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Research Square

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IoT-Based Intelligent Charging System for Kayoola EVs Buses at Kiira Motors Corporation in Uganda.

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Abstract

The increasing popularity of Electric Vehicles (EVs) has led to a surge in the need for charging stations in Kayoola EV buses. Most of existing EV charging stations have outdated features which is challenging to be remotely controlled. However, current EV charging systems experience with no remote battery operational charging status, unsafety control if charging station is faulted, and insecure charging RFID card payment. This paper, an IoT-based system was aimed to manage and monitor these EV charging stations. The battery management system (BMS) sends charging voltage and current information to charger via Controller Area Network (CAN) bus. Then, the Raspberry Pi4 receives and decode CAN charging data to be processed, analyzed and transmits to the cloud server. Each charger is equipped with sensors monitoring parameters like charging status, energy consumption, voltage, current, and time. The user can access that decoded charging information via android mobile application and desk remote management system. Additionally, the system server calculates the battery charging levels and commend RFID card transaction payment. The results show that developed IoT-based intelligent charging system provides and outperforms minimum and maximum cell voltages of 2.82V and 4.1V, min. and max. cell temperatures of 37℃ and 40℃ respectively. The charged energy of 10kWh, used energy of 0kWh, charging state indication, low-cell voltage as error state indication, charging price rate of 500Ugx/kWh, and full-latch of 0, pack voltage of 483.9V, pack current of 100.1A, battery health of 97%, battery state of charge (SoC) of 100% and remaining charging time of 38 mins were also detected and remotely monitored. In conclusion, the developed system proves 100% of real-time and remote data access and accuracy, efficiency, security, accessibility, sustainability, safety charging payment, and remote battery status monitoring system of EV charging infrastructure compared to the current charging where it offers only 58.75% of charging rate.

Keywords:* *Kayoola EVs buses, Intelligent charging system, IoT embedded Sensors, Mobile Application Development, Remote charging control Systems.

I. INTRODUCTION

Kiira Motors Corporation (KMC) is a state-owned enterprise that was established to champion the automotive value chain in Uganda, and advance job and wealth creation. The company developed Africa's first vehicle in 2011, Africa's first hybrid vehicle in 2014 and Africa's first solar electric bus in 2016 [1]. The company's market entry product is the KAYOOLA EVS, a fully electric, low-floor city bus with a range of 300 kilometers on a full charge [2]. The charging infrastructure is the backbone of electric mobility. Electric Buses are emerging as a favorable strategy to meet the increasing environmental concerns. Since Batteries has a finite energy capacity, Plug-in Electric Bus must be charged on a periodic basis. Deployment of Charging infrastructure in every location is expected to maximize the adoption of E-mobility. Understanding the real-time status of Charging Stations can provide valuable information to drivers and Charging Stations attendants, such as availability of charging provisions, and monitoring the availability of the charging services [3].

The intent of the proposed system is to provide a better Electric Bus Charging system by utilizing the advantages of the Internet of Things (IoT) technology. The IoT paradigm offers to the present facilities a real-time interactional view of the physical world by a variety of sensors and broadcasting tools. The system operates to monitors and controls the charger status by processing data from the Control Area Network (CAN) bus and send to the cloud for further analysis. This paper proposed a real-time server-based charger status and remaining charging duration monitoring to avoid waiting time. The proposed system provides a real-time Charging Station recommendation for KAYOOLA bus driver with economic cost and reduced waiting time at the stations [4]. Electric vehicle (EV) charger levels refer to the different power levels at which electric vehicles can be charged. These levels determine how quickly an electric vehicle's battery can be charged. The levels are standardized and categorized based on the charging power they provide. The most common EV charger levels are Level 1, Level 2, and Level 3 charging [5].

II. REVIEW OF RELATED WORKS

In this section, a review of research works related to this study is presented.

Triden et al. [6] has developed EV Charging Station management system. The system was identified that the system lacks the information regarding available EV charging points in the streets which might negatively impact the adoption of electromobility nowadays. The system also proposed a web

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based and mobile app platform to ensure ongoing collaboration between the various entities involved such as charging stations, charging station attendants, and EV drivers. With this platform, the system has used such entities and proposed optimizing Electric Buses allocation to the charging stations [7]. S. Moreshwar et al. [8] proposed a system for electric charging vehicle infrastructure. The system provides a design that uses machine learning techniques to improvise the charging and generate billing accurately and generic software stack and how machine learning system has to interact with this stack [9]. Elen Lobato et al. [10]. developed an amazon prototype monitoring system for electric vehicle charging stations. In this system, the charging station management informs the user as soon as the station goes offline while charging, giving the EVs owners to search alternative charging station. In addition, the benefits of implementing smart charging in case of remote support and maintenance was emphasized. An intelligent charging and discharging of electric vehicles in a vehicle-to-grid system using a reinforcement learning-based approach was developed by M. Julie [11]. The system uses a model-free reinforcement learning (RL) approach to optimize EV charging and discharging decisions until the battery's end-of-life. The goal was to minimize charging costs and maximize battery use. The algorithm was evaluated using real-world data and tested in experimental scenarios. RL was advantageous than other approaches for reducing overall costs but shrinking battery use in EV vehicles was an issue during system development.

An intelligent electric vehicle charging system for new energy companies based on consortium blockchain was also developed by Zhengtang Fu et al [12]. This system, a novel EV charging system for new energy companies, utilizing a tamper-resistant and multi-centralized consortium blockchain was proposed. A smart contract was designed to balance charging user allocation, ensuring fair profits for companies. The Bio-Objective Mixed-Integer Programming model (BOMILP) was used for smart contracts, while a new algorithm, Limited Neighborhood Search with Memory (LNSM), was also developed for faster and better performance. The system and smart contract are validated through a real case study in Beijing, China.

