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Solar Cell Power Monitoring System on Unisla Solar Electric Vehicles Based on IoT

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ABSTRACT

In this study, Unisla's solar electric vehicles uses five 100Wp solar panels assembled in series so that it has a total power of 500Wp. The design of this solar cell power monitoring system uses ESP32 as a microcontroller with the concept of Internet of Things (IoT) so that the device can be connected to the internet in real-time. The sensors used to read the current and voltage flowing from the solar panel are the ACS712 sensor and the voltage sensor is a voltage divider circuit made from resistors with R1 66100 Ohm and R2 3200 Ohm values respectively. Of the 10 test samples, the average error value of the voltage sensor used had a fairly good accuracy, with an average error of only 0.301%. This shows that the measurement difference between the sensor and the multimeter is relatively small. Meanwhile, the measurement difference between the ACS712 sensor and the power supply is very small, ranging from 0.01 to 0.02 Amperes with an average error of 0.01%. This shows that the measurement deviation of the ACS712 sensor compared to the reference value is very small, making it reliable for current measurement applications. The power monitoring tool developed was successfully implemented on Unisla Solar Electric Vehicles in real-time. Tests show that the appliance can read the voltage, current, and power generated by 5 solar panels assembled in series with a total power of 500Wp. The highest rated voltage data is 73.12Volts at 14.00, while the lowest data is 65.22Volts at 17.00, the rated highest rated current is 7.11A at 12.00, while the lowest current is 1.10A at 17.00, the highest rated power is 505.65Watt at 13.00, while the lowest power is 71.74 Watts.

Keyword: Solar Panels; Electric Vehicle; Lifepo4; Internet of Things

1. Introduction

In line with the rapid advancement of electronics, the development of electricity as an energy source is also growing. And also because electrical energy is the most flexible and cheap form of energy to be used by all parties. Therefore, the use of many types of energy sources, including the latest energy sources, is currently being widely applied to meet daily electricity needs [1]. One of the uses of renewable energy is solar panel technology. Solar panels, or photovoltaic solar cells, offer great potential as an unlimited source of reliable energy. However, to apply this technology broadly, a deep understanding of a number of aspects is needed, including efficiency, cost, and integration into existing energy infrastructure [2]. The development of increasingly efficient and cost-effective solar panel technology provides an important impetus for the research and development of solar electric cars. Its potential implications for reducing greenhouse gas emissions, dependence on fossil resources, and increasing transportation sustainability are major attractions [3]

In an era of uncertainty related to energy resources and the environmental impact of conventional transportation, electric cars are becoming an increasingly important solution. However, the main obstacles that electric cars face are limited range and reliance on external battery charging. To overcome

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these obstacles, solar electric cars have emerged as an innovative solution that has the potential to change the paradigm of sustainable transportation [4]. Solar electric cars combine the advantages of solar panel technology with the energy needs of electric vehicles. By harnessing solar energy to charge car batteries directly, the concept promises energy independence and reduced reliance on outside power sources. The trend of electric cars in Indonesia is experiencing rapid development, especially among university students. One of the competitions held in Indonesia is the Indonesian Electric Car Contest (KMLI), Energy Saving Car (KMHE), Indonesia Energy Marathon Challenge (IEMC) for the National level and Shell Eco Marathon (SEM) for the international level of university competitions. To maintain the condition of electric cars so that electric cars can be used as a learning medium in the field of vocational education. The idea of this research is based on the need for an energy-efficient car, does not cause harmful emissions for the environment, and is in accordance with the Indonesian electric car competition standards (KMLI) [5].

This research presents an Internet of Things (IoT)-based power monitoring system on solar electric cars by utilizing the Firebase platform as the main solution in real-time data management. The novelty of this study lies in the integration of the monitoring system with Firebase which allows for *real-time data storage: Firebase Realtime Database* is used to store current, voltage, and power data measured by sensors continuously. This allows fast, stable, and reliable access to data, both for analysis and system evaluation purposes. Multi-Platform access, so that data stored in *Firebase* can be accessed through various devices (web and mobile applications) by users. This provides flexibility and convenience in monitoring the performance of solar panels in electric cars. The implementation of an IoT-based power monitoring system on UNISLA's solar electric cars is expected to make a significant contribution to the research and development of solar-powered electric vehicle technology. In addition, this system will also be a useful learning model for students in understanding the integration of renewable energy technology and IoT.

