IoT-Based Monitoring System for Photovoltaic Battery Management

[1]Gonçalo Sarmento, [1]Mickael Mota
[1,2,4]João Henriques,[3,4]Maryam Abbasi, [2]Pedro Martins, [5,6]Filipe Cardoso
, [1,2]Cristina Wanzeller,[1,2,4]Filipe Caldeira

[1] Polytechnic of Viseu, Portugal.
[2] CISeD - Research Centre in Digital Services, Polytechnic of Viseu, Portugal.
[3] Polytechnic Institute of Coimbra, Institute of Applied Research, Coimbra, Portugal.
[4] Centre for Informatics and Systems of the University of Coimbra, University of Coimbra, Coimbra, Portugal.
[5] INESC, Coimbra, Portugal.
[6] Polytechnic of Santarem, Portugal.

[1]`{estgv17175,pv26720}@alunos.estgv.ipv.pt`
[1,2,4]`joaohenriques@estgv.ipv.pt`, [3,4]`maryam@dei.uc.pt`,
[1]`pedromom@estgv.ipv.pt`, [5,6]`filipe.cardoso@esg.ipsantarem.pt`
[1]`cwanzeller@estgv.ipv.pt` [1,2,4]`caldeira@estgv.ipv.pt`

Abstract. As number of photovoltaic systems being installed is increasing, also many users are deciding to include batteries, and postpone the consumption of that energy when it is most needed. Moreover,a crucial issue can keep undetected for long time causing dangerous situation which can lead to a potential disaster. However, the chemical nature of batteries makes them unreliable and dangerous. In this risky scenario, it becomes essential to monitor their behaviour in order to avoid accidents. In that purpose, a enabled Internet of Things (IoT) framework is proposed for monitoring the batteries values for temperature and voltage through the use of sensors. If these values becomes abnormal, a notification is triggered to the responsible person. Based on experimental results, the proposed framework to detect and notify hazard situations caused by battery faults.

Keywords: battery overheating monitoring, monitoring of solar panel batteries, battery charge monitoring

1 Introduction

Solar energy become increasingly popular as a renewable energy source worldwide, with solar energy production more than doubling between 2017 and 2021, rising from 443.4 TWh to 1002.9 TWh [1]. The rise in popularity is due to more households opting to install solar panels to power their homes. As solar energy is only produced during the day, some households install batteries to store the energy for later use. The charge controller converts direct current

(DC) electricity, resulted from the solar panel generation, to alternating current (AC) electricity, to be kept in batteries (Figure 1). The AC from the batteries is then transformed into alternating current by the inverter, which can power the house. Proper monitoring and maintenance of batteries is crucial to avoid any malfunctions or accidents [2].

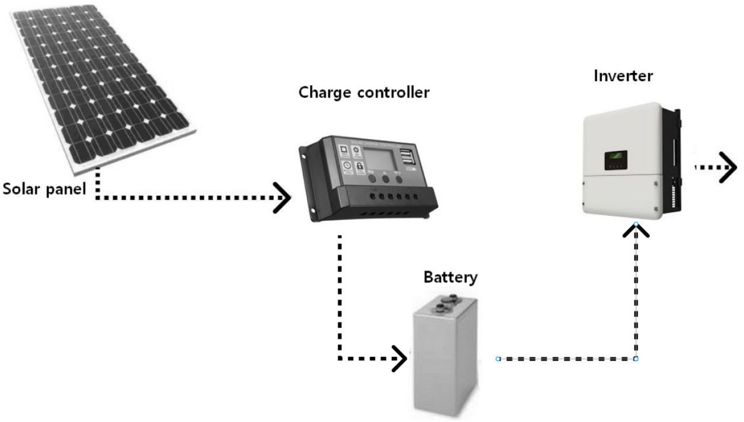


Fig. 1: Solar panel system with batteries [3]

As batteries are becoming critical and an expensive part of this installation, it is important to monitor them. In fact, in case of malfunction of the controller, a high voltage current could be sent to the batteries which could cause significant problems, such as overheating which can lead to irreversible damage in battery cells causing premature wear and tear and even in some cases explosion or combustion [4].

The 15°C to 35° range is the adequate temperature for batteries [5][6], but the larger range -20°C to 60°C is also safe [5][7]. In case these thresholds are surpassed, and notification is triggered. Regarding the voltage, if it is above 14.6V [8] or below 11V, a notification will also be triggered.