IoT-Based Advanced Electric Vehicle Charging Infrastructure was developed by J. Surendiran et al [13]. This infrastructure presents an intelligent process-based design for efficient electric vehicle (EV) charging processes. The smart charging station uses three sources: solar system, wind system, and main supply. The controller switches source automatically based on their availability, maintaining power from multiple sources. The IoT Thing Speak cloud service allows users to view available slots, ensuring efficient charging. The design addresses limitations in electrical power distribution and ensures efficient charging for EVs.

R. Suresh Kumar et al. [14] suggested an IoT-based monitoring and management of electric vehicle charging systems for DC fast charging facility. In this system, cloud-based monitoring and management of smart charger stations for electric vehicles (EVs) using security-driven IoT-enabled direct current (DC) fast chargers were discussed. The methodology predicts battery energy consumption and bill payment processes, and considers conventional AC and DC fast chargers. The information is shared with equipment manufacturers, allowing for analysis of charging costs and optimizing energy trading solutions. The EV metering architecture acquires real-time data, providing an execution framework for energy demand solutions.

J. Shanmugapriyan et al. [15] - [16] designed and developed an IoT-blockchain-enabled charging station for electric vehicles. The proposed blockchain-based electric vehicle charging station (EVCS) system connects all charging stations within a cell using a distributed ledger algorithm. The algorithm routes electric vehicles to the station based on charging requirements. This system helps in futuristic analysis and development of charging stations, considering factors like peak demand and profit. While not entirely based on blockchain, it integrates with IoT.

Electric Buses require Charging Infrastructure in their daily operations. Even bus to charger distribution is a major concern in adopting electric vehicles in East Africa. There is a requirement to adopt remote charging station for monitoring daily activities of their charging stations, remote trouble shooting, secure RFID card payment, error and state reporting with the use of IoT to maximize customer satisfaction, resource management and ensure automatic revenue collection.

However, the issue of completely charging the EV buses with appropriate verification, dynamic RFID card security key and auto safety control is not entirely solved. Therefore, this paper provides further verification on battery management system (BMS) fully latch information while battery state of charge is at 100% SoC and dynamic security key for RFID card payment.

In order to achieve the maximum efficiency of EVs charging station system, an IoT-based Intelligent charging system is proposed. The main contributions of this papers are also summarized as follows:

1. Real-time monitoring of charging stations and remote management capabilities.
2. Security enhancement by enabling robust user authentication and authorization mechanisms.
3. Enhancement of the overall performance, reliability, and security of charging infrastructure.
4. RFID card payment deployment.

This paper is organized as follows. Section I gives the overall introduction of EVs battery charging systems based on IoT. It introduces also the overview of Kayoora EVs charging infrastructure including the motivation and novelty of the proposed IoT-based intelligent charging system for Kayoora EVs buses. Secondly, the past research works in EVs charging station monitoring systems where battery status, charger management systems are briefly reviewed and presented. It also identifies the past research gaps and proposes a novel solution to the challenges. Thirdly, the materials and methodology were addressed to solve the EVs battery charging station monitoring systems problem where the IoT based intelligent charging and monitoring system with their remote and RFID card payment control in the case study are studied and developed. Fourthly, the research article also proposes the solution and discusses the battery status such battery state of charge, battery health, battery cell temperature, battery pack voltage, charged energy, and RFID card payment management. The developed IoT intelligent charging system is compared with the current Kayoora EV charging station system. Finally, the general conclusion and future works are documented.

III. MATERIALS AND METHODS

3.1 Battery System Charging Infrastructure

The proposed system as shown in Fig.1 uses USB-CAN adapter to monitor the activities of KAYOOLA bus's chargers. Raspberry pi 4 decode and process the CAN frame data from both the KAYOOLA bus and the charger, then after this information was sent to cloud server. Kiira Motor Corporation control center to monitor, control activities, and analyses data for further charging station scalability. The charging station attendants also were able to get charger status notifications, monitor battery health, perform payment transactions, and control charger through smartphone's android application.

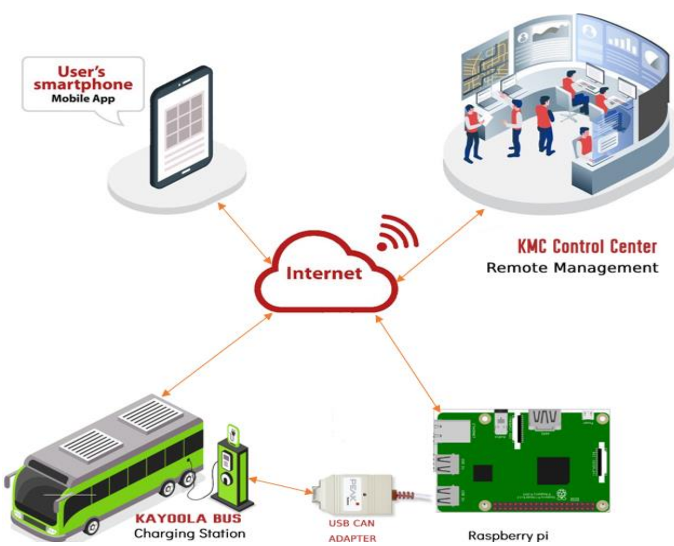

Fig. 1. System Charging Infrastructure

. 3.2 EVs Use Case Charging Design

The drivers, station attendants, and charging station system have interacted with IoT based intelligent charging system. The driver was enabled to register, book charging device port, pay remain charges, receives notification regarding charging completeness or errors. In addition, the charging station could get the available charging stations and make payment based on the remaining charges while the station attendant would initiate the charging process and make notification on charging errors or completeness. Fig. 2 shows the use case diagram of the EV bus communications between actors.