2. Method

This research uses several stages, starting from component selection and software selection along with details of each research stage:

- The stage of hardware manufacturing and the design of this tool is adjusted to the function of the components to be used so that it is ready to be realized.
- The stage of designing and manufacturing software is the process of programming microcontrollers for the creation of applications from Koular software.
- System integration is the arrangement of hardware and software into an overall system that integrates with each other. Testing the system that has been thoroughly integrated for further performance analysis according to its function. To understand how this system works.

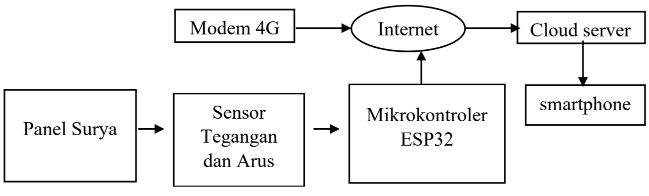

Fig. 1. System block diagram

In figure 1, the function and working method in this study is explained with the explanation for each block function as follows: Solar Panels as energy inputs; Voltage and current sensor block as a voltage and current reader on solar panels; ESP32 microcontroller block as the regulating brain of all circuits; Internet as a global communication network that connects microcontrollers with smartphone networks; 4G modem as an internet network provider for microcontrollers; Cloud server as a data

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sender through a cloud computing platform on the Internet to a smartphone; Smartphone as a receiver of data information that a microcontroller has processed

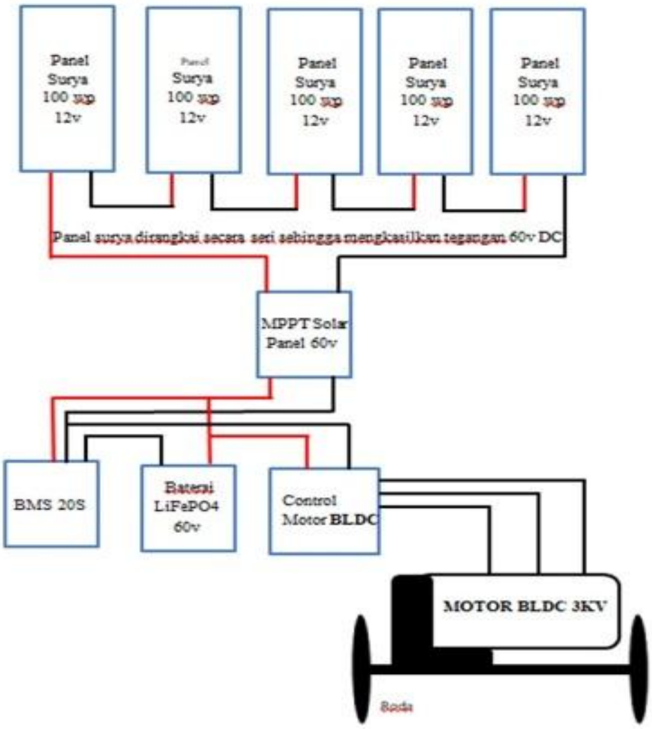

Fig. 2. Unisla Solar Electric Vehicle System Diagram

In Figure 2, it can be concluded that the system uses 5 solar panels with a capacity of 100 Wp with an output voltage of 12 V each. The output voltage from the solar panel is then transmitted to the MPPT *Solar Charge Controller*. MPPT is tasked with optimizing the power generated by solar panels by maintaining operation at the maximum power point. The MPPT output voltage is routed to a 60V LiFePO4 battery equipped with a 20S BMS. The BMS functions to manage the charge and discharge of the battery and protect it from overcharge and over-discharge. Furthermore, the energy from the battery is transmitted to the BLDC motor controller, which serves to regulate the rotation of the motor based on the control signal, with a power specification of 3 kV used to drive the wheels of the electric vehicle.

