DOI: 10.15849/IJASCA.240330.04

Int. J. Advance Soft Compu. Appl, Vol. 16, No. 1, March 2024
Print ISSN: 2710-1274, Online ISSN: 2074-8523
Copyright © Al-Zaytoonah University of Jordan (ZUJ)

Low-Cost IoT-based Charging Management System for Electric Vehicles: Design Guidelines

Mohammad Alia[1], Yousef Jaradat[2], Mohammad Masoud[3], Khaled Swais[4], Ahmad Manasrah[5], Iqbal Jebril[6], and Sally Almanasra[7]

[1]Department of Cybersecurity, Al-Zaytoonah University of Jordan, Jordan.
[2,3]Department of Electrical Engineering, Al-Zaytoonah University of Jordan, Jordan
[4,7]Faculty of Computer Studies, Arab Open University, Riyadh, Saudi Arabia
e-mail: khaled.suwais@arabou.edu.sa
[5]Department of Mechanical Engineering, Al-Zaytoonah University of Jordan, Jordan
[6] Department of Mathematics, Al-Zaytoonah University of Jordan, Jordan.

Abstract

The Electric vehicles (EVs) are progressively supplanting gasoline vehicles in the automotive industry as a result of their environmental and economic advantages. Jordan's investment in the electric vehicle (EV) market is projected to grow by 35% by 2025. In addition, the Jordan National Vision 2025 initiative provides backing for environmentally friendly energy projects, specifically those related to electric vehicles (EVs) and the necessary infrastructure, including charging stations. This paper presents the proposal, design, and implementation of an affordable intelligent EV charging management system based on the Internet of Things (IoT). This system streamlines the charging process while simultaneously ensuring robust security measures and enhancing customer convenience. Given that the entire university campus is reliant on solar energy, the management system at Al-Zaytoonah University of Jordan (ZUJ) is being introduced to regulate the charging process of electric vehicles (EVs) belonging to ZUJ staff, students, visitors, and the local community

Keywords: *Charging station, Electrical vehicle, IoT, ZUJ.*

1 Introduction

The transportation sector is critical to the global society and economy. Nonetheless, among all other energy-consuming sectors, it remains the most difficult to achieve sustainability goals in terms of conservation, diversification, pollution, and emissions control [1]. Gasoline cars and diesel-powered vehicles are the main sources of air pollution in Jordan. The emissions from conventional vehicles have negative impacts on air quality and human health [2]. Several studies

Received 14 November 2023; Accepted 12 January 2024

have shown that adopting electric mobility in transportation can reduce harmful exhaust components while also quietly reducing the impact of climate change [3], [4]. With increased awareness, the number of people replacing their fossil-fuel-powered cars with electrically powered vehicles is growing [5].

However, two of the main reasons for hindering the growth of the number of EVs are the lengthy time required to recharge them when compared to the time required to refuel fuel vehicles [6]. One solution to this problem is to increase the EV distance range before the next charge. This solution has seen a lot of progress over the years as shown in Table 1 [7].

Table 1: EVs distance range on a single charge.

year	Avg. EV Range (km)	Max. EV Range (km)
2010	127	NA
2011	138	151
2012	159	426
2013	188	426
2014	209	426
2015	211	435
2016	233	507
2017	243	539
2018	304	539
2019	336	595
2020	338	647
2021	349	837*

* Max range for EVs offered in the United States.

A second reason for limiting the growth of EVs numbers is a lack of charging stations [5]. Some businesses, such as shopping malls, hotels, universities, and others, provide free EV charging services to their customers. For example, Al-Zaytoonah University of Jordan (ZUJ) has created ten free charging stations for staff, students, and the surrounding community as a community service. Charging stations should meet specific requirements such as capacity, number of electric vehicles, charging time, and so on [8].

Jordan EVs market investment is expected to increase by 35% between 2019 and 2025 [9]. Furthermore, the Jordan National Vision 2025 initiative supports green and clean energy projects, such as EVs and their infrastructure [10]. Figures 1 and 2 show the number of EVs sold each year in the Jordanian market, as well as the total number of EVs sold from 2015 to the end of 2022 as the data collected from the Jordanian driver and vehicle licensing department (DVLD). The government announced in 2015 that taxes and customs duties on EVs and charging devices would be eliminated. Furthermore, EVs were exempted from registration fees (between 11000 − 12500$). This encourages people to replace their cars with EVs. This increase in the number of EVs in the Jordanian market lasted until the beginning of 2019, when the government imposed a 25% tax on EV prices, causing the number of EVs to fall in 2019 and continue to fall in 2020 when the COVID-19 pandemic took over. By the end of 2020, the government had reduced the tax from 25% to 10% for EVs with less than 250 KW of power and 15% for EVs with 251 KW or more, allowing more EVs to enter the local market.