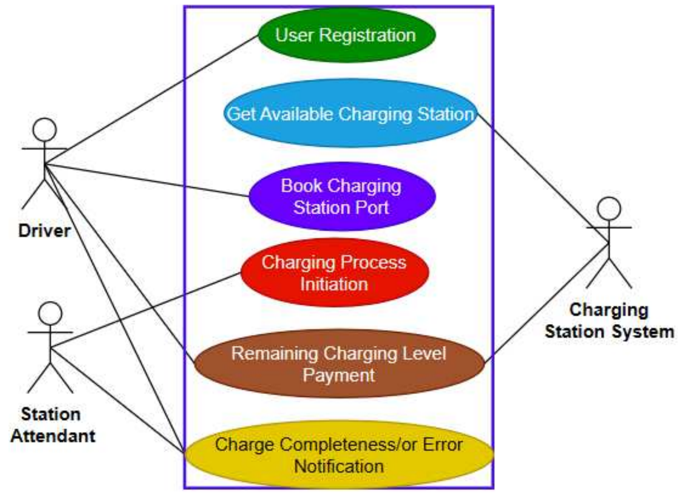

Fig. 2. EVs Charging use case diagram.

3.3 EV Bus charging flowchart system

The system was powered by an external 5 VDC voltage backup battery for detecting the status of charger even at the time of electricity power failure. By detecting and decoding charger and BMS CAN messages, the system was enabled to control and report real-time data on what is going on in the charging station. The system detects CAN charger and checks its corresponding ID or if the charger is out of services. The errors data frame which might be available from CAN were also detected, decoded, and reported. If no data frame, the system itself detects BMS CAN and its available errors while updating charger activities to cloud server. Fig. 3 shows the flowchart diagram of EVs bus charging system flowchart diagram.

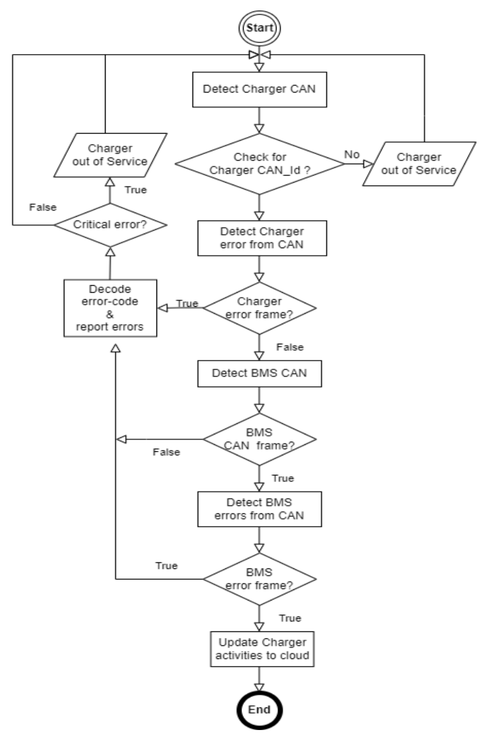

Fig. 3. EV Bus flowchart charging system.

3.4 Hardware System Design

The hardware system design is shown in Fig. 4. It was powered by 5VDC voltage, the isolated PCAN module was also powered from the USB of Raspberry pi 4. The real-time clock was also powered directly from Raspberry pi to keep exact time and date. Lithium Polymer module was used as backup power to ensure the reliability in case of blackout. The Raspberry pi 4 received charging framed data from EV bus battery via CAN, then process, and analyze those charging data and transmit them to the internet cloud server. The safety relay was also utilized to switch ON/OFF the level 3 charging node in the power failure emergency. In addition, the real-time clock sensor was added to time the charging time in order to verify the charging period taken by one charger.

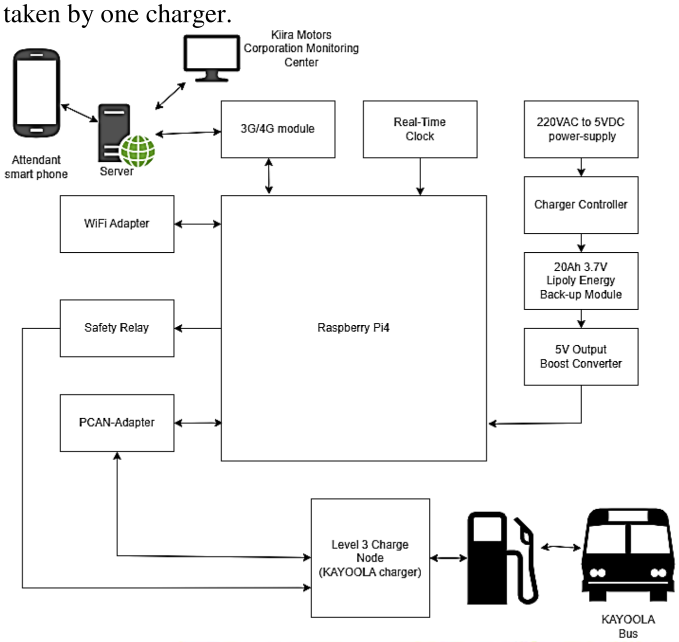

Fig. 4. Hardware interconnection diagram.

