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Design of a monitoring and protection system for lithium ion (Li-Ion) batteries on solar panels

Hartono Hartono[a], Samsul Hidayatulloh[a], Yusraini Muharnin[*,b]

[a]*Department of Electrical Engineering, Universitas Sultan Ageng Tirtayasa, Jl. Jend. Sudirman KM 3, Cilegon 42435, Banten, Indonesia.*
[b]*Department of Industrial Engineering, Universitas Sultan Ageng Tirtayasa, Jl. Jend. Sudirman KM 3, Cilegon 42435, Banten, Indonesia.*

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ABSTRACT

Solar energy is one of several new and unlimited renewable energy sources. In Indonesia, sunlight, despite its abundance, is often underutilized as an energy source. It is designed to optimize battery charging and discharging performance while ensuring operational safety through automatic protection. Battery charging tests show that the solar panels can produce a total current of 3.56 Ah in one day, indicating high efficiency under ideal lighting conditions. During the no-load discharge test, the system maintained a stable output voltage between 5.1 and 5.2 V for input voltages between 4 and 12 V, but the output voltage became zero when the input was less than 4 V, indicating the presence of a cut-off mechanism to protect the battery from under-voltage. Further testing with a load showed the battery voltage dropping to 11.26 V, with the current stabilizing at 0.3 A. The protection system is proven to be effective, becoming active at a temperature of 50 degrees Celsius and a current of 1 A, preventing overheating and overcurrent, which can damage the battery or cause a safety hazard.

1. Introduction

Utilization of New Renewable Energy for electricity generation in 2018 amounted to 8.8 GW, or only around 14% of the total electricity generation capacity (fossil and non-fossil) of 64.5 GW (Ministry of Energy and Mineral Resources data) [1]. Despite this low utilization, solar energy offers significant potential. In Indonesia, sunlight is often underutilized as an energy source. This country has very high potential in utilizing sunlight as an energy source because of its location on the equator [2].

Solar power has several advantages that make it by far the fastest-growing renewable energy technology. It is cheap, low-maintenance, and scalable; solar power installations can be easily expanded to meet growing energy demands. Solar power plants are not only necessary but also contribute to reducing reliance on traditional energy sources. To maximize the use of electricity generated by solar panels, energy storage becomes crucial. Ideally, the storage medium should allow for discharging power at any time. This ensures the electricity grid can utilize the stored power when overall demand is high [3].

Batteries, which are electrical energy storage devices, come in two main types: primary (non-rechargeable) and secondary (rechargeable) [4]. Li-ion batteries have become the most widely used rechargeable batteries due to several advantages, including high specific energy density, efficiency, fast charging capabilities, and a relatively long lifespan [5, 6]. Li-ion batteries offer additional benefits compared to other secondary batteries. These advantages include low self-discharge, good cycle life (repeated charging and discharging performance), and environmental friendliness [7, 8].

Lithium-ion batteries can experience mechanical damage if external pressure deforms the battery casing or if it is punctured by a sharp object (e.g., a nail). Overcharging, overdischarging, and external short circuits can also cause damage [6]. Battery life can also be impacted by the charging current. While using a high current can shorten charging times, it can damage the electrolyte cells and cause the battery to overheat [9]. Therefore, a system or tool for monitoring and controlling power usage is crucial to ensure optimal battery health [10, 11].

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*Corresponding author:
Email: bundamia1974@gmail.com

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Several studies have explored the integration of solar panels with various applications, including smartphone charging with voltage monitoring [12], water pumping with solar tracking [13], and LED lighting with modular Li-ion batteries [7]. Additionally, research has been conducted on overload protection systems for solar panels [2] and portable solar panel battery management systems [14]. Furthermore, studies on smart home automation using microcontrollers and relay modules have been documented [15]. Building upon this existing research, this work proposes a novel Li-ion battery monitoring and protection system designed for a solar phone charger.

2. Material and method

The coulomb counting method, a current-based approach, calculates the state of charge (SOC) of a battery [16]. It integrates the measured charge and discharge currents to determine the remaining energy in coulombs relative to the battery's known capacity [17].

2.1. *Hardware design*

The electrical circuit for this project is designed and built using several key components. The first is a monitor with a 2x16 LCD screen. This monitor keeps an eye on the battery's health by displaying both its temperature and current. The brain of the system is an Arduino Uno microcontroller. This tiny computer is responsible for processing all the data collected from the various components [18].

