Solar Panel-based Wireless Battery Charging System using Fuzzy Control Method

Alfarid Hendro Yuwono¹, Muhammad Rivai², and Tri Arief Sardjono³

Department of Electrical Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia.
¹alfarid.man@gmail.com, ²muhammad_rivai@ee.its.ac.id, ³sardjono@bme.its.ac.id

Abstract. Rapid technological development leads to the growth of electronic devices powered by batteries. This requires a simple, fast and safe battery charging system. In this study, we have designed and realized a wireless battery charging system supplied by solar panel using the fuzzy control method. This system is equipped with solar tracking to produce optimal electric power. Furthermore, fuzzy control system is applied to determine the amount of charging voltage by taking into account the temperature of the battery. The experimental results show that the solar tracking system can improve the performance of solar panel. The system always detects the temperature of the battery and will reduce the voltage value during the charging process as the temperature increases. This battery charging system will also automatically decrease the charging voltage when the battery voltage approaches the maximum value. This system is expected to be used as a fast battery charging system without affecting the battery life.

Keywords: Fuzzy control method, Solar panel, Wireless battery charging.

1. Introduction

Currently, technological developments have an impact on the increasing number of portable electronic devices that are supplied with batteries such as cellphones, computers, and vehicles. This requires a simple battery charging system such as the wireless power transfer method. This method transfers energy of the electromagnetic field using inductive coupling. The energy is sent through the coil to an electrical device which can then be used for battery charging [1]. Research on the wireless power transfer is being developed that can be applied in various fields. In the medical field, wireless power transfer is used to supply implantable electronic devices to a patient's body [2]. The automotive industry has also begun to develop wireless power transfer systems to charge electric cars [3], [4]. One of the problems regarding wireless power transfer systems is the length of time required to charge an electronic device [5]. This is because the power transferred by the system tends to be constant regardless of the condition of the power available on the charged battery. Improper charging methods can affect the battery life.

Nowadays solar panels are considered as an alternative solution for a source of electricity that is low cost and does not produce pollution. Solar panels are still rarely used in both communities and industrial areas. The solar tracking system can be applied in order the solar panels can produce optimal electrical energy [6]. Among the control methods, fuzzy logic is often used widely in various fields such as the solar tracking system [7], robot navigation [8], [9], and electrostatic air filtration system [10]. This is because the fuzzy control method is able to apply to non-linear elements without having to find an exact
mathematical model [11]. In this study, we have designed and realized a wireless battery charging system supplied by solar panel using the fuzzy control method. This system is expected to produce optimal solar energy and fast charging time without affecting the battery life.

2. Methods
The overall block diagram of a solar panel-based wireless battery charging system is depicted in figure 1. In general, the system consists of three main parts including solar tracking, wireless battery charging, and fuzzy control method. The Arduino microcontrollers are employed to measure the sensor signal, to determine the amount of transferred energy, and to control the battery charging system.

2.1. The solar tracking
The solar tracking system is applied in order the solar panel can follow the movement of the sun which keeps the surface always perpendicular to the sunlight as shown in figure 2(a). This system involves a 100 WP solar panel, a servo motor, the Arduino Nano microcontroller, and two Light Dependent Resistor (LDR) sensors. The LDR resistance decreases with increasing light intensity and vice versa. The change in resistance will be represented by a change in voltage in a voltage divider circuit. This will give action to the servo motor to change the direction of the solar panel so that the two sensors receive similar energy indicating the surface of the solar panel is perpendicular to sunlight. The electrical energy produced by solar panels is stored in a battery or accumulator for supplies in the absence of sunlight either when covered by clouds or at night. The solar tracking algorithm is illustrated in figure 2(b).