IV. RESULTS AND DISCUSSION

4.1 Mobile Application Design

The KAYOOLA EVs Buses and their drivers are registered at any company branch using Web or Desktop application with their credentials. Upon submission of the registration information, a unique user ID is generated for each user. This information is stored in the database and RFID card to enable driver to login in android app and RFID card to enable driver at EV charger. Once the driver has logged in into android application, the driver can access Kiira Motors Corporation charging station status, charge complete notifications from KAYOOLA EVs Bus and Level3 Charger CAN shared bus, locations, pricing rate per kWh and check remaining money on RFID card. The driver can top up RFID card at any Kiira Motors Corporation branches using the developed Desktop application with smart card technology connected to the server. Kiira Motors Corporation control center through Web and Desktop application will monitor the activity, perform remote charger diagnosis, and generating report of energy used and total revenue. After having the server set up, the Mobile application for driver monitoring was designed with android studio. The designed application screens were accessed by different sets of users to ensure that all the requirements were adequately captured. Then finally the android application was linked to the server application for real-time monitoring as shown in Fig. 5.

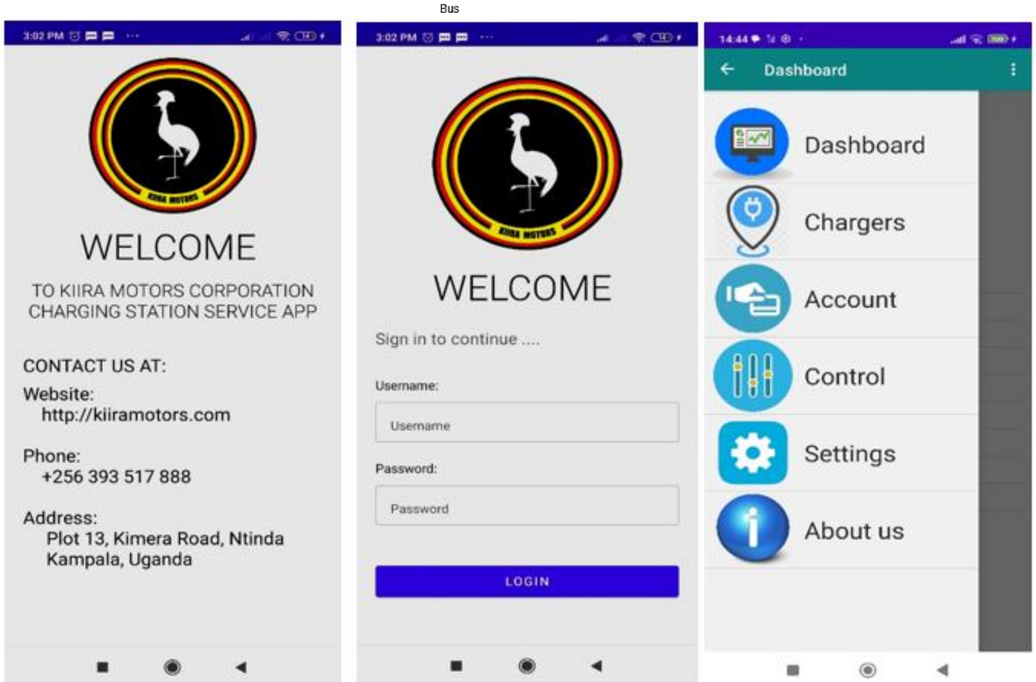

Fig. 5. Android application welcome, functional menus and login page.

4.2 Webpage Application Design

The driver was enabled to register with personal information, and insert the email address, password and RFID card number as generated by the system as shown in Fig. 6. The driver would recharge RFID card to unable card transactions. RFID Card and user IDs, customer name, RFID card balance and money to recharge should appear on the dashboard before making payment in a secured and authenticated card transaction process as shown in Fig. 7. Additionally, if the recharge was agreed to be paid, the transaction process would be completed successfully as shown in Fig. 8.

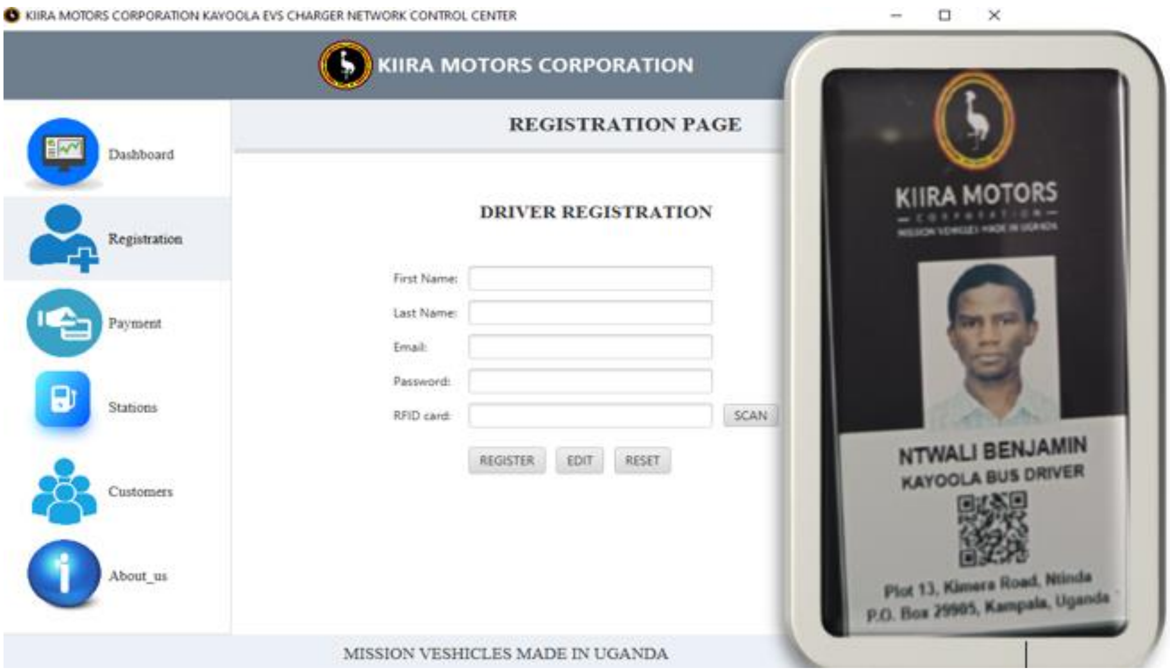

Fig. 6. RFID User registration.