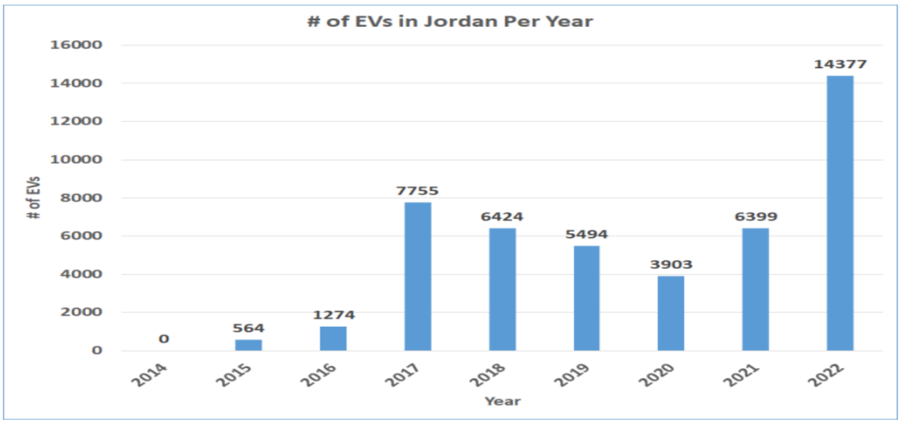

Figure 1: number of EVs in Jordan/year

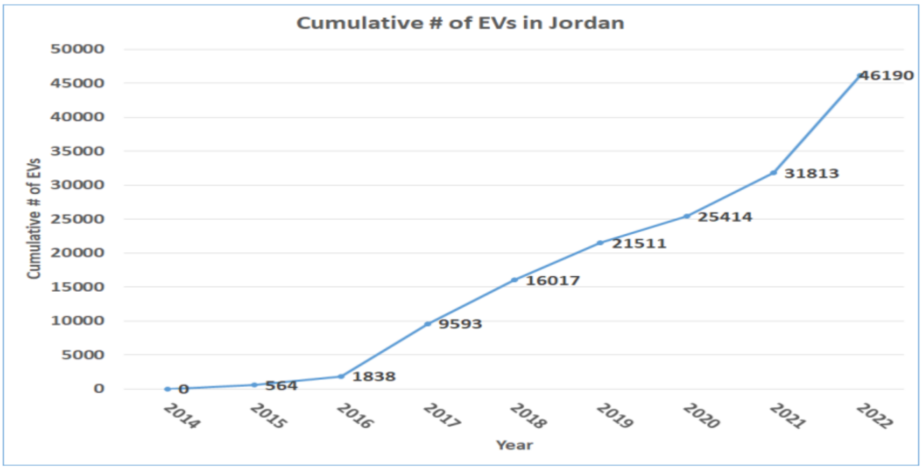

Figure 2: Cumulative number of EVs in Jordan/year

However, as with any free product or service, a new challenge arises with the increased number of EVs: the charging process must be organized. According to a study of the behavior of ZUJ charging station visitors, the main points of contention are:

- An employee's car that begins charging in the early morning remains connected to the charger until the end of the workday (approximately 8 hours), even if the car has finished charging.
- The station acts as a queue, so cars that arrive early in the morning have a much better chance of charging than cars that arrive later. In some cases, the cars that charge every day are the same ones.
- All cars can be charged with the same priority and for an unlimited period, regardless of whether the owner is an employee, a guest, a student, or simply came to charge.
- Regardless of battery charge capacity, all cars can charge for an indefinite period.

Although the traditional requirements of a car charging management system can be easily met, we still need to address and solve all of these issues to ensure that everyone has the same chance to charge his/her EV.