System Planning

- ESP32 Connection Circuit with Voltage Sensor

  This sensor is used to measure the amount of voltage coming out of the solar panel and the amount of voltage from the MPPT. This sensor will make the input voltage 5 times the original voltage. Thus, the sensor is only able to read a maximum voltage of 25 V when the input with a voltage of 5 V is desired, and if it is for a voltage of 3.3 V, the input voltage must be no more than 16.5 V.

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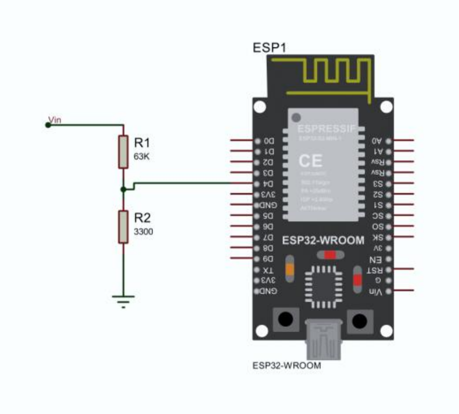

Fig. 3. ESP32 Connection Circuit with Voltage Sensor.

- ESP32 Connection Circuit with ACS712 Sensor shown in Fig. 3.
  The ACS712 module's current sensor has a voltage sensitivity of 66-185 mV/A. Just like the voltage sensor we discussed earlier, the current sensor has a reading range of 0.0049V from 0 at 0V input to 1023 at 5V input.
- Whole Range of Components
  On the whole network of schematics, there are systematic components of the research bow. It can be seen that the battery is used to provide the input voltage for the ESP32 Microcontroller. The use of step-down in this circuit is because the maximum input voltage on the ESP32 is 3.3 V, while the battery used has a voltage of 9V, so it is necessary to have a step-down to lower the voltage of the battery that will enter the ESP32. The ESP32 microcontroller itself is the control centre of the entire circuit. The programming of the ESP32 microcontroller is written using an IDE software with sketch/code based on flowchart flows on the output system.

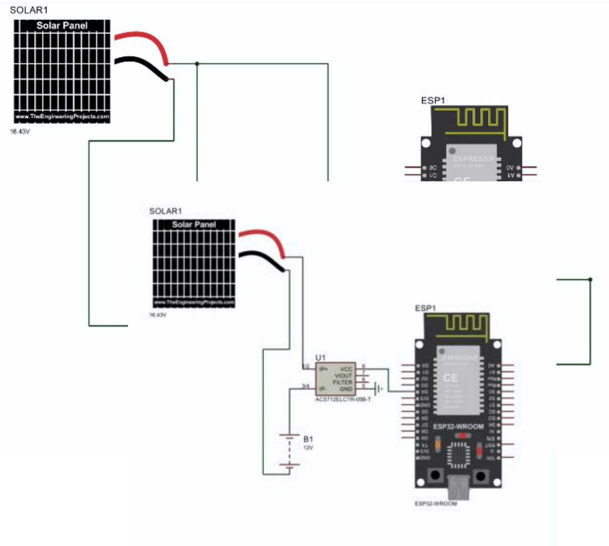

Fig. 4. Whole Range of Components

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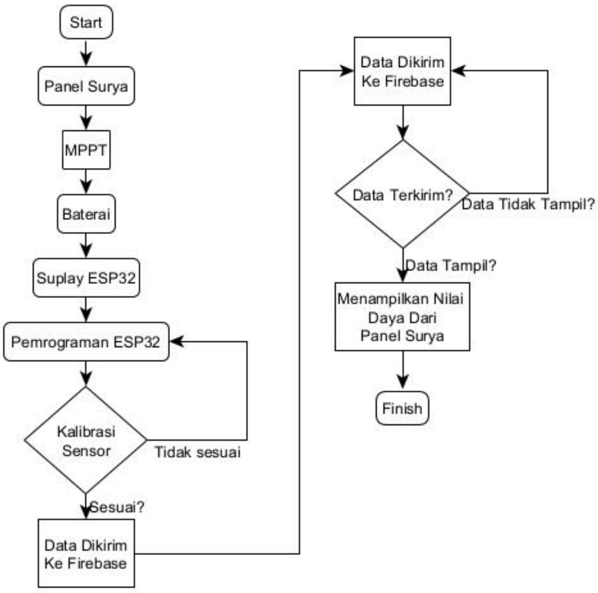