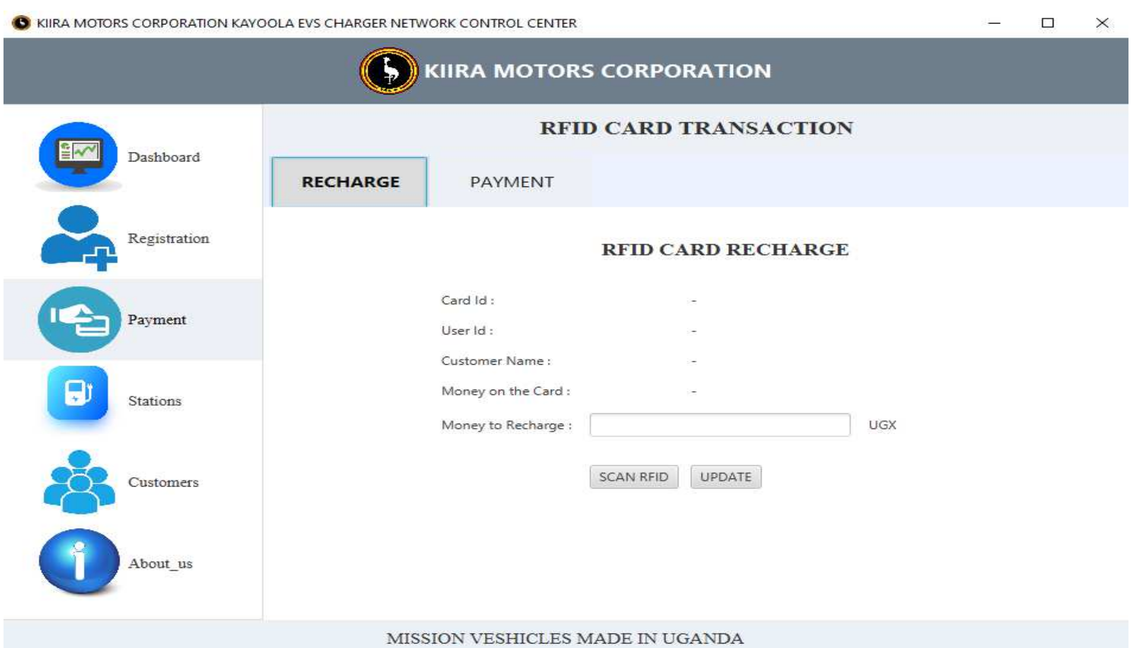

Fig. 7. RFID card recharging through desktop application.

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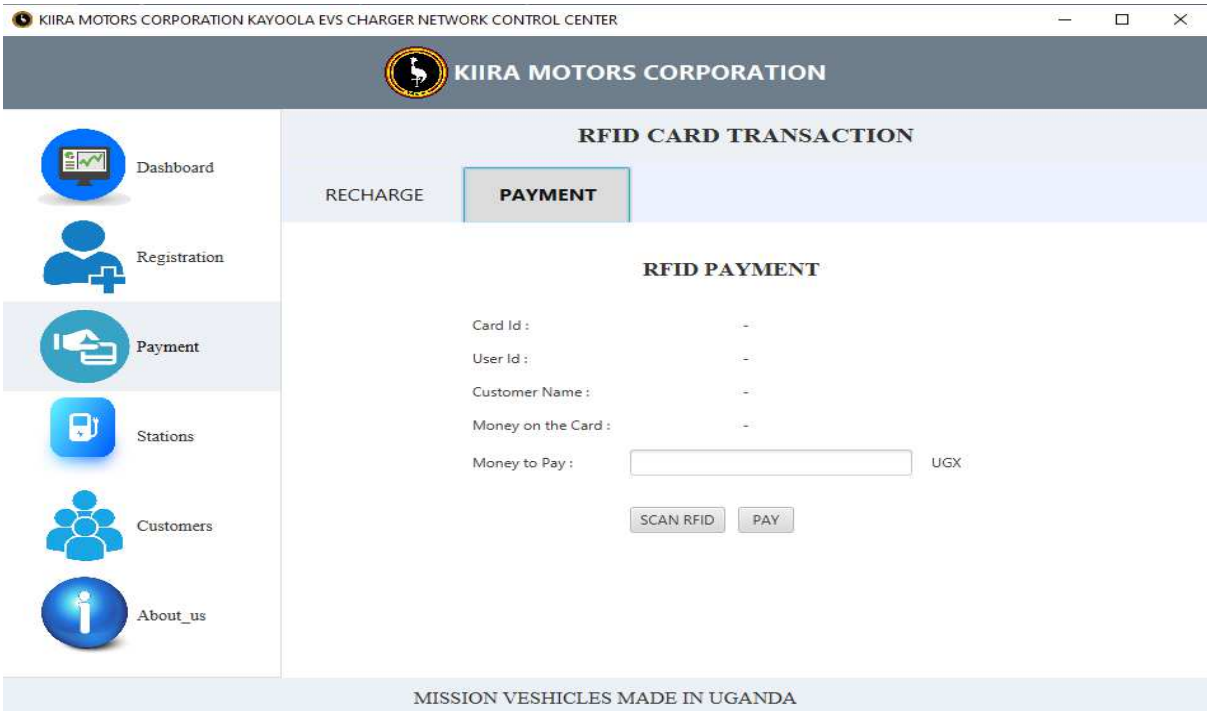

Fig. 8. RFID card payment through desktop application.