Another component is an indicator light. This light serves a simple but important purpose: it signals when the battery has enough power to charge a device through the USB port. The USB port itself is the endpoint where you can connect your device for charging. The final key component is a relay. This acts like a switch, and it controls whether electricity flows from the battery to the USB port. The user plays a crucial role in this system. They program the Arduino Uno to prioritize long battery life [19]. This program relies on data from the current and temperature sensors to take protective measures. If the current flowing through the battery becomes excessive, or if the battery temperature rises too high, the microcontroller springs into action [20]. It activates the relay, which cuts off the current flow to the USB port, protecting the battery from damage. Fig. 1 shows the desig of the current circuit.

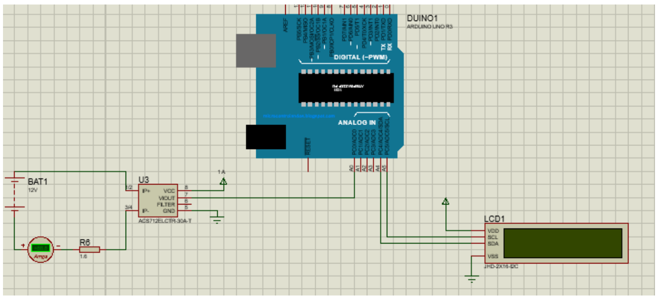

Figure 1. Design of current circuit

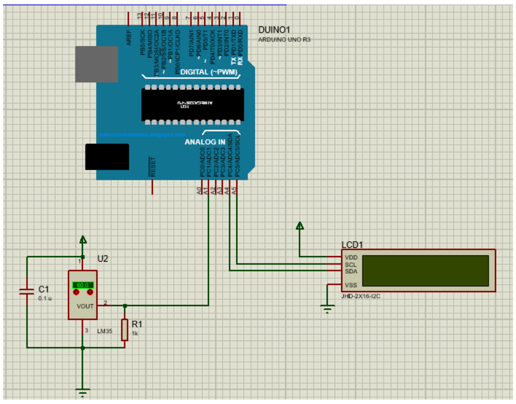

Figure 2. Design of temperature sensor circuit

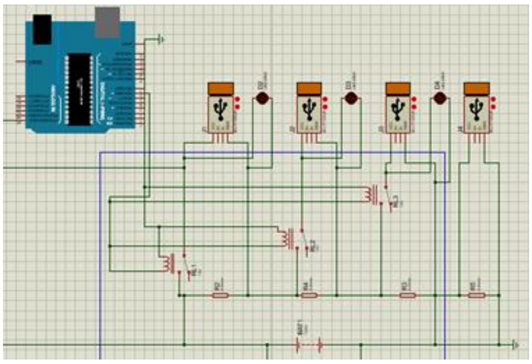

Figure 3. Design of protection

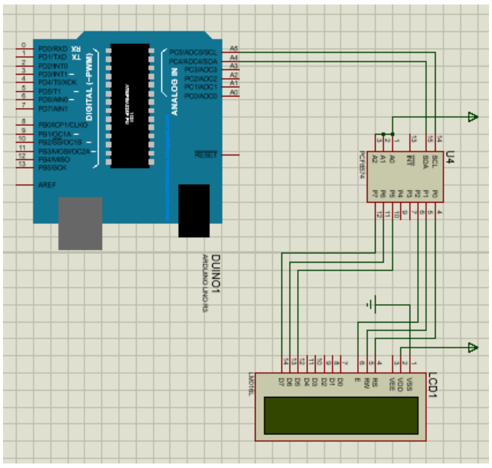

Figure 4. Design of monitoring

2.1.1. *Current sensor design (ACS712)*

The current sensor serves two purposes: it measures the current flowing during charging and discharging, displaying the value on the LCD. Additionally, it detects overcurrent conditions. This research employs the ACS712-30A current sensor, chosen for its 66 mV/A sensitivity and -30 A to 30 A measurement range, as specified in the ACS712 datasheet.