In this paper, we describe the design and implementation of an intelligent electric car charging management system based on low-cost wireless sensor networks. This system will organize the charging process and will provide automatic management and high-security measures, as well as convenience to the customers. The remainder of this paper is organized as follows. Section 2 provides an overview of the related work in EV charging. Charging specifications are investigated in section 3. Section 4 provides an overview of the overall system design. In section 5 a description of the charging process is explained. The hardware design of the charging management system is described in section 6. Section 7 discusses the research benefits and concludes the paper

2 Related Work

Several studies have been conducted on the EV charging process and EV charging management utilizing different state-of-the-art techniques. These studies focused on optimizing the actual charging process, efficient implementation of charging circuitry, and management of EV charging systems. In [11] the authors proposed and provided a conceptual smart EV charging system. The proposed system utilized vehicle-to-grid (V2G) to connect both EVs and renewable energy sources to the smart grid. The system provided a platform to identify overloaded electrical distribution lines as well as simulate the behavior and operating conditions under various assumptions in this smart charging process. The authors in [12] described the architecture and algorithms of the Adaptive Charging Network (ACN), which was first deployed on the Caltech campus in early 2016 and is now operational at over 100 other sites across the United States. The architecture allows for real-time monitoring and control, as well as large-scale EV charging. The authors discussed some of the real-world charging systems challenges, such as quantized control signals, non-ideal battery charging behavior, and unbalanced three-phase infrastructure. Using real workloads recorded from the Caltech ACN and accurate system models, they showed how the Adaptive Scheduling Algorithm handles these challenges and outperformed other baseline scheduling algorithms. The authors of [13] proposed a machine learning-based EV charging management system. The authors' main goal is to solve several issues with the power distribution system when charging a large number of EVs. These issues can be addressed by routing EVs to charging stations to reduce voltage fluctuations, power losses, load variance, and charging costs while taking conventional charging, fast charging, and vehicle-to-grid (V2G) technologies into account. In [14] the authors proposed to use the excess energy from the smart street lights' batteries, which are typically powered by solar energy, to charge EVs. A smart street light requires 4-5 hours to fully charge in a typical setting, and because solar power is available in nature for nearly 8 hours, the remaining time of solar power can be effectively used to charge an EV from the series/parallel connection of all street light batteries. The Internet of Things (IoT) is used to monitor and control the entire process.

To the best of our knowledge, this paper is the first to present the design and implementation of a low-cost intelligent EV charging management system in a university setting (ZUJ University). The system is designed using requirements and specifications gathered from a university setting. Employees, students, academic staff, and the local community are among the many variables in this environment. Additionally, solar energy supplies all of the university's needs.

3 EV Charging Management System Specifications

The rules and regulations that have been established for the EV charging management system are discussed in this section.

- First of all, let's define the individuals who are interacting with the system:
    1. The administrator: is the person in charge of defining users, rules, and penalties. Also in charge of determining the time to charge for each type of user and the time to move the car without incurring a penalty.
    2. The registered user: this could be a university employee/staff or a student who owns an electric vehicle. In that case, the administrator will add him as a registered user to the system.
    3. The Guest: could be anyone who owns an electric car, and doesn't need to ask the administrator to add him to the system.
- Some of the stations are open to the public, while others are restricted to specific users (guests are not permitted). Moreover, the stations are classified according to their location. The stations near the public road are open to the public, but those inside the university are only accessible to registered users.
- There are some consequences for users who violate the rules and regulations. Penalties prevent the user from charging for a specified period of time, which increases with each violation of the rules.
- The Rules of charging:
    1. Each registered user has a monthly allotment of charging hours that depends on his vehicle and title (employee or student). By the end of the month, the remaining charging hours for the following month could not be rounded. For example, 30 hours per month.
    2. Each registered user has the option to charge once per day for a set amount of time. For example, 2 hours.
    3. Guests are permitted to charge once per day for a specific period. The administrator sets the time. For example, 30 minutes per day.
    4. A user who is subject to a penalty may not be charged until the penalty period has expired.
    5. If the user or guest does not move the electric car from the charging station after notifying them, a penalty will be added.

4 Overview of the EV Charging Management System

This section describes the design of an electric vehicle charging management system. Figure 3 depicts the system's three main layers:

1. The user layer: this is the layer with which the user will interact and is linked to the charging station. Each charging station has its node. On each node, the user can begin charging his electric car according to the rules described and the procedure described in the following section.
2. The server layer: this is the layer that contains the databases and codes (php codes, HTML pages). These codes allow the administrator to define the registered users as well as check the penalty of the users. There is also a database that contains all of the data and transactions that occurred on all of the charging nodes. Furthermore, the system allows or denies charging based on data collected and stored on the server.
3. The integration layer: a single node in charge of sending messages from the server to the user and between charging nodes. Some examples of these messages are a message indicating that the charging process has begun, and a message sent to the user at the end of the charging period informing him to remove the car from the charging spot.