2.2. The wireless battery charging
The working principle of wireless power transfer is to convert DC signals into sinusoidal AC signals which are then sent to the primary coil and emitted in the form of magnetic flux so that it can be received by the secondary coil [12], as shown in figure 3. The sine wave applied to the coils can provide higher power transfer efficiency [13]. The rectifier and low pass filter circuits are employed to ensure the battery receives a DC signal for charging purposes. In this experiment, we set the distance between the coil is about 1 cm with the series-parallel (SP) topology. The transmitter inverter is provided by the AD9833 Programmable Waveform Generator, X9C103 Digitally Controlled Potentiometer, and TDA7386 Amplifier modules. The AD9833 module can be programmed to produce sine, triangle, and square wave signals with a frequency range of 0 MHz to 12.5 MHz. This device has the function of turning off the power when the device is not in use to minimize electrical power consumption. The X9C103 module has 100 wiper tap points which the position can be stored in non-volatile memory. The TDA7386 module has a high output power capability of 4 x 49 W / 4 Ω load with high cut-off frequencies up to 200 kHz.

![Figure 1. The overall block diagram of a solar panel-based wireless battery charging system.](image-url)
2.3. The fuzzy control method
Fuzzy logic is a mathematical means that represents decision making based on imprecise and non-numeric information. In this method, the variables can assume linguistic values. Fuzzy logic consists of three stages, namely fuzzification, inference, and defuzzification depicted in figure 4. Fuzzification is the process of converting crisp input into a fuzzy input [14]. In this study, there are two input membership functions, namely the electric current ($I$) and the temperature ($T$) of the battery as shown in figure 5(a). Fuzzy control system is used to determine the amount of charging voltage by taking into account the temperature of the battery. When the battery temperature is low, the charging voltage will be high so that the battery fills up quickly. Moreover, when the temperature of the battery begins to rise, the charging voltage will be adjusted so that it does not damage the battery. The analog signals from the current and temperature sensors are converted to digital values using a 10-bit Analog-to-digital converter (ADC) embedded in the Arduino Uno microcontroller.

Inference consists of IF-THEN rules expressed as:

$$\text{if } X_1 \text{ is } A_1 \text{ and } \ldots \text{ and } X_n \text{ is } A_n \text{ then } Y \text{ is } B$$  \hspace{1cm} (1)
Meanwhile, the implication function of the rules can be declared as:

$$
\mu_B(y) = \max \{\min[\mu_{A_1}(input(i)), \mu_{A_2}(input(j)), ...] \} 
$$

(2)

The fuzzy output membership functions, and the rule evaluation are shown in figure 5(b) and figure 5(c), respectively. Defuzzification is the process of converting fuzzy output to crisp output [15]. The defuzzification method used in this study is the Center of Area (CoA) which is expressed as follows:

$$
Z_0 = \sum_{i=1}^{n} \frac{\mu(Z_i)Z_i}{\mu(Z_i)} 
$$

(3)

3. Result and Discussion
The solar tracking system used in the experiments is shown in figure 6(a). In the first experiment, we compare the output power of solar panel with and without tracking system recorded every hour. The result of this experiment is shown in figure 6(b). In the morning and evening, the solar panel equipped with the tracking system produces higher electrical power. The solar panel equipped with solar tracking provides a higher average electric power of 44%. This shows that the solar tracking system can improve the performance of solar panel.
The next experiment is wireless power transfer. Several measurements are carried out using sinusoidal signals with frequencies between 50 kHz and 150 kHz as shown in figure 7(a). This signal is fed to the primary coil, then the power is received in the secondary coil. The results of this experiment indicate that the optimal value for wireless power transfer is a sine wave with a frequency of 90 kHz.
shown in figure 7(b). This system can transfer power with an efficiency of 80% at a distance between the coils of 1 cm as shown in figure 7(c).

![Figure 7](image)

Figure 7. (a) Wireless battery charging system, and (b) the charge time.

The last experiment is wireless battery charging system using fuzzy control method as shown in figure 8(a). The experimental results show that the initial charging voltage is set to the maximum. The temperature tends to increase during the battery charging process. The system always detects the temperature of the battery and will reduce the voltage value during the charging process as the temperature increases. Therefore, the battery can avoid damage due to overheating. This battery charging system will also automatically decrease the charging voltage when the battery voltage approaches the maximum value indicated by a decreasing current, as shown in figure 8(b). This system is expected to be used as a fast battery charging system without affecting the battery life.

