells are part of the IXOLARTM SolarBITs high efficiency solar cells made from monocrystal silicon. Its efficiency is about 17%, and they can work in low light conditions, so they are suitable for WSN nodes and portable instrumentations. The main advantage of used solar cells is small size and they can be easily accommodated in many designs.

In the first configuration, shown in Fig. 2, two solar cells are connected in series, so the output voltage is 3.5 V – 3.6 V in the light range of interest. In this configuration, the supercapacitor can be charging directly from solar cells, without any additional circuits. Between solar cells and the supercapacitor Schottky diode is needed to prevent discharging in the inverse direction in low light conditions. The Zener diode should be placed in parallel with the supercapacitor because the output voltage of solar cells can rise above the critical level in high light conditions.

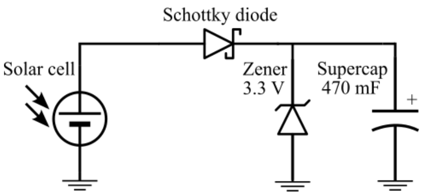


Fig. 2. Electric circuit for charging the supercapacitor with two solar cells connected in series.

The second configuration is a parallel connection of solar cells. In this configuration solar cells produce higher current, so the charging time of the supercapacitor should be shorter than in series configuration. But, in this case, the output voltage of solar cells is not sufficient (1.8 V) for charging the supercapacitor, so the voltage booster (booster) must be inserted in the circuit (Fig. 3). The booster can produce higher voltage on his output than the input voltage is. This concept is very widely used in many applications with multiple energy harvester sources [8].

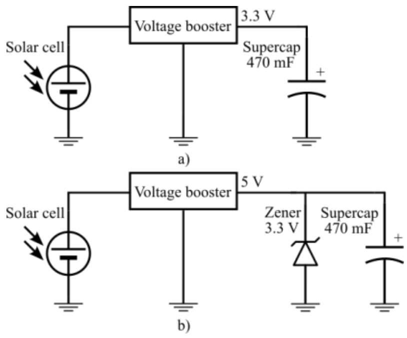


Fig. 3. Electric circuit for charging the supercapacitor with two solar cells connected in parallel. a) The output voltage of the booster at 3.3 V; b) The output voltage of the booster at 5 V.

In case a) the output voltage of the booster is 3.3 V and the supercapacitor is connected directly to this voltage without any additional component. The Zener diode is not necessary because the output voltage of the booster is regulated and independent from changes in input voltage.

The second way is charging the supercapacitor with a voltage that is higher than it is needed. In this case it is 5 V, like it is shown on b) part of Fig. 3. The Zener diode is necessary here.

The idea is to determine whether the charging time of the supercapacitor decrease when the output voltage of the booster rises.

One more way is a series connection of cells and charging the supercapacitor with the booster. In this case, the booster is not needed but, like in the former case, the idea is to measure charging time at a higher voltage with the same configuration.

In this research was used high-efficiency, fixed frequency, DC-DC voltage booster MCP1640 [9]. It can be used for power supply with batteries and energy harvester sources. The output voltage range is from 2 V to 5.5 V and the input voltage range is 0.35 V < $V_{OUT}$ < 5.5 V, with the start-up voltage of 0.65 V. This circuit can automatically switch over between PWM and PFM mode to maximize efficiency. The output voltage can be easily adjusted by selecting just two resistor values ($R_1$ and $R_2$). $R_1$ is a resistor connected between FB pin and ground pin and $R_2$ is the resistor connected between FB pin and OUT pin. The output voltage can be expressed by equation 1:

$$V_{OUT} = V_{FB}\,(1 + R_1/R_2), \qquad (1)$$

where $V_{FB}$ is a fixed voltage reference of 1.21 V.

More practical way for setting the output voltage, shown in Fig. 4, can be realized using a potentiometer instead of resistors $R_1$ and $R_2$.

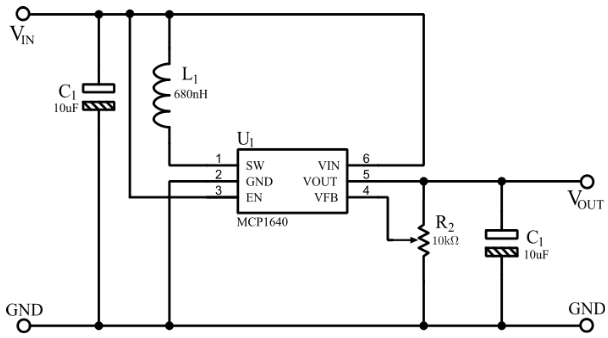


Fig. 4. Simplified electronic circuit with voltage booster MCP1640.