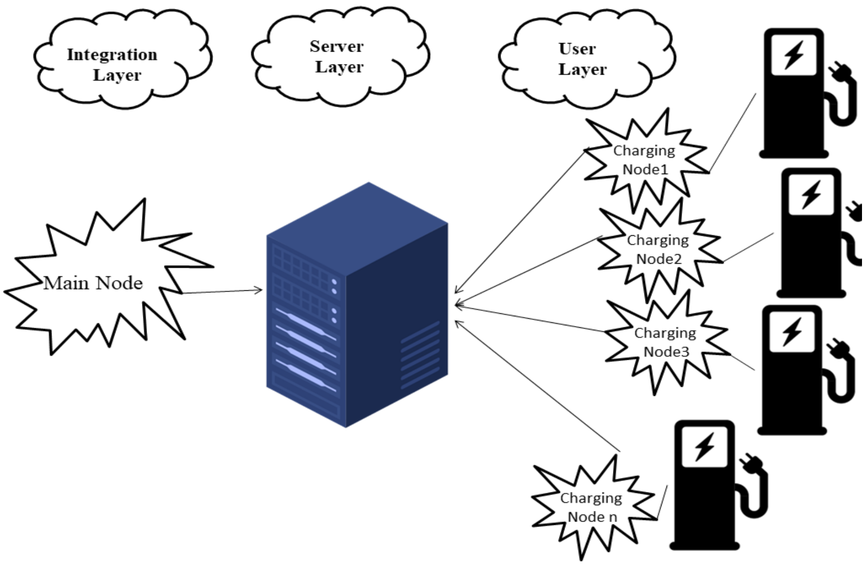

Figure 3: EV charging system overview

5 Charging Process Procedure

This section provides a detailed overview of the charging process specified by the charging system. The charging procedure has two views: The user view and the system view.

5.1 Charging Procedure - User View

When an electric car owner wants to charge his vehicle, he must first locate an empty charging station and connect his vehicle to it. Later, he must enter his credentials to the user node, which in this case is his mobile number, and he will receive a one-time password consisting of six numbers, which must also be entered. To simplify the procedure, there is an additional way to use the RFID reader and the card that the registered user has. Figure 4 summarizes the procedure from the user's perspective.