4. Conclusion
In this study, we have designed and realized a wireless battery charging system supplied by solar panel using the fuzzy control method. This system is equipped with solar tracking to produce optimal electric power. Furthermore, fuzzy control system is applied to determine the amount of charging voltage by taking into account the temperature of the battery. The experimental results show that the solar panel equipped with solar tracking provides a higher average electric power of 44%. The optimal value for wireless power transfer is a sine wave with a frequency of 90 kHz. This system can transfer power with an efficiency of 80% with a distance between the coils of 1 cm. The system always detects the temperature of the battery and will reduce the voltage value during the charging process as the temperature increases. This battery charging system will also automatically decrease the charging voltage when the battery voltage approaches the maximum value. For future works, sensor signals as the control feedback will be sent via a wireless connection. The buck-boost converter will be employed to increase the system efficiency.

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5. References
[1] Bomber A, and Rosa L, 2006. Wireless Power Transmission: An Obscure History, Possibly a Bright Future. Phys 464: Appl. Opt., pp. 1–15.
[2] Jiang H, Zhang J, Lan D, Chao, Liou S, Shahnasser H, Fechter R, Hirose S, Harrison M, Roy S, 2013. A Low-Frequency Versatile Wireless Power Transfer Technology for Biomedical Implants. IEEE Trans. Biomed. Circuits Syst., 7, pp. 526–535

[3] Yashchenko V, Turgaliev V, Kozlov D, Vendik I, and Katsay A, 2017. Adaptive impedance-matching network for wireless power transfer system with off-center receiver, Electromagnetics Research Symposium, pp. 2185–2189

[4] Samanta S, Rathore AK, and Thrimawithana DJ, 2017. Analysis and Design of Current-Fed Half-Bridge (C)(LC)–(LC) Resonant Topology for Inductive Wireless Power Transfer Application. IEEE Trans. Ind. Appl., 53, pp. 3917–3926

[5] Mou X, and Sun H, 2017. Analysis of multiple segmented transmitters design in dynamic wireless power transfer for electric vehicles charging. Electron. Lett., 53, pp. 941–943

[6] Nayak SR, Pradhan CR, Ali SM, and Sabat R, 2012. Application of Solar Energy Using Artificial Neural Network and Particle Swarm Optimization. International Journal of Advances in Engineering & Technology, pp. 550-560

[7] Guo L, Han J, and Otieno AW, 2013. Design and Simulation of a Sun Tracking Solar Power System. ASEE Annual Conference & Exposition, pp.1-6

[8] Rivai M, Rendyansyah, and Purwanto D, 2015. Implementation of Fuzzy Logic Control in Robot Arm for Searching Location of Gas Leak. International Seminar on Intelligent Technology and Its Application, pp 69-74

[9] Putra R, Rivai M, and Irfansyah AN, 2018. Unmanned Surface Vehicle Navigation Based on Gas Sensors and Fuzzy Logic Control to Localize Gas Source. Journal of Physics: Conference Series, 1201, pp.1-8

[10] Meivita DN, Rivai M, and Irfansyah AN, 2018. Development of an Electrostatic Air Filtration System Using Fuzzy Logic Control. International Journal on Advanced Science, Engineering and Information Technology, 8, pp. 1284-1289

[11] Asadi H, Kaboli A, Mohammadi A, and Oladazimi M, 2011. Fuzzy Logic Control Technique in Li-Ion Battery Charger. International Conference on Electrical, Electronics and Civil Engineering, pp. 179-183

[12] Yashchenko V, Turgaliev V, Kozlov D, Vendik I, and Katsay A, 2017. Adaptive impedance-matching network for wireless power transfer system with off-center receiver. Electromagnetics Research Symposium - spring, pp. 2185–2189

[13] Sarwar MB, Nallagownden P, Baharudin Z, and Muthuvalu MS, 2016. Review of Different Techniques used for Wireless Transmission of Electrical Energy. MATEC Web of Conferences, 38, pp. 1-7.

[14] Sugiarto K, Rivai M, Irfansyah AN, 2019. Control of Livestock Waste Odors Using Gas Sensors and Fuzzy Logic. International Conference on Information & Communication Technology and System, pp. 81-86

[15] Rendyansyah, Rivai M, and Purwanto D, 2019. Olfactory Arm Mobile Robot for Object Inspection Based on Fuzzy Logic and Support Vector Machine. Journal of Physics: Conf. Series, 1196, pp.1-9