This work proposes a framework for monitoring temperature and voltage of the batteries in a solar panel system in order to avoid incidents. In case anomalies are detected, this device will immediately trigger a notification to the operators capable to intervene and fix the potential failure.

Several techniques have been recently adopted to monitor the batteries health status. Despite the high costs, lithium-ion batteries are used as the main energy source in electronic devices, electric vehicles, photovoltaic systems, etc. This is due to the fact that lithium-ion batteries have a high capacity in terms of energy, density, power and longevity. It is therefore essential to monitor their condition in order to avoid damage to the battery which could endanger the whole installation.

Wang et al. [9] presented a system to monitor the battery temperature wirelessly, so that it would be possible to keep an eye on the charging of the batteries of electric vehicles remotely. The proposed technique uses the UHF RFID protocol for data transmission and at the hardware level a new ceramic antenna was designed for a better range. The main objective of the project was to design a low cost system that could be easily applied in electric vehicles. Their method controls only the temperature of the battery, we have chosen to control also the voltage because it allows in some cases to detect an abnormal situation earlier and to be more precise on its diagnosis.

Siregar et al. [10] presented a system composed of a current and voltage sensor to monitor the batteries of solar panels and the data obtained by the sensors are transmitted by a GSM communication module. The technique used involves the storage of the data from these sensors for later consultation from the internet, from a client-server system. The main objective was to develop a system to be used in the monitoring of the energy of batteries of solar panels for public lighting. In this work, the temperature of the battery is not checked because the objective here is not to identify important malfunctions that could be dangerous contrary to our case.

Novais et al. [11] presented a system that monitors the internal and external temperature of batteries, the technique used was the use of fibre Bragg grating sensors placed inside and outside the cell to measure the temperature difference in both locations with the aim of contributing to the creation of a temperature gradient inside the battery in real time. In this paper, the temperature of the battery was measured internally and externally, in our case since the objective is to design a device easily usable and cheap, we decided that the temperature is measured outside the battery.

Finally, Wahab et al. [12] presented a battery monitoring system for electric vehicles. The applied technique involves using an Arduino with a voltage sensor to monitor the battery and a GSM module to communicate the battery status by message. The aim of this work was to inform users of the state of degradation of the battery of their vehicles for future actions. In this case also, the temperature is not controlled since the objective is mainly to monitor the performance of the battery of an electric vehicle.

2 Architecture

The proposed framework operates in two phases for monitoring batteries in photovoltaic systems. In the first phase, the data from the site are acquired while in the second phase data is processed in the cloud.

The architecture of the proposed framework is shown in Figure 2. It uses sensors to collect data in real-time from the site where battery is located. The collected data are forwarded into the API and stored in a cloud-hosted database. The Analytics component retrieves the data from the database and allows its visualization in a dashboard. Additionally, it monitors anomalies and triggers notifications as warnings. This provides the manager of the photovoltaic system with the ability to promptly intervene and address any battery-related issues, ultimately ensuring the system operates optimally.

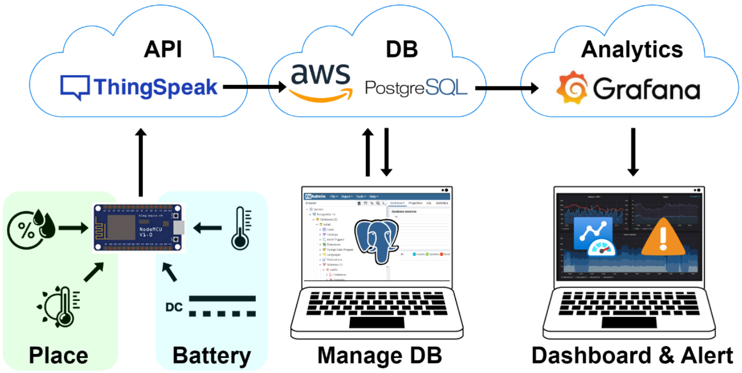


Fig. 2: Overall system architecture

3 Experimental setup

A device in contact with the photovoltaic system battery helps to monitor its temperature and voltage. This device includes a NodeMCU that uses a DS18B20 temperature sensor, a DHT22 temperature and humidity sensor, and a circuit to measure the battery voltage.