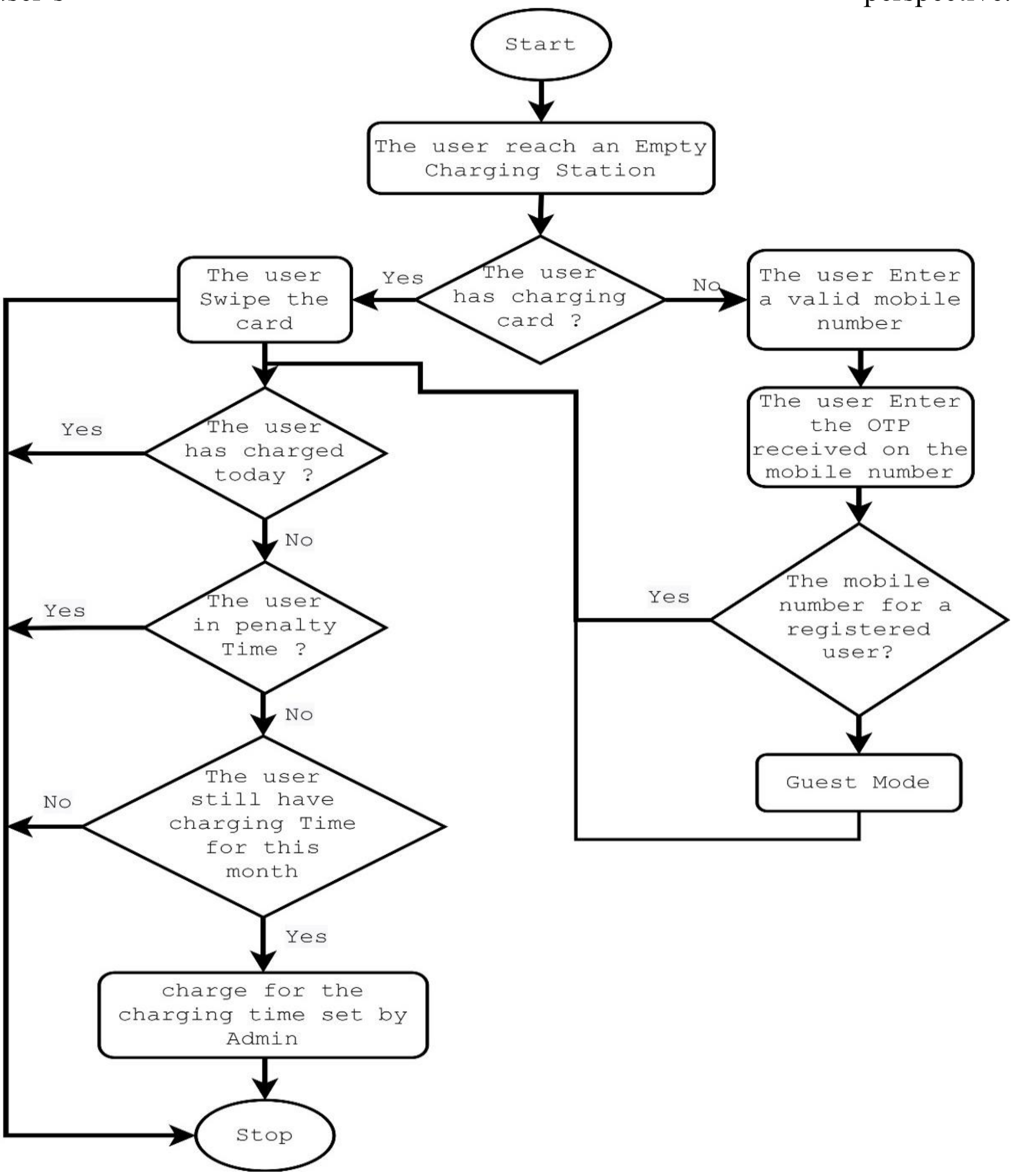

Figure 4. User view of the charging procedure

5.2 Charging Procedure - System View

From the standpoint of the system, the user may use the RFID reader and his card, indicating that he is a registered user. In addition, the user may enter his mobile number and the received code; in this case, the user may be registered or a guest, and the system should check to see if the user is not a registered user and add it to the database as a guest. After determining whether the user is a registered user or a guest, the system determines whether the user has a penalty, and if he does, the system prevents him from charging. If there are no penalties, the system checks to see if the user has already charged his car today; because charging is only permitted once per day if the user has already charged his car, the system will deny the charging process. If there are no penalties and no previous charges on the same day, the system checks to see if the registered user still has a balance of charging hours, and if there is, the system starts the charge and sends a message to the user to notify him that the charging process has started. Figure 5 summarizes the procedure from a system standpoint.