2.1.2. *Design of thetemperature sensor (LM35)*

The temperature sensor circuit is made to measure battery temperature. Temperature sensors are also used to detect overheating conditions in the battery. The temperature sensor used is LM35 with a sensitivity of 10 mV/°C. The temperature series in this study was designed to have a measurement range of 0°C to 60°C. Fig. 2 shows the temperature sensor circuit.

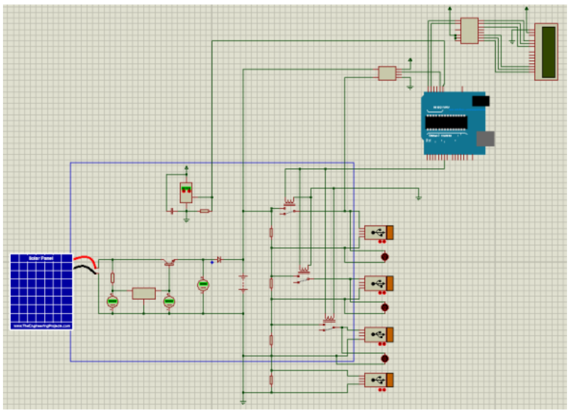

Figure 5. Design of electrical circuit

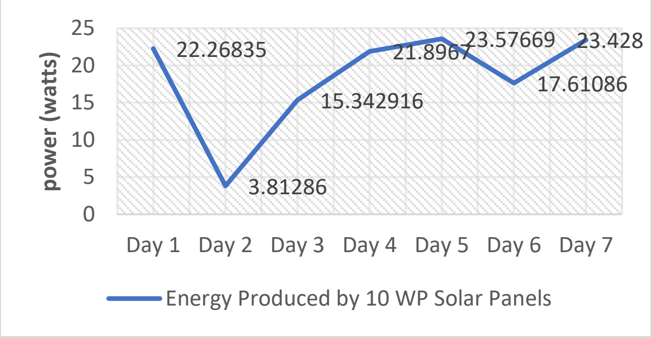

Figure 6. Solar panel energy graph for 7 days

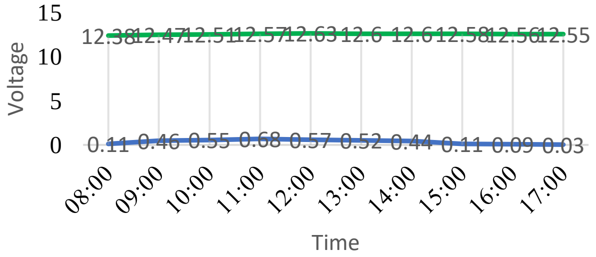

Figure 7. Battery charge test results

2.1.3. *Protection design*

The protection circuit, designed to disconnect the battery from the load or charger during overcurrent or overheating conditions, utilizes a relay as its main component. This relay can handle a maximum current of 1 A and operates at a working voltage of 12 V. Fig. 3 shows the design of protection.

2.1.4. *Monitoring design*

In general, a monitoring system provides feedback on a program's execution by displaying information or the system's current state. The battery monitoring system here serves this purpose by gathering information on battery health, such as temperature and current. An Arduino Uno microcontroller is used to process this data, and the key parameters are then displayed on a 16x2 LCD screen. Fig. 4 shows the monitoring design.

2.1.5. *Electrical circuit design*

The charger station's electrical circuit incorporates several electronic components: a 10 WP monocrystalline photovoltaic solar panel, SCC PWM solar charger controller, step-down buck converter, diode, battery circuit, Arduino microcontroller, relay, LED lights, and charger module. The battery system utilizes 15 18650 lithium-ion batteries, a 20 A BMS board, and a 3S battery holder. The circuit design was created using Proteus software (Fig. 5).

2.1.6. *Tool design*

In 3D tool design, a well-organized component layout is key for a neat and user-friendly device. This tool features five components: a 10 WP solar panel, a USB port, an emergency port, a 10 Ah battery with BMS (Battery Management System), and an Arduino Uno microcontroller.

2.2. *Software design*

To provide a clear reference for the microcontroller's operation, the software is designed using a program algorithm written in C language.

2.3. *Tool testing*

2.3.1. *Current sensor circuit testing*

The current sensor circuit is tested to verify its accuracy in reading current values. This is achieved by comparing the current readings obtained by the microcontroller with those from a reference ammeter.