The decision to select the NodeMCU was due to the fact that it is a complete system gathering a microprocessor, bus, and memory. It is a low-cost device and allows the sensor data to be delivered over Wi-Fi without the need for an external module. The DS18B20 sensor was selected because as result of its small size and easy attachment to the battery. Moreover, it is cost-effective and provides precision reading for temperatures in the -55ºC to 125ºC range with an accuracy of ±0.5ºC. Beyond measuring temperature, the DHT22 sensor also allows reading the humidity on the air, with a temperature reading range of -40 °C to 80 °C and an accuracy of ±0.5ºC, while humidity readings range of 0% to 100% with an accuracy of ±1%.

The circuit to measure voltage was built with a voltage divider consisting of two resistors. It can be used with a direct current, thus allowing the state of charge of the battery to which it is connected to be verified.

With these components interconnected, a data acquisition device allows reading the battery temperature and voltage, as well as the temperature and humidity at the location where the battery was placed.

The hardware schematic is illustrated in Figure 3 amd was developed using Fritzing software. The schematic depicts the voltage meter circuit connected to analog port A0 and the DS18B20 and DHT22 sensors are respectively connected to digital ports D4 and D3.

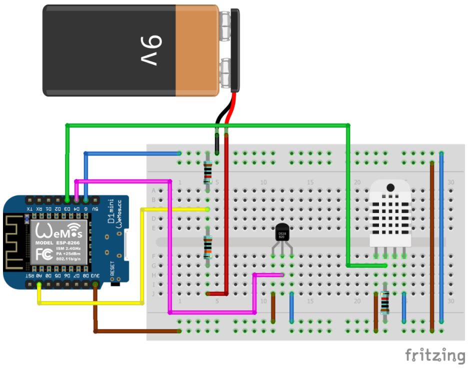


Fig. 3: Device electronic scheme

Figure 4 depicts the hardware that was used for battery monitoring, which as can be seen is similar to the schematic in Figure 3.

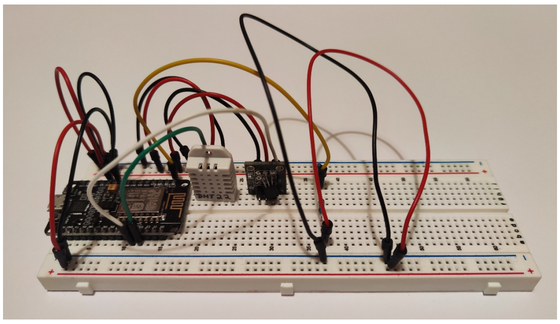


Fig. 4: Developed hardware

The programming of the NodeMCU (as denoted in Figure 5) starts with the setup function that initializes all the necessary components, as well performs the connection to an available Wi-Fi network. After that, it is looped, reading the DS18B20 and DHT22 sensors and also the voltmeter circuit every 2 seconds. Therefor, then possible reading failures are checked, for example, if there is an internal error in the DHT22 sensor, the program repeatedly tries to take readings until it gets the values. Finally, the values from readings are written to the serial monitor and are sent to the API every 15 seconds.

The platform used to develop the API is ThingSpeak, an open source software and allows IoT devices to connect to the internet. On this platform, a channel

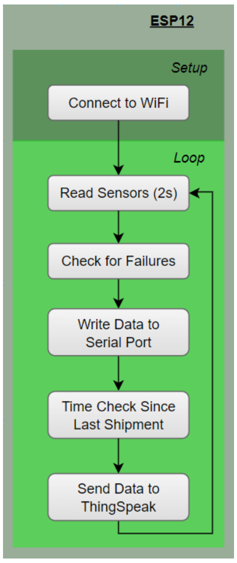


Fig. 5: Program flow block diagram

was activated to which the five fields needed to store the data received from the device created were assigned, these being the battery temperature, the battery voltage, the site temperature index, the site humidity, and the temperature of the site where the battery is located. A graph was created for each variable, gauges for battery temperature and voltage, numeric displays, and visual indicators, which are triggered when the values go out of the expected range. This API allows to store and obtain data in JSON format, but does not allow to query the internal database.

In order to have more control over the data, the API was connected to an external database created on the ElephantSQL platform, which allowed to define a database in pgAdmin containing a bidirectional connection between the DB and AWS.