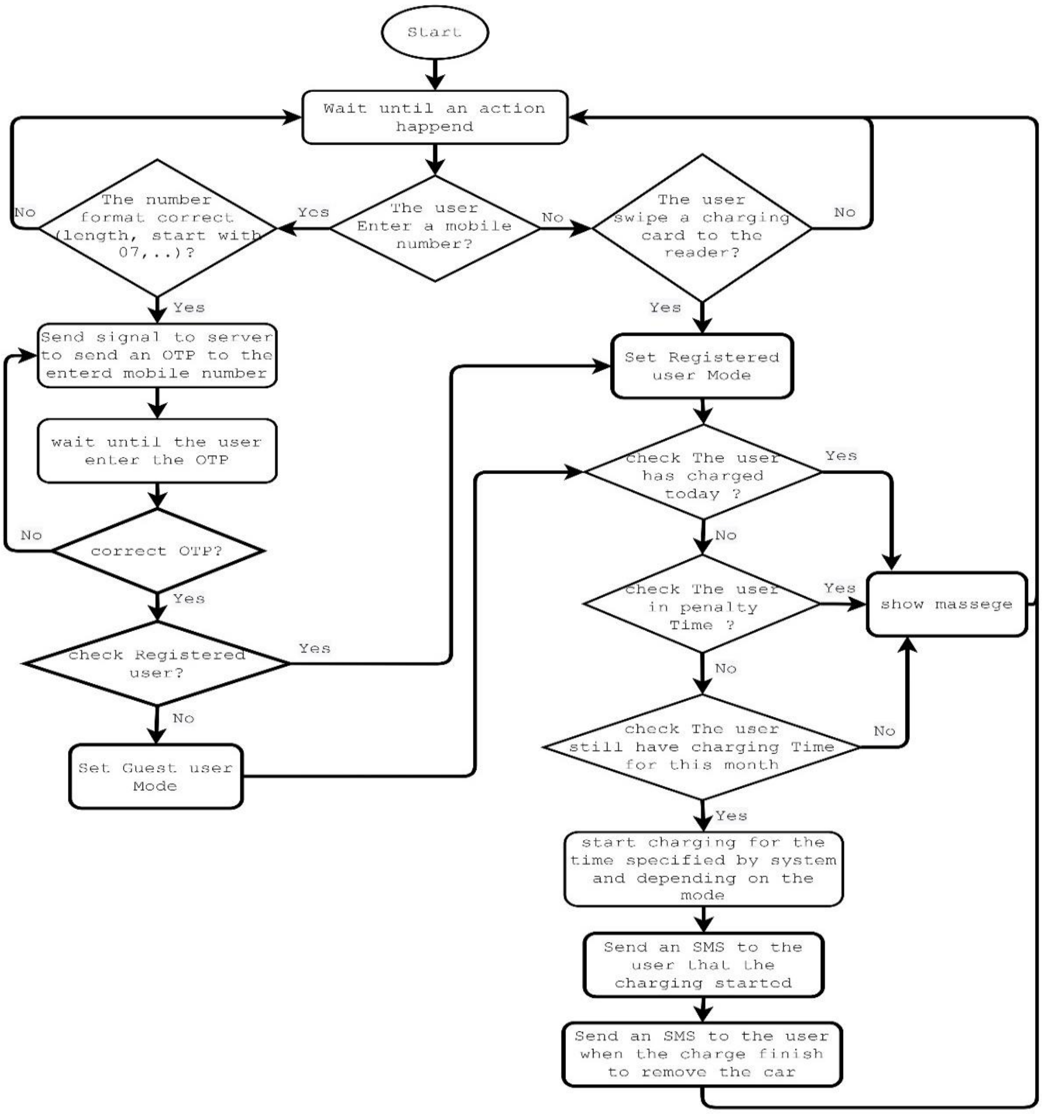

Figure 5. System view of the charging procedure

6 Hardware Design of the Charging System

The EV charging system consists of two main components: the main node and the charging node, or station.

1. The main node is made up of an ESP32 with a GSM module. ESP32 is the primary Internet of Things (IoT) device [15], [16]. This module is primarily responsible for sending messages to the user at the start, end, and when the user violates the charging rules. It is also linked to a server via a wireless connection (Wi-Fi) to read and write data [17], [18]. There is only one main node in the entire system, regardless of the number of charging stations, and it is in charge of sending messages to all charging station users (in our design, 10 nodes).
2. The Charging Nodes: There are ten charging nodes in our system; each node is in its charging station, which is located in a different part of the university. An ESP32, an LCD, a keypad, an RFID card reader, a relay, and a contactor comprise the node. The components are depicted in Figure 6.
    - The ESP32 connects to the server via Wi-Fi to read and write data to it.
    - The LCD, displays messages to the user and allows him to see the numbers he enters.
    - The Keypad allows the user to enter his credentials, which include his mobile number and one-time password.
    - The RFID card reader identifies the user more quickly and easily than the keypad.
    - The relay and contactor are used to control the charging process by acting as a switch to open or close the charger output. Because the installed charger charges up to 32 Amperes, the used contactor in our system can afford up to 32 Amperes.

Figure 6: Hardware components of the EV charging node

Figure 7 depicts the charging node’s circuit design. The circuit contains a keypad and an RFID module, which serve as input devices for the node, and using one of them, the system can recognize the user’s identity. The system also includes an LCD that displays messages to the user. Furthermore, the system includes a relay that is in charge of controlling the charger’s on and off state by sending a signal to the Contractor. The main component of the circuit is the controller, which is an

ESP32. The controller is in charge of handling the input from the keypad and the RFID, the output to the LCD and the relay, and it is also connected to the server and database via WiFi. As a result, the controller is responsible for verifying the user's identity and determining whether or not he is authorized to charge. Figure 8 depicts the charging node circuit in action.