2.3.2. *Temperature sensor circuit testing*

The purpose of testing the temperature sensor is to read the temperature value on the LM35 sensor. The test was carried out by comparing the temperature value on the digital thermometer with the LM35 temperature value read on the microcontroller.

2.3.3. *Protection circuit testing*

Protection circuit testing evaluates the relay's ability to respond to overcurrent and overheating conditions. This is achieved by simulating these fault conditions and observing the relay's response signal.

3. Results and discussions

3.1. *Hardware design results*

The hardware design or hardware that has been designed is implemented in a form that is in accordance with the design to make it easier to implement and simulate the system. The tools used are made of wood which contains tool components.

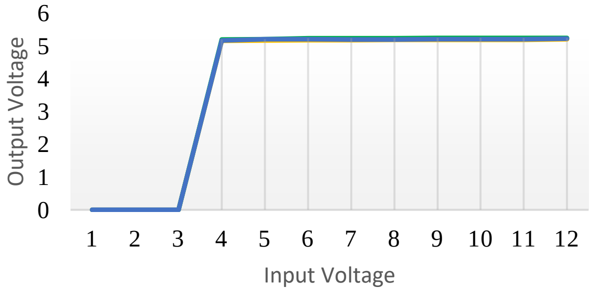

Figure 8. Battery charge test results (without load)

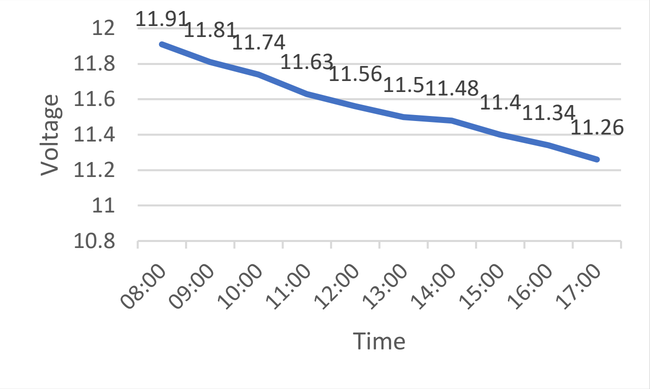

Figure 9. Battery discharge voltage (with load)

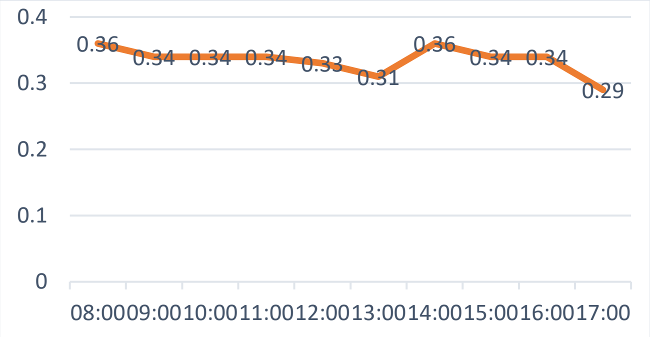

Figure 10. Battery discharge current (with load)

3.2. *Testing 10 WP monocrystaline solar panels*

To measure their voltage output, solar panels undergo a drying process in direct sunlight. Testing was conducted for seven consecutive days, with a total duration of 10 hours per day. The testing period began at 8:00 AM and concluded at 5:00 PM each day. The graph depicts the energy production of a 10 WP solar panel over seven days. Notably, the energy produced on the second day deviates significantly from the other days. This is likely due to weather conditions on the second day, which was characterized by rain and overcast skies. The resuts are shown in Fig. 6.

3.3. *Battery charge testing*

Battery charging efficiency was evaluated by monitoring voltage and current flow from the solar panel to the battery during a 10-hour test (08:00 AM to 17:00 PM). Multimeter and ampere pliers were used to capture these measurements. The results are shown in Fig. 7.

3.4. *Battery discharge testing*

The charger module is tested by providing a range of input voltages, from 0 V to 12.3 V. [Separate sentence] Additionally, battery charging efficiency is evaluated in a separate test. This charger module operates within an input voltage range of 4 V to 12 V. When functioning properly, it provides a stable output voltage between 5.1 V and 5.2 V. However, the module will not produce any output voltage if the input voltage falls below 4 V. In such cases, the device's buck converter module remains inactive.