4.3 Desktop app Card writing and Recharge

Fig. 9 shows the KMC Dashboard software for real-time remote charging stations information such as revenues collected, charge sessions, battery energy, daily charging faults, active and under-maintenance chargers. Fig. 10 shows Driver registration, and Fig. 11 shows RFID card Writing and recharge. The identifications of specific driver are written on the card with the use of Desktop application software.

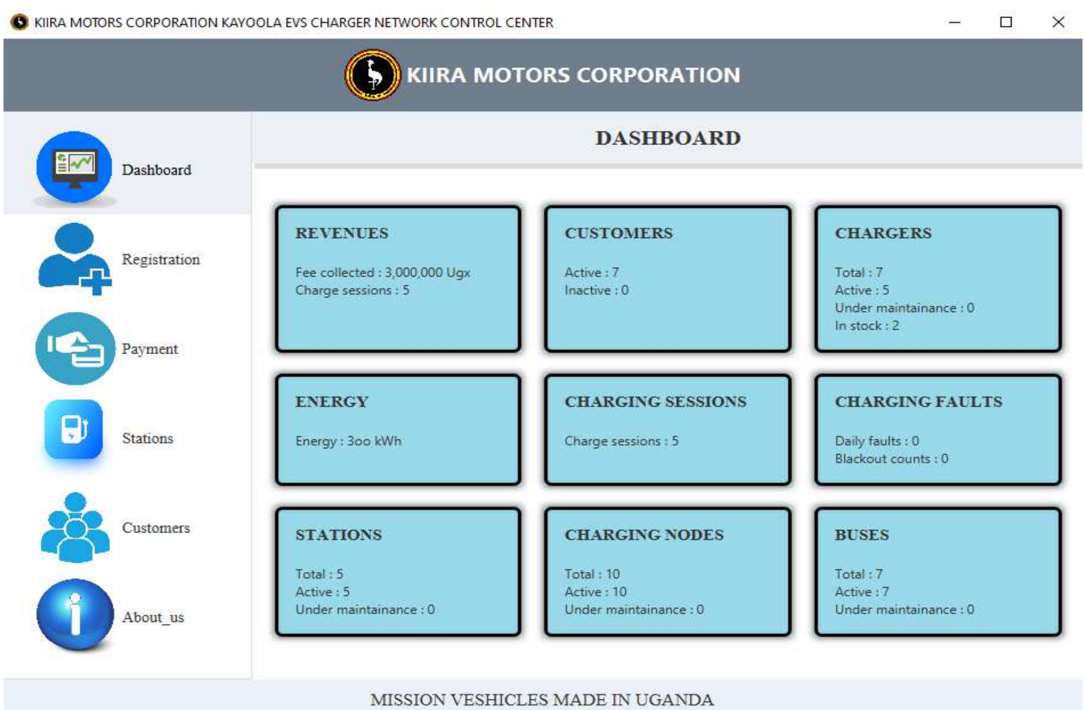

Fig. 9. KMC Station remote monitoring.

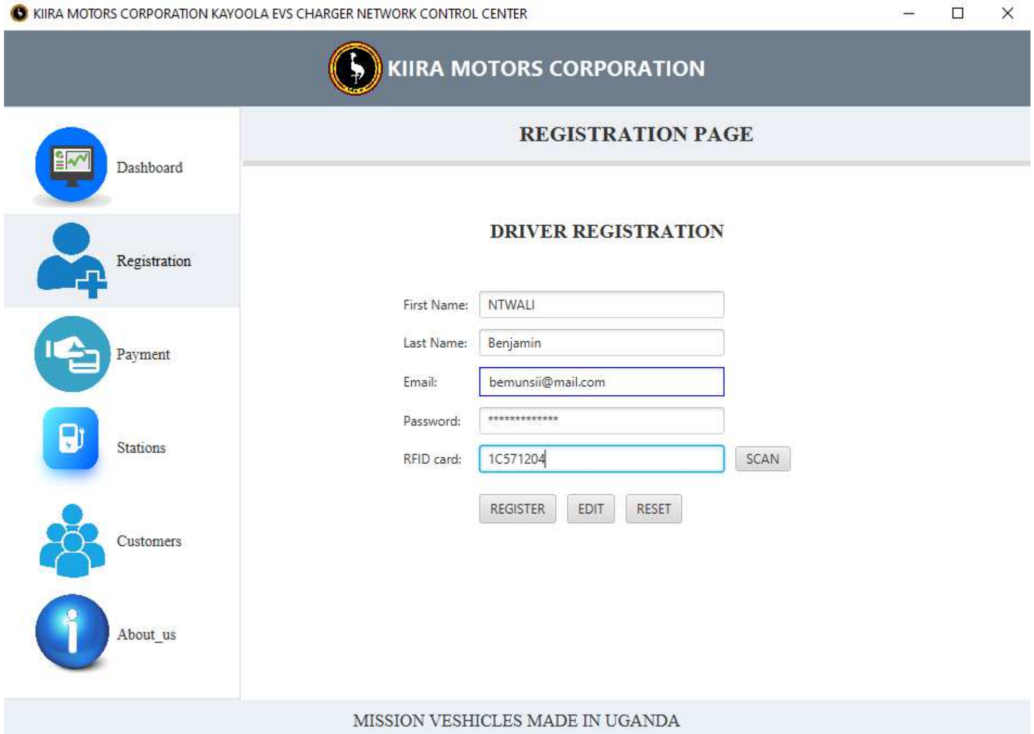

Figure 10. Driver Registration.