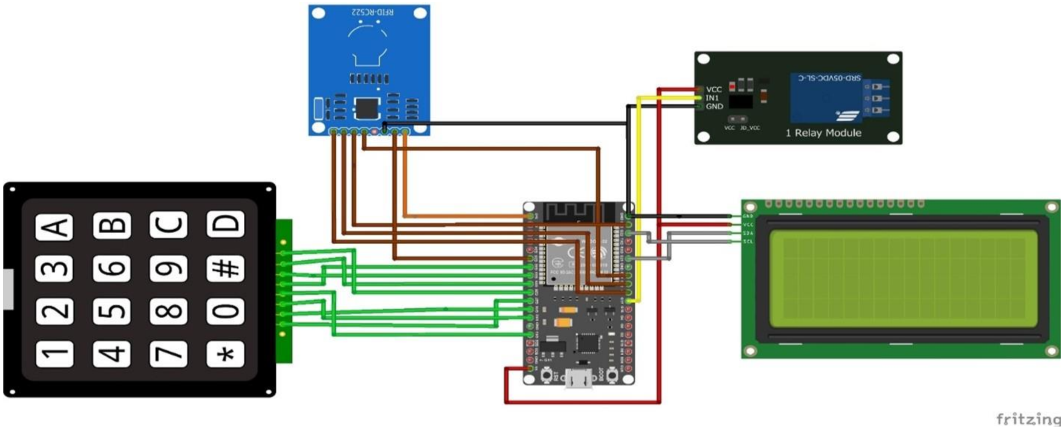

Figure 7. Charging node circuit design

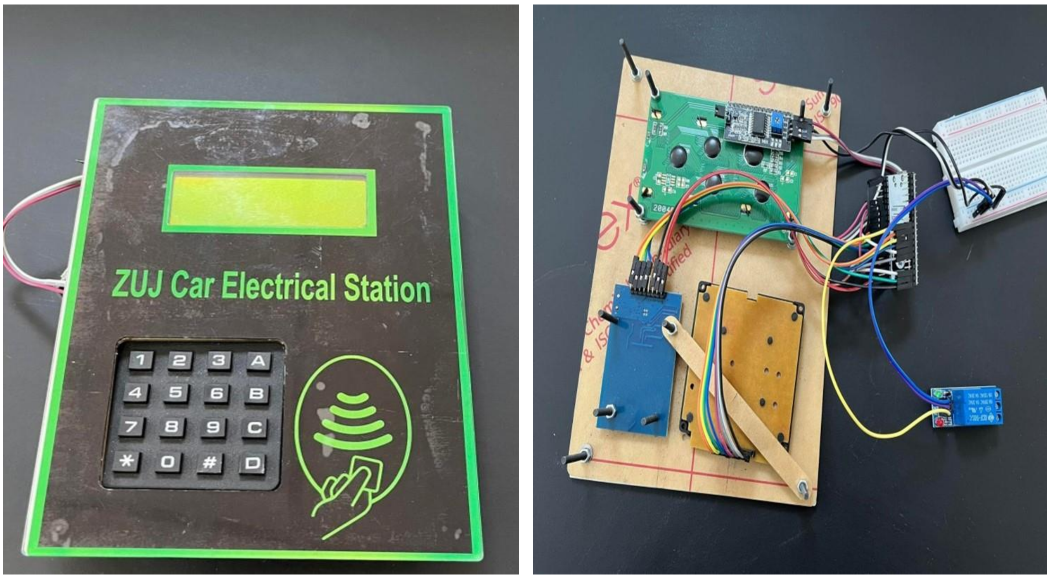

Figure 8. Charging node circuitry in action

The charging node circuit hardware was programmed using the Arduino 1.8.13 IDE, which was installed on Microsoft Windows 10, 64-bit. However, to program the ESP32 development board with the Arduino IDE, the ESP32 Arduino core must first be downloaded and installed from GitHub [19].

7 Conclusion

We present in this paper the design and implementation of a low-cost intelligent EV charging management system in a university setting (ZUJ

University). The system was created with the help of requirements and specifications gathered from a university setting. Among the many variables in this environment are employees, students, academic staff, and the local community. The system is made up broadly of two types of nodes: the controller and the charging nodes. Through IoT devices, communication can be established between the controller and the charging stations, as well as between the controller and the EVs' users. The system is made up of low-cost components that are easily reproducible if the research guidelines are followed. The system is now operational on the ZUJ campus.

ACKNOWLEDGEMENTS

The authors would like to thank the Arab Open University and Al-Zaytoonah University of Jordan for providing the necessary scientific research supplies to implement this work.

FUNDING

The authors extend their appreciation to the Arab Open University for funding this work through AOU research fund no. (AOURG 2023-006).

References

[1] Al-Ghandoor, A., Jaber, J., Al-Hinti, I., & Abdallat, Y. (2013). Statistical assessment and analyses of the determinants of transportation sector gasoline demand in Jordan. Transportation Research Part A: Policy and Practice, 50, 129-138.