The battery discharge test evaluates the change in voltage and current after turning on a 10 W LED lamp. The test is conducted using multimeter and ampere pliers to measure these reductions in voltage and current. Fig. 8 illustrates the voltage drop experienced by the battery when subjected to a light load. Notably, the current flowing from the battery remains stable during this test. As expected, the battery discharge time is directly related to the size of the load. In simpler terms, a larger load will cause the battery to discharge or drain more quickly. The results are shown in Fig. 9.

3.5. *Current sensor testing (ACS712-30A)*

The ACS712 current sensor test is designed to verify its functionality by measuring the current flowing through the circuit. The Arduino Uno microcontroller is connected to the sensor for programming. The sensor itself is connected in series between the battery (external power source) and the load (LED). The current value is measured using a multimeter and displayed on the monitor screen.

3.6. *Temperature sensor testing (LM35)*

Temperature sensor testing is conducted to verify its accuracy in measuring temperature. This is achieved by comparing the temperature readings displayed on the sensor's screen with those from a reference thermometer. The test is carried out twice: once in an ambient temperature environment and again with a heat source applied. The comparison revealed minimal discrepancies between the sensor and thermometer readings, well within an acceptable range of error (0% to 0.09%).

3.7. *Protection circuit testing*

Overcurrent testing utilizes the ACS712 current sensor to monitor the relay's response when the current output surpasses a predetermined limit set on the Arduino microcontroller. The test setup includes essential components: batteries, Arduino, the ACS712 sensor, a relay, an LED, and two resistors acting as loads. Tables 1, 2, 3, and 4 show the protection circuit testing.

Table 1.
Test results current sensor

Resistor (Ω)	Sensor Test Data (A)		Percentage Error (%)
	LCD	Calculation	
74.3	0.07	0.06	0.167
32.5	0.16	0.15	0.067
9.5	0.55	0.52	0.058
8.8	0.59	0.56	0.054
5.2	1	0.96	0.042

Table 2.
Test results temperature sensor

No	Sensor Test Data (A)		Percentage Error (%)
	LCD	Thermometer	
1	30.27	30.30	0.099
2	30.76	30.75	0.033
3	31.25	31.25	0.000
4	31.74	31.75	0.031
5	47.85	47.90	0.104
6	50.29	50.32	0.03

Table 3.
Test results for relays and current sensors

Resistor (Ω)	Current (A)	Relay status		
		1	2	3
330	0.3	OFF	OFF	OFF
35	1.3	ON	ON	ON

Table 4.
Test results for relays and temperature sensors

LCD	Status relay		
	Relay 1	Relay 2	Relay 3
30.27	OFF	OFF	OFF
30.76	OFF	OFF	OFF
31.25	OFF	OFF	OFF
31.74	OFF	OFF	OFF
47.85	OFF	OFF	OFF
50.29	ON	ON	ON

These resistors are used to achieve specific current levels: below 1 A for an inactive relay and above 1 A for an active relay. The respective resistance values for these loads are 330 Ω and 35 Ω. The first test used a 330 Ω resistor, resulting in a current of 0.3 A. Consequently, the relay remained inactive, and current continued to flow through the circuit. In the second test, a 35 Ω resistor was used, producing a current of 1.3 A. This triggered the relay to activate, thereby cutting off the current flow [21].

Overheat testing utilizes the LM35 temperature sensor to monitor the relay's response. The relay remains inactive when the temperature reading stays below a predetermined limit set on the Arduino microcontroller [22]. Conversely, the relay activates if the temperature reading surpasses this limit [23]. The test setup includes essential components: Arduino, LM35 sensor, relay, LED, and a 1 µF capacitor. This capacitor functions as a voltage stabilizer for the LM35 sensor, ensuring consistent temperature readings [24], [25].

A lighter was used as a heat source to raise the temperature from ambient to a level exceeding the set limit of 50°C. The test results confirmed that the relay remained inactive when the temperature stayed below 50°C. Conversely, the relay activated when the temperature surpassed 50°C.