Fig. 5. Research Flow Diagram

The designed system aims to monitor and record the power generated by solar panels in real-time using the ESP32 microcontroller connected to Firebase as a cloud-based data storage medium. The workflow of this system is summarized in the flowchart as follows:

- The System Start process begins by activating solar panels as the main energy source. The electrical energy generated by the solar panels is regulated by the Maximum Power Point Tracking (MPPT) module to ensure maximum efficiency.
- Energy Storage: the energy that has been regulated by MPPT is stored in the battery. This battery serves as a power provider to operate the ESP32 microcontroller and other devices.
- Data Processing by ESP32 is used to read data from connected sensors. The initial step is to calibrate the sensor to ensure that the data generated has high accuracy. If the data does not match, the calibration process will be repeated until the expected results are obtained.
- Sending Data to Firebase: once the data from the sensor is successfully calibrated, it is sent to Firebase for storage. Firebase was chosen for its ability to provide cloud-based storage that is easily accessible from a variety of devices.
- Data Submission Validation: the system performs validation to ensure that data has been sent to Firebase. If the delivery fails, the system will retry to send the data until it succeeds.
- Data Appearance Validation, so data that has been sent to Firebase is re-verified to ensure that it can be displayed on the user interface (dashboard or app). If the data is not displayed, the system will continue to attempt to improve the display until the data is visible to the user.
- Final OutputAfter the data is successfully displayed, the system will show the value of the power generated by the solar panels in real-time. This process provides users with important information regarding the performance of the solar panels.
- Finish The system process is declared complete after the data is successfully displayed.

The system is designed to ensure the data generated is highly accurate and can be accessed in real-time by users through a cloud-based interface. With this approach, users can effectively monitor the performance of solar panels while storing data for further analysis.

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3. Results and Discussions

The voltage sensor used is a series of resistors, r1 and r2 have the same value of 6.1k ohms and r3 have a value of 3.2k ohms. With the input voltage source of the power supply adjusted to the value of the solar panel in the electric car, which is around 60V to a maximum voltage of 100V. The output value of the voltage sensor that appears on the multimeter, will be calibrated to calculate the error value on the sensor. With the following equation (1) and (2).

$$Error = \left|\frac{Measurement - Sensor}{Measurement}\right| x\ 100\% \quad (1)$$

$$Error\ average = \frac{\sum \%\ Error}{n} \quad (2)$$

With the formula of the equation above where the value on the sensor is subtracted by the original value on the multimeter, divided by the original value on the multimeter, and multiplied by 100 in the form of a percentage. The measurement of error values is presented in Table 1.

Table 1. Voltage Sensor Testing

No	Sensor (Volt)	Multimeter (Volt)	Error (%)
1	60.32	60.4	0.13
2	62.16	62.2	0.64
3	64.78	64.8	0.30
4	66.55	66.6	0.75
5	68.4	68.41	0.15
6	70.5	70.6	0.14
7	71.4	71.6	0.27
8	74.5	74.7	0.26
9	76.32	76.45	0.17
10	78.76	78/92	0.20
Average Error (%)			0.301

From the 10 samples in the table and calculated according to formula (1), (2), it can be determined that the average error value of the sensor used has quite good accuracy, with an average error of only 0.301%. This shows that the measurement difference between the sensor and the multimeter is relatively small. Testing the ACS712 sensor has several important objectives related to validating the functionality, accuracy, and correctness of the sensor in measuring electric current..

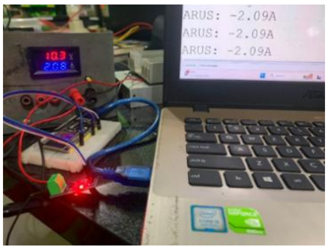

Fig. 6. ACS712 Sensor Testing

In Figure 6, you can see the value of the sensor on the screen is 2.09A while in the power supply the current value that appears is 2.08A. The measurement difference between the ACS712 sensor and the power supply is very small, ranging from 0.01 to 0.02 Amperes with the average error being 0.01%. This shows that the measurement deviation of the ACS712 sensor compared to the reference value is very small, making it reliable for current measurement applications. From the

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results of measurements with relatively small currents, it can be concluded that the monitoring tool can work well.