## IV. Results

The most simplified way to charge the supercapacitor, of all presented, by using solar cells is one in Fig. 2. The charging curves of the supercapacitor based on this configuration are shown in Fig. 5.

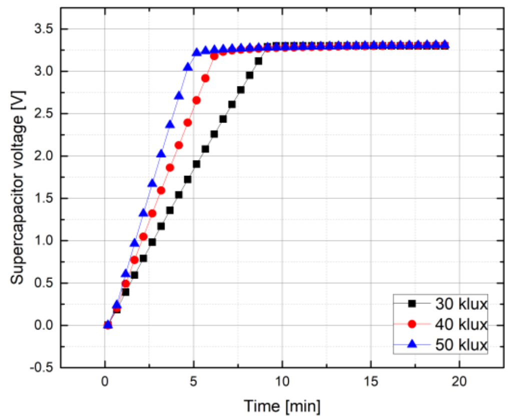


Fig. 5. Charging time of the supercapacitor in case of a series connection of solar cells. These results are obtained using the circuit shown in Fig. 2.

It needs several minutes for charging the supercapacitor up to 3.3 V and the charging curves have different slope at different levels of light intensity. The curve has a higher slope at a higher level of light intensity and it confirms theoretical claims. The reason for that is the fact that solar cells produce more output power at a higher level of light intensity. In other words, if the level of light intensity rises then charging time decreases.

The charging time of the supercapacitor is longer when the solar cells are connected in parallel although they produce higher current in that case. The curves in Fig. 6 confirm that.

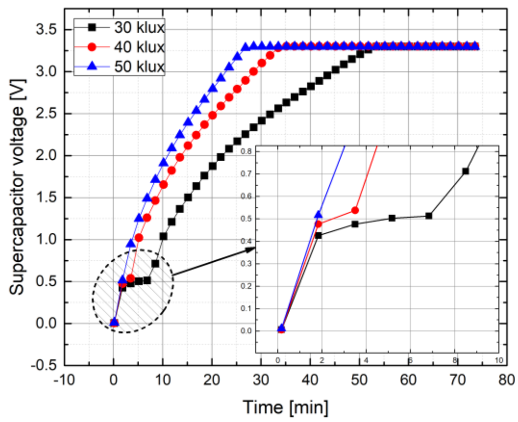


Fig. 6. Charging time of the supercapacitor in case of a parallel connection of solar cells with MCP1640 booster. The output voltage of the booster is 3.3 V. These results are obtained using the circuit shown in Fig. 3. a).

The booster used in this case helps to get sufficient voltage level to charging the supercapacitor (input voltage is 1.8 V), and without it, the charging process will not be possible. However, the voltage booster consumes energy and can not deliver all of the energy produced by solar cells to the supercapacitor. It is a reason because the charging time is much longer in this case than in the case without the booster.

The moment when the booster becomes active is shown on the circled and enlarged part of Fig. 6. Like can be seen, it is needed some time for the booster to accumulate enough energy for generating a certain voltage level on its output. This time is longer at a lower level of light intensity because of lower input energy. In Fig. 7 is shown voltage level (PFM form) on the SW pin of the booster when the circuit is in the active state. In this case, the input voltage is boosted and passed to the output pin.

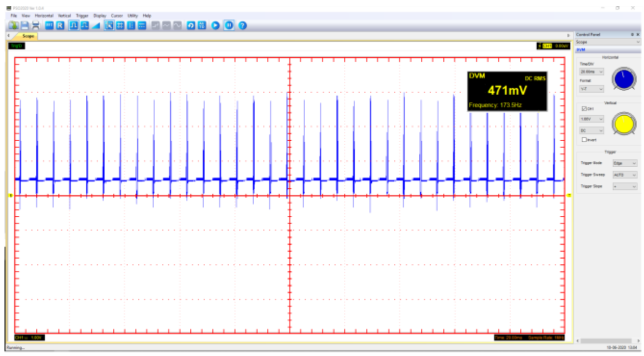


Fig. 7. The voltage on the SW pin while the MCP1640 booster is in the active state.

Like already said, the second way to charge the supercapacitor with the booster is to set the output voltage of the booster to a higher level than it is necessary. With a higher output voltage of the booster (potential difference between the booster and the supercapacitor), it can be expected that the charging time of the supercapacitor will be shorter. However, this claim is valid only if the intensity of the current is still constant. It can not be achieved with the booster and the curves in Fig. 8 confirm that.