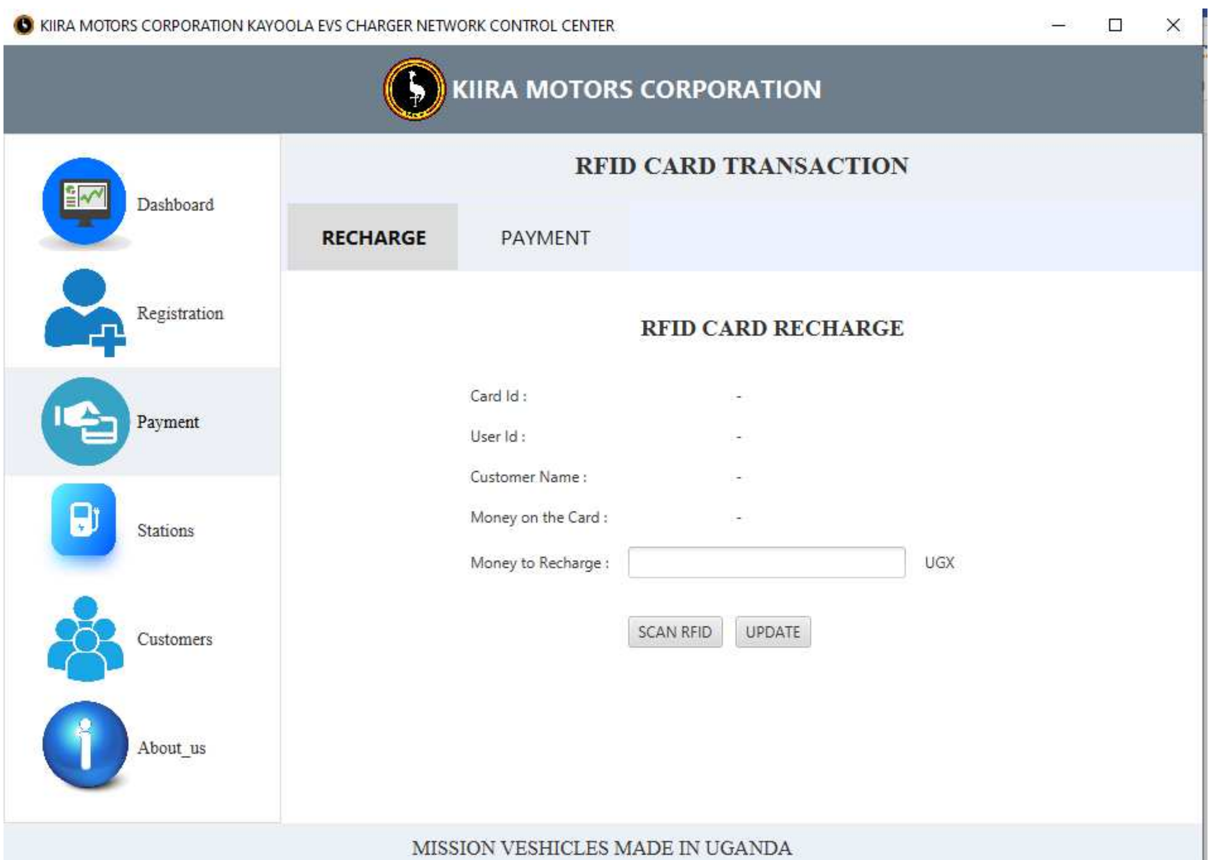

Figure 11. RFID Recharge.

4.4 Desktop Application Real-time Monitoring

Fig. 12 shows Desktop application page for monitoring level 3 chargers' status, and offering remote emergency safety controls. In every charging station, the system safety control and its corresponding battery status parameters such as charged energy, pack voltage, full-latch, and charging percentage levels.