The purpose of this integration is to provide a clear picture of how Firebase can be implemented in IoT-based monitoring systems, as well as to evaluate the effectiveness of Firebase in handling current and voltage sensor data obtained from ACS712 current sensors and self-generated voltage sensors with resistors. The implementations discussed in this chapter include the configuration of the firebase console, as well as the integration between the ESP32 and the Firebase via the Arduino IDE.

The power monitoring application system was developed using Kopular software. Implementation includes setting up the user interface and integration with Firebase as a database. The main interface of the application consists of several components that function to receive data in the form of voltage, current, and power from the Realtime Firebase. After the application has been completed, performance testing is carried out to ensure that the application runs smoothly without lag or errors. Some of the aspects tested include Response Time: Ensures fast application response times when retrieving data from Firebase. App Stability: Ensures apps don't crash during use.

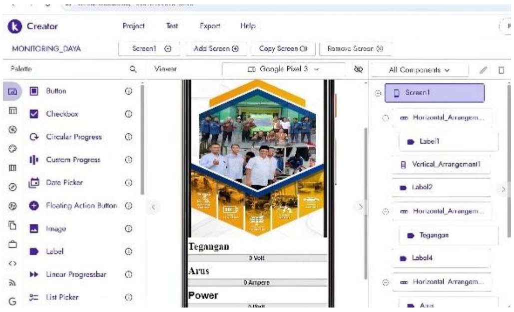

Fig. 7. Application Display on Kodular Menu

Table 2. Application Performance

Parameters	Results	Explanation
Time response	1-2 s	Average of 10 experimental samples
Failure Frequency	0	No failure to receive data
Stability of Data Processing	10/10 Data Processing	In 5 minutes the stable application test follows the changes that exist in realtime *firebase*.

The test results in Table 2 show that the application developed from Kodular meets the expected performance and reliability criteria. The fast response time indicates that the application is efficient in data processing. Based on the tests carried out, the application managed to perform all the expected functions well. Data from Firebase is successfully displayed in the app in real-time and there are no significant obstacles in the use of the app.

The overall purpose of tool testing is to ensure that the developed tool or system functions according to the specifications and requirements that have been determined. Overall testing makes it possible to identify problems or shortcomings in the system thoroughly. The following are the results of the test carried out, where the input of the monitoring device is connected to the solar panel as the voltage source to be read. The output will be connected to the MPPT on the electric car. The test results of all components will be presented in the form of a Table 3.

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Fig. 8. Unisla Solar Electric Vehicle

Table 3. Performance results

No	Time	Voltage (Volt)	Current (A)	Power (Watt)	Intensity (1000Lux)
1	08.00	66.30	2.78	184.31	12.1
2	09.00	68.89	3.56	245.24	26.5
3	10.00	69.30	5.32	368.67	42
4	11.00	70.24	5.89	483.95	58.4
5	12.00	70.85	7.11	503.74	62.3
6	13.00	71.32	7.09	505.65	61
7	14.00	73.12	6.54	478.42	59.2
8	15.00	70.20	3.14	220.42	43
9	16.00	69.14	1.24	85.73	25
10	17.00	65.22	1.10	71.74	6.9