After data being collected from the NodeMCU, they are stored in the Database component. Grafana (as presented in Figure 6) allows to build different dashboards depicting data in different ways for later analysis. It also allows to define alerts four types of notifications. Two of them are for the battery temperature (one above 60$^{\mathrm{o}}$C and the other below -20$^{\mathrm{o}}$C) and two other ones are for the battery voltage (one for values above 14.6V and the another one for values below 11V).

The notification module checks if values being checked surpasses their defined thresholds. When that happens, the alert goes to the 'Pending' state, as denoted by Figure 7 and stores the read values for 5 minutes and with those values updates the average. In case that average exceeds the thresholds for temperature or battery voltage, its status changes to 'Alerting' and an notification email

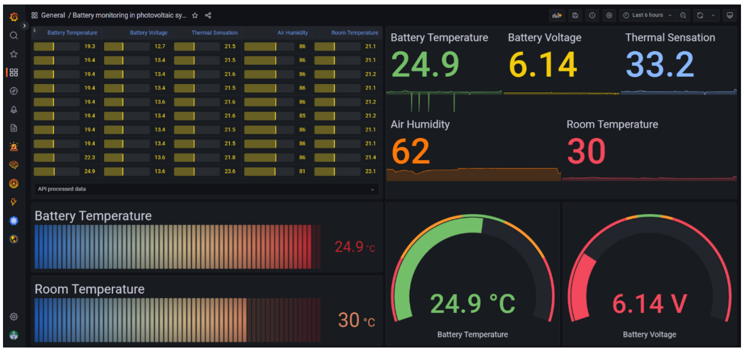
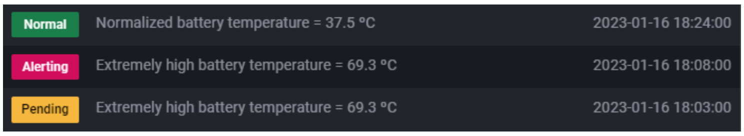


Fig. 6: General dashboard with all variables

notifies the manager. As soon as those value are within the defined thresholds, the notification status becomes 'Normal' and an notification informs the issue is not solved.



Normal Normalized battery temperature = 37.5 °C 2023-01-16 18:24:00

Alerting Extremely high battery temperature = 69.3 °C 2023-01-16 18:08:00

Pending Extremely high battery temperature = 69.3 °C 2023-01-16 18:03:00

Fig. 7: Notification history

4 Results and analysis

To evaluate the previous device, several tests for persistence and reliability were defined. In the persistence test, the device was enabled along 72 consecutive hours, where no anomaly was identified. Then, data reliability from sensors, as shown in Table 1, the DS18B20 sensor obtained a maximum difference of 0.5ºC, when are compared the measured values with those ones of a digital IR thermometer. Based on this value, the error margin of the DS18B20 sensor is ± 0.5ºC, thus verifying that it is within the standards reported by the sensor's datasheet. To test the voltmeter circuit created, the values read by it were compared to the values obtained by a UT33+ multimeter, Table 2 shows that the quite low error interval reaching a maximum of ± 0.2V.

Simulations run by different temperature and battery voltage values in order to evaluate the device. During this simulation, 1000 temperature and voltage values were read. The objective of these simulations is to vary the readings for temperature and voltage above the high limits and below the low limits in order to generate notifications.

Table 1: DS18B20 sensor test (values presented in ºC)

T. IR	DS18B20	Difference
22.7	22.5	-0.2
22.7	22.8	+0.1
22.7	22.7	0
22.9	23.1	+0.2
23.1	23.3	+0.2
23.4	23.7	+0.3
23.6	23.5	-0.1
24.0	24.4	+0.4
24.5	24.7	+0.2
25.0	25.3	+0.3
25.5	26	**+0.5**

Table 2: Voltage sensor measurements (values presented in V)

Multimeter	Voltmeter	Difference
13.5	13.7	**+0.2**
13.6	13.7	+0.1
13.6	13.6	0
13.5	13.6	+0.1
13.7	13.7	0
13.8	13.9	+0.1
13.9	14.0	+0.1
13.9	14.0	+0.1
13.9	14.0	+0.1
13.7	13.6	-0.1
13.6	13.4	**-0.2**

Figure 8 depicts the variation of the battery temperature and notifications triggered along the simulation. As we can see, the temperature exceeds the thresholds four times, at time T1 to T2 the temperature reaches a peak near 80 degrees, at time T3 to T4 as well as time T5 to T6, the temperature drops beyond -20 degrees to almost -30 degrees. Finally, at time T7 to T8, the temperature rises sharply to approximately 100 degrees, these situations are particularly critical for the integrity of the battery.