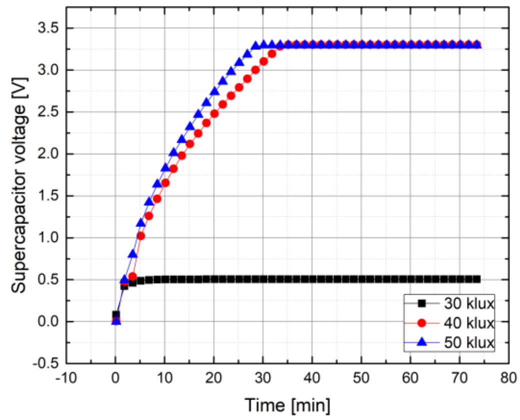


Fig. 8. Charging time of the supercapacitor in case of a parallel connection of the solar cells with MCP1640 booster. The output voltage of the booster is 5 V. These results are obtained using the circuit shown in Fig. 3. b).

The charging time at 40 klux and 50 klux is several minutes longer than in the case when the output voltage of the booster is 3.3 V. Actually, this can be explained as a consequence of the law of conservation of energy. If the input power is constant then the output power will be constant also. The consequence of that is smaller output current with increasing the output voltage and because the output current is smaller, the more time is needed to charge the supercapacitor.

The additional problem in this case is occurred at a low level of light intensity conditions because of the low current that solar cells produce. A low current means low input power and the booster can not be activated (Fig. 9). The unregulated frequency of the PFM signal on the SW pin and amplitude of this signal indicates a deficiency of the energy to produce a high output voltage. Thus, the output current is the same as input and is not sufficient for charging the supercapacitor, and it will be charged only up to 0.5 V, approximately.

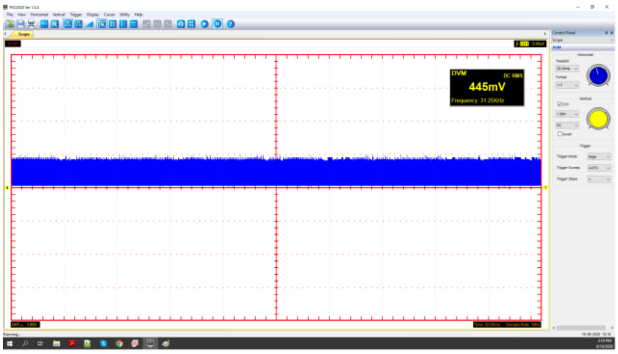


Fig. 9. The voltage on the SW pin while the MCP1640 booster is in the inactive state. Time base and the voltage per division are equal as on Fig 7.

Fig. 10 and Fig. 11 show the summarized comparisons of the charging time of the supercapacitor for different circuit configurations at two different levels of light intensity.

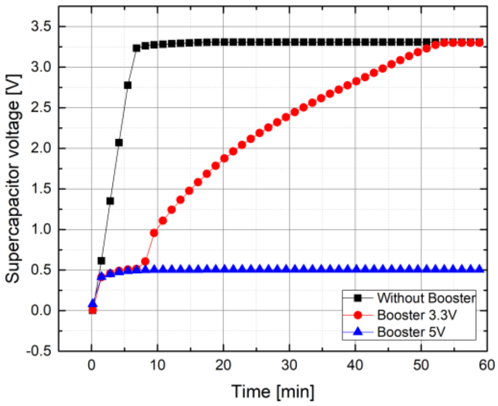


Fig. 10. Comparison of charging time of the supercapacitor for different circuit configurations at 30 klux.

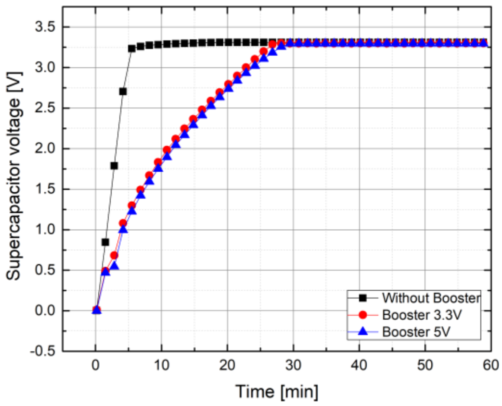


Fig. 11. Comparison of charging time of the supercapacitor for different circuit configurations at 50 klux.

## V. Conclusion

Based on the obtained and presented results it can be resumed that the best solution for charging the supercapacitor using solar cells is the circuit without the booster. That is because there is not an additional waste of energy on the booster circuit and almost all produced energy goes to the supercapacitor.

On the other hand, when the combination of solar cells has a smaller output voltage then it is necessary, the booster is a good solution.

One should keep in mind that the booster consumes some part of produced energy so the charging time of the supercapacitor will be longer. Also, a certain amount of energy and time is needed to activate the booster. It extends the charging time of the supercapacitor and it can be a problem at a lower level of light intensity. If the output voltage of the booster rises, the output current will decrease and the charging time will be longer, so the output voltage of the booster should not be higher than it is needed when a source is a solar cell or some other energy harvester with dependent output current.

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