[2] Requia, W. J., Mohamed, M., Higgins, C. D., Arain, A., & Ferguson, M. (2018). How clean are electric vehicles? Evidence-based review of the effects of electric mobility on air pollutants, greenhouse gas emissions and human health. Atmospheric Environment, 185, 64-77.

[3] Mądziel, M., Campisi, T., Jaworski, A., & Tesoriere, G. (2021). The development of strategies to reduce exhaust emissions from passenger cars in Rzeszow city—Poland. a preliminary assessment of the results produced by the increase of e-fleet. Energies, 14(4), 1046.

[4] Abu Mallouh, M.; Abdelhafez, E.; Alajlouni, S.; Salah, M. (2021). Battery Electric Vehicle Powertrain Modeling, Simulation, and Performance Analysis. International Review on Modelling and Simulations (IREMOS), 14, 466–475.

[5] Shalalfeh, L., AlShalalfeh, A., Alkaradsheh, K., Alhamarneh, M., & Bashaireh, A. (2021). Electric Vehicles in Jordan: Challenges and Limitations. Sustainability, 13(6), 3199.

[6] Brandstätter, G., Kahr, M., & Leitner, M. (2017). Determining optimal locations for charging stations of electric car-sharing systems under stochastic demand. Transportation Research Part B: Methodological, 104, 17-35.

[7] Bibra, E. M., Connelly, E., Dhir, S., Drtil, M., Henriot, P., Hwang, I., ... & Teter, J. (2022). Global EV outlook 2022: Securing supplies for an electric future.

[8] Amry, Y., Elbouchikhi, E., Le Gall, F., Ghogho, M., & El Hani, S. (2022). Electric vehicle traction drives and charging station power electronics: current status and challenges. Energies, 15(16), 6037.

[9] Jordan Electric Vehicle Market Analysis Outlook, 2019–2025: Vehicle Types, Regions, Competitive Landscape. https: //www.businesswire.com/news/home/20190906005441/en/Jordan-Electric-Vehicle-Market-Analysis-Outlook-2019-2025-Vehicle-Types-Regions-Competitive-Landscape---ResearchAndMarkets.com. Accessed: 2022-12-30

[10] Jordan 2025, A national Vision and Strategy. https://gbd.gov.jo/Uploads/Files/jordan-2025/2025-en.pdf. Accessed: 2022-12-25.

[11] Ferreira, J. C., Monteiro, V., Afonso, J. L., & Silva, A. (2011, June). Smart electric vehicle charging system. In 2011 IEEE Intelligent Vehicles Symposium (IV) (pp. 758-763). IEEE.

[12] Lee, Z. J., Lee, G., Lee, T., Jin, C., Lee, R., Low, Z., ... & Low, S. H. (2021). Adaptive charging networks: A framework for smart electric vehicle charging. IEEE Transactions on Smart Grid, 12(5), 4339-4350.

[13] Shibl, M., Ismail, L., & Massoud, A. (2021). Electric vehicles charging management using machine learning considering fast charging and vehicle-to-grid operation. Energies, 14(19), 6199.

[14] Divyapriya, S., Amudha, A., & Vijayakumar, R. (2021). Design of solar smart street light powered plug-in electric vehicle charging station by using internet of things. Journal of The Institution of Engineers (India): Series B, 102, 477-486.

[15] Al Rawajbeh, M.; AlZu'bi, S.; Alkhatib, A. (2023). IoT-Paradigm: Evolution Challenges and Proposed Solutions. In Proceedings of the 2023 IEEE International Smart Cities Conference (ISC2). IEEE, pp. 1–5

[16] Masoud, M.; Jaradat, Y.; Manasrah, A.; Jannoud, I. (2019). Sensors of Smart Devices in the Internet of Everything (IoE) Era: Big Opportunities and Massive Doubts. Journal of Sensors 2019.

[17] Balakrishnan, M.; Huang, H.; Asorey-Cacheda, R.; Misra, S.; Pawar, S.; Jaradat, Y. (2012). Measures and countermeasures for null frequency jamming of on-demand routing protocols in wireless ad hoc networks. IEEE transactions on wireless communications ,11, 3860–3868.

[18] Jaradat, Y.M.; Al-Bahadili, H. (2007) Development and Performance Analysis of a Probabilistic Flooding Algorithm in Noisy Mobile Ad Hoc Networks. PhD thesis, University of Jordan.

[19] ESP32 Arduino core code. https://dl.espressif.com/dl/package_esp32_index.json. Accessed: 2021-12-06.