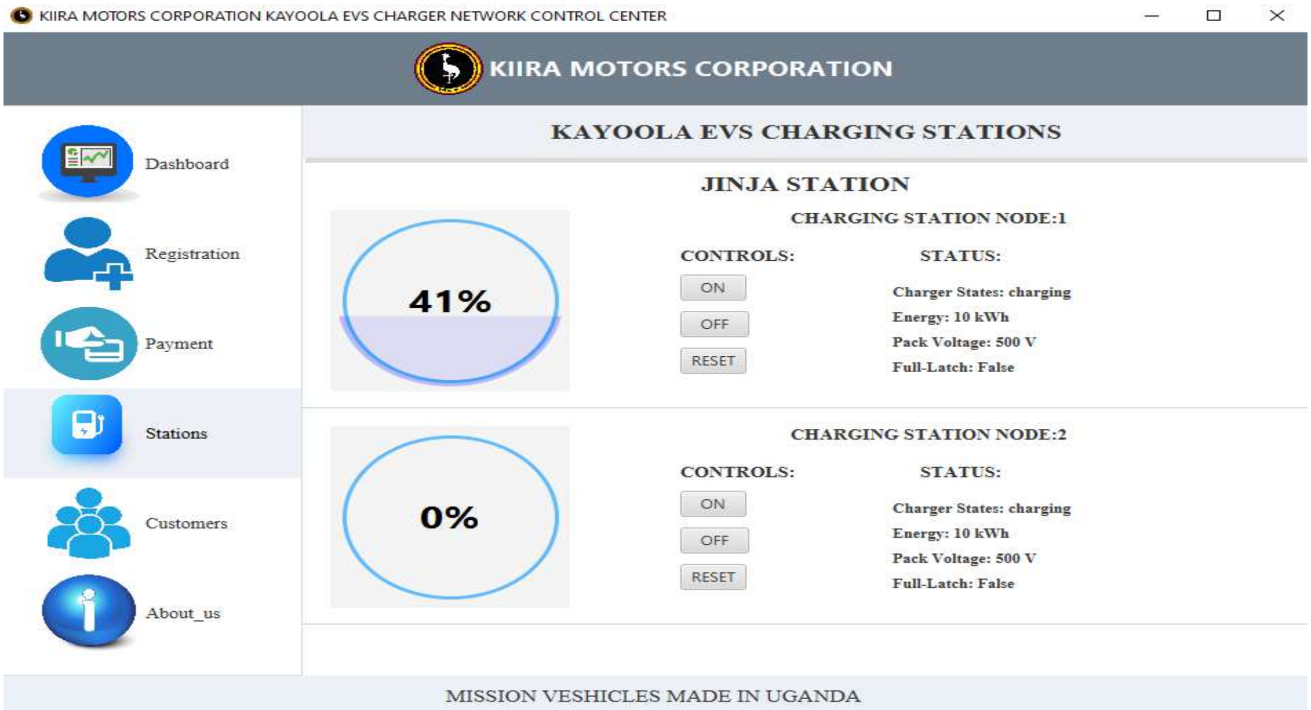

Fig. 12. Remote Monitoring of charging progresses.

4.5 Mobile Application Real-time Monitoring

Fig. 13 shows Mobile application enabling the Driver to receive charge complete notification, checking the status KMC Charging Station, and checking the amount remaining on the RFID card. The pack state of charge (SoC) of 28% and 100% of battery full charged were observed. Other battery charging parameters like pack current, pack voltage, min. and max. cell voltages, min. and max. cell temperatures were detected respectively. Fig. 14 indicates the account and charging station information. In addition, the user can be able check the RFID card balance and check charging station status at every charger node.

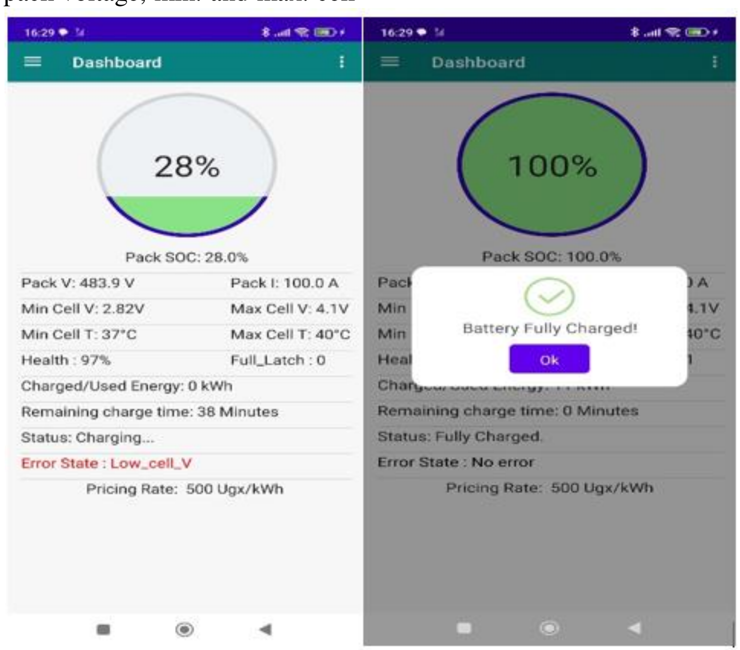

Fig. 13. Dashboard for charge compete notification.

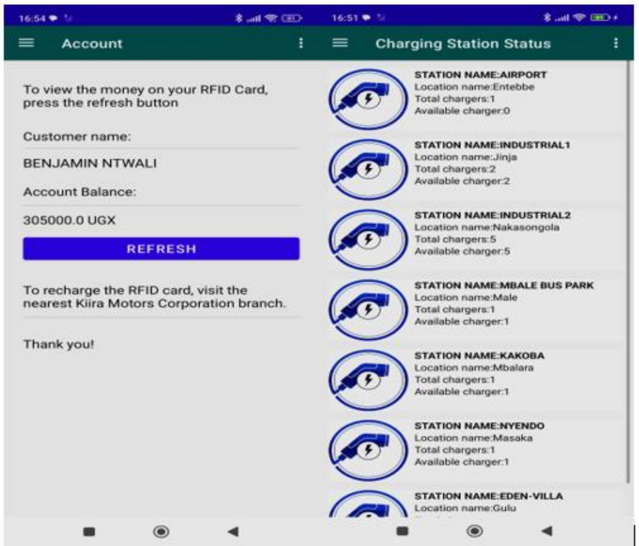

Fig. 14. Account and Charging Station Information.

V. CONCLUSION AND FUTURE WORK

An IoT based Mobile system that allow KAYOOLA Bus drivers to receive charge complete notification, Web and desktop app that allows charging station attendant and KMC management to monitor charging station operations, technicians to easily troubleshot charger issue remotely was developed and tested. The partial charge and unplugging KAYOOLA EV Bus before BMS calibration can lead to potential problems and inconveniences. Batteries are designed to undergo full charging and discharging cycles to maintains their health and longevity. Interrupting the KAYOOLA EVs charging process by disconnecting it from the charger before BMS coulomb counting recalibration by SOC-OCV may results in incorrect SOC prediction, leading to reduced battery life over time and poor reliability of battery pack. Relying on charge complete notification by ensuring all the necessary BMS's SOC calibration has completed instead of relying on SOC by coulomb counting which is inaccurate due to BMS's Lithium-ion cell passive balancing, the developed system was able to verify BMS charge complete information and other hidden information from shared CAN bus and notify the users when these conditions are met. The developed IoT Based Charging System has saved maintenance cost, helped KMC in early detection of charging errors and battery end of life for replacement, and ensuring reliable transportation for KAYOOLA EVs Bus and adoption in Uganda. Further study should then be upgraded by including machine learning for better mains power load distribution and dynamic electricity cost depending on time and peak hours.

Data Availability

Upon request, the corresponding author will provide the data that support the conclusions of this paper.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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