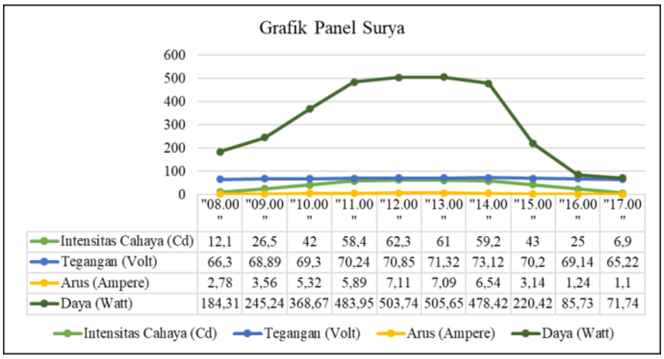

Fig. 9. Testing results

In Table 3 and the solar panel graph above, it presents the measurement results of the monitoring system device monitored through the power monitoring application and shows voltage, current and power data with measurements every 1 hour. From the results of the study, it can be described as follows: the voltage increased from 08.00 (66.30 Volts) with a Light intensity of 12100Lux until it reached its peak at 14.00 (73.12 Volts) with a Light intensity of 59200Lux. After reaching peak at 14.00, the voltage begins to decrease at 17.00 (65.22 Volts) with a Light intensity of 6900. In addition, there is a curve that rises from morning to noon and then descends towards the afternoon. Therefore, it can be concluded that the highest voltage recorded at 13.00 was 71.32 Volts. While the lowest voltage was recorded at 17.00 of 65.22 Volts, thus causing a significant

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change in voltage from morning to evening, the change was due to external factors that affected the voltage value. This analysis can be helpful in understanding how voltage changes over time and what factors may affect it, such as temperature, weather conditions, light intensity, electrical load, or energy source used.

The measured current at 08.00 is 2.78 Ampere with the condition of the battery drop, at 12.00 the current rises to a high value of 7.11 Ampere and slightly decreases to 7.09 Ampere at 13.00. After 14.00, the current experienced a consistent decrease throughout the day until it reached 1.10 Amperes at 17.00. As the measurement time changes, the current begins to decrease from 7.09 Ampere at 13.00 to 3.14 Ampere at 15.00, and continues to decrease until it reaches 1.10 Ampere at 17.00. This decrease in current indicates that the battery is getting more and more charged and approaching full capacity. From this explanation, it can be concluded that when the battery is close to full capacity, the internal resistance of the battery increases and reduces the current that can flow into the battery. This can be referred to as a control mechanism in the battery management system (BMS) whose function is to prevent overcharging that can damage the battery. High power in the morning indicates that the charging system is working with greater power when the battery is still relatively empty. In the above data presentation, the peak power was recorded at 13.00 at 13.00 of 505.55 Watts, and after reaching the peak at 13.00 the power began to decrease gradually throughout the day. This significant decrease occurred after 14.00, where the power dropped from 478.20Watt at 14.00 to 220.42Watt at 15.00 and continued to decrease to 71.74 Watt at 17.00.

The relationship of power to battery charge is described in Figure 9, which explains where a high charge stage indicates that the battery receives a large amount of energy that can speed up the battery charging process. Therefore, a periodic decrease in power indicates that the battery is getting charged and the charging system reduces the power to prevent overcharging. Previous current data shows a decrease in current over time, and this is in line with the decrease in power. When the battery is close to full, the current decreases, which causes the power used to also decrease. Based on the analysis of the voltage, current, and power measurement data that has been presented, it can be concluded that the battery charging process shows a consistent pattern from morning to evening when the weather conditions are clear. In the initial stage of charging to the peak of charging, which is at 08.00-17.00, it shows optimal charging, with increased voltage until it reaches its peak.

4. Conclusions

Based on the results of the implementation and testing that has been carried out on the power monitoring application system, it can be concluded that: The power monitoring tool developed has been successfully implemented on the Unisla Solar Electric Car in real-time. Tests show that the appliance can read the voltage, current, and power generated by 5 solar panels assembled in series with a total power of 500Wp. The highest rated voltage data is 73.12Volts at 14.00, while the lowest data is 65.22Volts at 17.00, the rated highest rated current is 7.11A at 12.00, while the lowest current is 1.10A at 17.00, the highest rated power is 505.65Watt at 13.00, while the lowest power is 71.74 Watts.

The tool successfully integrates the ACS712 current sensor and voltage sensor with a microcontroller (e.g. ESP32) to send data to the Firebase Realtime Database. The data stored in Firebase can be accessed in real-time through the MIT App Inventor-based app, allowing users to monitor electrical power remotely. Ease of Use: The application interface built with Kodular is easy to use and provides users with clear and informative data visualizations. Users can monitor power data directly through the mobile app.

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