Now that critical intervals are defined, it is required to confirm notifications. Figure 8 presents four notifications have been successfully triggered. These notifications are all triggered when the temperature was either above 60ºC or below -20ºC, which confirms the notifications are indeed related to real excessive temperature values and are therefore not false alerts. Similarly, it is possible to see that all the critical situations have triggered the corresponding notification.

We can also see that, in a first instance, the alert is considered pending when a value is received that exceeds the thresholds, even though the alert has not been triggered yet. Therefore, to be sure that it is an alert, Grafana averages the values received in the next 5 minutes after being pending and if this average is above the threshold the notification is triggered, assuming that the received values are still above the alert threshold limits. This is why the notification takes a certain amount of time after the received temperature values have risen above their threshold. Similarly, if during the alert a temperature value considered normal is received, the alert is announced as resolved.

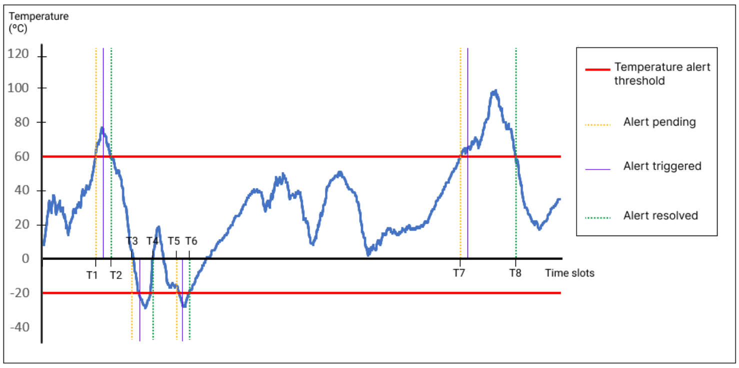


Fig. 8: Variation of the battery temperature

In addition, Figure 9 shows the variation of the battery voltage during the simulation. This variation has four critical situations, there are three peaks at approximately 15.5V between time T1 to T2, and T3 to T4 as well as between T7 to T8. Moreover, at time T5 to T6, the battery voltage is getting dangerously close to 10V. In addition, four notifications were created, all when the battery voltage was above 14.6V or below 11V, which also confirms that the alerts created are due to these excessive voltage values. Furthermore, the three cases where the voltage exceeded 14.6V and the one where it fell below 11V, raised the corresponding notifications.

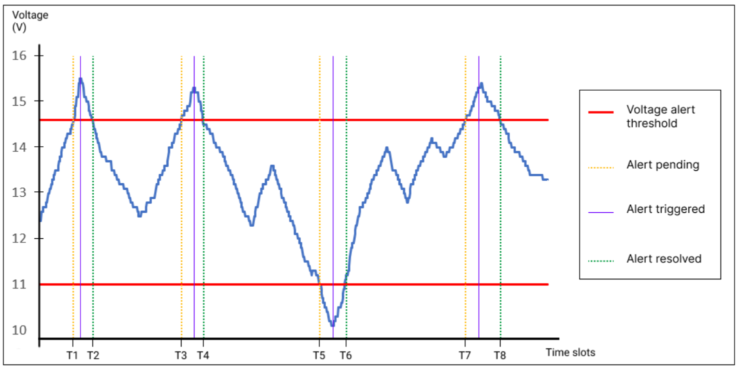


Fig. 9: Variation of the battery voltage

Table 3 shows the number of critical situations in Figure 8 and the number of temperature notifications defined along the simulation according to the type of threshold exceeded. Likewise, table 4 shows the number of critical situations in Figure 9 and the triggered notifications. Thus, as shown in the Table 3 and Table 4, for all the critical situations simulated, the system generated the corresponding warning notifications.