4. Conclusions

Based on the results of the research conducted, it can be concluded that there are 38 risk events and 24 risk sources, with 3 priority risk sources: sudden demand from consumers, not regularly checking needs before the production process, and dependence on small suppliers. To address these issues, 8 proposed mitigation actions can be considered by Dapur Mama Shanum MSMEs, with 3 priorities: determining supplier criteria, establishing minimum order regulations for pempek, and maintaining records related to the stock of production raw materials.

Declaration statement

Hartono: **Conceptualization, Methodology, and Resources**. Samsul Hidayatulloh: **Writing Original Draft, Data Processing, Visualization, Investigation**. Yusraini Muharni: **Editing and Supervision**.

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Disclosure statement

The authors report there are no competing interests to declare.

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Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

[1] N. R. Alham, F. H. Rumawan, M. Muslimin, R. M. Utomo, and A. Maulana, "Aplikasi Photovoltaic Cell (Pv) Terhadap Variasi Beban Elektrik Sebagai Energi Alternatif," *J. Tek. Elektro Uniba (Jte Uniba)*, vol. 5, no. 2, pp. 123–129, 2021.

[2] F. Al Hasan, "Rancang Bangun Metode Proteksi Overload Pada Panel Surya," *J. Kaji. Tek. Elektro*, vol. 8, no. 1, pp. 7–11, 2023, doi: 10.52447/Jkte.V8i1.6603.

[3] I. A. Premaratne, B. G. L. T. Samaranayake, and P. J. Binduhewa, “An Analytical Study on Methods to Detect Degraded Cells in A Multi-Cell Lithium-Ion Battery Pack,” *2020 Ieee 15th Int. Conf. Ind. Inf. Syst. Iciis 2020 - Proc.*, no. 978, pp. 59–64, 2020, doi: 10.1109/Iciis51140.2020.9342642.

[4] Y. Astriani, A. Kurniasari, E. R. Priandana, and N. A. Aryono, "Penyeimbangan State of Charge Baterai Lead Acid Pada Prototipe Battery Management System A Prototype Battery Management System for Balancing," *Jurnal Ketenagalistrikan dan Energi Terbarukan*, vol. 17, no. 1, pp. 43–52, 2018.

[5] U. Nursusanto, K. Khairunnisa, and H. Hartoyo, “Real Time Battery Monitoring Control in Mini Generating System,” *Jurnal edukasi elektro*, vol. 6, no. 2, pp. 96–104, Nov. 2022, doi: 10.21831/jee.v6i2.54299.

[6] S. Yin, J. Liu, And B. Cong, “Review of Thermal Runaway Monitoring, Warning and Protection Technologies for Lithium-Ion Batteries,” *Processes*, vol. 11, no. 8, 2023, doi: 10.3390/Pr11082345.

[7] M. Otong, A. Didik, and W. Rizky, "Perancangan Modular Baterai Lithium Ion (Li-Ion) Untuk Beban Lampu LED," *Jurnal Ilmiah SETRUM*, vol. 8, no. 2, pp. 260–273, 2019.

[8] Y. Liu, R. Zhang, J. Wang, And Y. Wang, “Current and Future Lithium-Ion Battery Manufacturing,” *Iscience*, Vol. 24, No. 4, P. 102332, 2021, doi: 10.1016/J.Isci.2021.102332.

[9] N. D. Rahmadhani, F. Faizah, I. W. Yudhi, and M. Wiguna, "Prototipe Sistem Proteksi Pengisian Baterai Dengan Metode Fuzzy Logic," in *Seminar Nasional Inovasi Teknologi Penerbangan (SNITP)*, 2020, pp. 1–9.

[10] M. Mario, Boni Pahlanop Lapanporo, and Muliadi Muliadi, “Rancang Bangun Sistem Proteksi dan Monitoring Penggunaan Daya Listrik Pada Beban Skala Rumah Tangga Berbasis Mikrokontroler ATMega328P,” *Prisma Fisika: Publikasi Riset Mahasiswa*, vol. 6, no. 1, pp. 26–26, Apr. 2018, doi: 10.26418/pf.v6i1.23339.

[11] H. Abdulloh, M. Fanriadho, W. B. Pramono, Y. A. Amrullah, and U. Albab, "Rancang Bangun Battery Management System," in *TECHNOPEX-2018*, Institut Teknologi Indonesia, 2018, pp. 128–137.