Table 3: Notifications verification (Temperature)

	Temperature above 60°C	Temperature below -20°C
Critical situations in Figure 8	2	2
Notifications created	2	2

Table 4: Alerts verification (Voltage)

	Voltage above 14.6V	Voltage below 11V
Critical situations in Figure 9	3	1
Notifications created	3	1

5 Conclusions and future work

This work presented the design and development of a device in the purpose of monitoring the temperature and voltage of the batteries used in a photovoltaic system. Batteries are becoming high demanding hardware when solar panel system are installed. Because they are sensitive points for failures, monitoring their temperature and voltage, it is possible to know the state of health of the battery and, above all, to be notified rapidly in the event of abnormal behaviour of the battery that could lead to particularly dangerous situations.

The development of this framework included hardware for monitoring temperature and voltage values in batteries, and the design of a software capable of interpreting this data and triggering notifications via email. As demonstrated by the results obtained, the system is able to detect a dangerous situation and send an alert when the temperature or voltage values exceed the alarm thresholds.

Future work, in the event of a power failure, the device would no longer be able on monitoring batteries, so it would be interesting to ensure the device could continue to operate. Moreover, an option to improve the framework is deploy a machine learning algorithm to predict future failures. Finally, building a mobile application will improve the user interaction by providing visualziation capabilities over the incoming data and receive notifications.

Acknowledgements

"This work is funded by National Funds through the FCT – Foundation for Science and Technology, I.P., within the scope of the project Ref. UIDB/05583/2020. Furthermore, we would like to thank the Research centre in Digital Services (CISeD) and the Instituto Politécnico de Viseu for their support."
Maryam Abbasi thanks the National funding by FCT - Foundation for Science and Technology, P.I., through the institutional scientific employment program-contract (CEECINST/00077/2021)

References

[1] IEA.org. *Solar PV*. visited on 2022-11-12. 2022. URL: `https://www.iea.org/reports/solar-pv`.
[2] Energy Storage Association. "Battery Storage". In: (2020). URL: `https://energystorage.org/what-is-energy-storage/battery-storage/`.
[3] Pedro Reis. *Qual o preço das baterias para um sistema solar fotovoltaico?* visited on 2022-11-19. 2019. URL: `https://www.portal-energia.com/preco-baterias-sistema-solar-fotovoltaico-147012/`.
[4] Shuai Ma et al. "Temperature effect and thermal impact in lithium-ion batteries: A review". In: *Progress in Natural Science: Materials International* 28.6 (2018), pp. 653–666. ISSN: 1002-0071. DOI: `https://doi.org/10.1016/j.pnsc.2018.11.002`. URL: `https://www.sciencedirect.com/science/article/pii/S1002007118307536`.
[5] Shuai Ma et al. "Temperature effect and thermal impact in lithium-ion batteries: A review". In: *Progress in Natural Science: Materials International* 28.6 (2018), pp. 653–666.

[6] Ienkaran Arasaratnam et al. "Adaptive temperature monitoring for battery thermal management". In: *2013 IEEE Transportation Electrification Conference and Expo (ITEC)*. IEEE. 2013, pp. 1–6.

[7] Yan Ji, Yancheng Zhang, and Chao-Yang Wang. "Li-ion cell operation at low temperatures". In: *Journal of The Electrochemical Society* 160.4 (2013), A636.

[8] CA Osaretin and FO Edeko. "Design and implementation of a solar charge controller with variable output". In: *Electrical and electronic engineering* 12.2 (2015), pp. 40–50.

[9] Bo Wang, Javier Hernandez Fernandez, and Ahmed Massoud. "A Wireless Battery Temperature Monitoring System for Electric Vehicle Charging". In: *2019 IEEE SENSORS*. 2019, pp. 1–4. DOI: `10.1109/SENSORS43011.2019.8956733`.

[10] Simon Siregar and Duddy Soegiarto. "Solar panel and battery street light monitoring system using GSM wireless communication system". In: *2014 2nd International Conference on Information and Communication Technology (ICoICT)*. 2014, pp. 272–275. DOI: `10.1109/ICoICT.2014.6914078`.

[11] Susana Novais et al. "Internal and External Temperature Monitoring of a Li-Ion Battery with Fiber Bragg Grating Sensors". In: *Sensors* 16.9 (2016). ISSN: 1424-8220. DOI: `10.3390/s16091394`. URL: `https://www.mdpi.com/1424-8220/16/9/1394`.

[12] Mohd Helmy Abd Wahab et al. "IoT-based battery monitoring system for electric vehicle". In: *International Journal of Engineering & Technology (IJET)* 7.4.31 (2018), pp. 505–510.