[12] E. Yulitiarni Parhusip, “Rancang Bangun Pemanfaatan Panel Surya Sebagai Smart Charger Handphone Dengan Sistem Monitoring Tegangan Berbasis Arduino Nano,” Undergraduate Thesis, Universitas Sumatera Utara, 2020.

[13] J. Ramadhani and Yogi Sirodz Gaos, “Optimasi Sistem Panel Surya Sebagai Sumber Energi Pada Mesin Cuci Tangan Otomatis,” *Teknobiz*, vol. 13, no. 1, pp. 34–40, Mar. 2023, doi: 10.35814/teknobiz.v13i1.4846.

[14] F. Mohammadi, “Lithium-ion battery State-of-Charge estimation based on an improved Coulomb-Counting algorithm and uncertainty evaluation,” *Journal of energy storage*, vol. 48, pp. 104061–104061, Apr. 2022, doi: 10.1016/j.est.2022.104061.

[15] N. Sadikin, M. Sari, and B. Sanjaya, “Smarthome Using Android Smartphone, Arduino Uno Microcontroller, And Relay Module,” *J. Phys. Conf. Ser.*, vol. 1361, no. 1, 2019, doi: 10.1088/1742-6596/1361/1/012035.

[16] A. Wijaya, Bengawan Alfaresi, and Feby Ardianto, “Perancangan dan Implementasi Tracking Solar Cell System dengan Menggunakan Overload Protection,” *Jurnal serambi engineering*, vol. 6, no. 4, Nov. 2021, doi: 10.32672/jse.v6i4.3522.

[17] D. Suryana, “Pengaruh Temperatur/Suhu Terhadap Tegangan Yang Dihasilkan Panel Surya Jenis Monokristalin (Studi Kasus: Baristand Industri Surabaya),” *JTPII (Jurnal Teknologi Proses dan Inovasi Industri)*, vol. 1, no. 2, Nov. 2016, doi: 10.36048/jtpii.v1i2.1791.

[18] M. Mungkin, H. Satria, J. Yanti, G. Boni, and S. Suwarno, “Perancangan Sistem Pemantauan Panel Surya Pollycristalline Menggunakan Teknologi Web Firebase Berbasis IoT,” *Intecoms*, vol. 3, no. 2, pp. 319–327, Dec. 2020, doi: 10.31539/intecoms.v3i2.1861.

[19] A. Shufian, Md. Mominur Rahman, K. Ahmed, R. Islam, M. Hasan, and T. Islam, “Design and Implementation of Solar Power Wireless Battery Charger,” *2019 1st International Conference on Advances in Science, Engineering and Robotics Technology (ICASERT)*, May 2019, doi: 10.1109/icasert.2019.8934579.

[20] W. Li *et al.*, “High-performance solar flow battery powered by a perovskite/silicon tandem solar cell,” *Nature materials*, vol. 19, no. 12, pp. 1326–1331, Jul. 2020, doi: 10.1038/s41563-020-0720-x.

[21] F. I. Pasaribu and M. Reza, "Rancang Bangun Charging Station Berbasis Arduino Menggunakan Solar Cell 50 Wp," *Rekayasa Elektrikal dan Energi*, vol. 3, no. 2, pp. 46–55, 2021.

[22] P. K. Atri, P. S. Modi, and Nikhil Shashikant Gujar, “Comparison of Different MPPT Control Strategies for Solar Charge Controller,” Feb. 2020, doi: 10.1109/parc49193.2020.236559.

[23] F. Ali Shah, S. S. Sheikh, U. I. Mir, and S. O. Athar, “Battery Health Monitoring for Commercialized Electric Vehicle Batteries: Lithium-Ion,” Aug. 2019, doi: 10.1109/pgsret.2019.8882735.

[24] K. Movassagh, A. Raihan, B. Balasingam, and K. Pattipati, “A Critical Look at Coulomb Counting Approach for State of Charge Estimation in Batteries,” *Energies*, vol. 14, no. 14, pp. 4074–4074, Jul. 2021, doi: 10.3390/en14144074.

[25] V. Prakasam, V. K. Tiwari, and K. R. A. L. Kanth, “Labview Based Temperature Controller Using Arduino,” *Int. J. Recent Technol. Eng.*, vol. 8, no. 4, pp. 6830–6835, 2019, doi: 10.35940/Ijrte.D5230.118419.