Next-Generation EV Charging: A Hybrid Approach with Seamless Automated Fee Collection

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Abstract:- Electric vehicles are currently seen as a highly promising solution for sustainable transportation. However, a significant drawback is the extended time required for charging, which poses a substantial obstacle to their widespread adoption. The conventional method of fee collection for EV charging in public charging stations is time consuming and has a lot of errors and causes confusion. In this study, we introduce an innovative approach to address the previously mentioned challenges. We integrate a lithium-ion battery and a super-capacitor bank in a 60-40 ratio to tackle the initial problem. This combination is charged with a specified current, supported by a battery protection system and a super-capacitor balancing mechanism. While running the charge inside the super-capacitor is transferred to the EV Battery bank and power generated by regenerative braking is charged to the super-capacitor bankTo reduce the errors and make this fee collection hassle free we are proposing an RFID based automatic fee collection system, where a RFID Tag is affixed near the charging port of the vehicle and a RFID Scanner is connected on the charging gun. Thus, by using this mechanism fee collection is done automatically and it also avoids the use of credit energy.

Keywords:- *Electric Vehicle; Fee Collection; Charging;RFID;*

I. INTRODUCTION

The ongoing expansion of our population and the associated pollution are gradually exerting influences on both our well-being and the surrounding environment. The persistent utilization of nonrenewable energy sources for generating electricity in residential and commercial domains, as well as for powering vehicles, has been linked to adverse environmental consequences. Consequently, scientists are actively exploring technologies that can achieve similar objectives without being dependent on non-renewable energy sources, instead embracing sustainable alternatives like solar and wind power. This is the backdrop against which electric mobility is slowly emerging, aiming not only to harness energy from renewable sources but also to alleviate the air pollution associated with conventional fuel-powered vehicles. In 2019 [1], despite the advancements in charging infrastructure technology, the number of publicly accessible slow chargers worldwide was only 598,000. Half of these slow chargers were situated in China, and an additional 38% could be found in seven other countries. Similarly, there were 264,000 publicly available fast chargers globally, with 81% of them located in China and the remaining 14% distributed across six other nations.

One of the major issues in the electric vehicle field is the charging time of Lithium Ion batteries used in it. The discovery of various battery technologies and improved charging systems has helped to reduce the charging time but it can be even reduced significantly with the use of a super capacitor bank and battery bank combination for energy storage. The battery life cycle being low if we charge or discharge it over a certain limit, the battery capacity will be reduced creating a situation to replace it which is costly. Another problem faced by EV users is the difficulty in the payment of fees in public charging station.

Numerous research studies have been conducted to address this issue. Karangia et al.[2] employed a hybrid storage system, incorporating both a battery module and a supercapacitor module, which they simulated using MATLAB to assess the hybrid storage system's performance (HSS). Their findings clearly demonstrated that the introduction of supercapacitors reduced electrical stresses on the batteries, establishing a complementary relationship between the two. This combination of batteries and supercapacitors efficiently managed the uneven loading profile of electric vehicles without compromising battery lifespan.Another approach to reducing effective charging time involved the use of a lithium-ion battery and a supercapacitor bank [3]. In this method, the lithium-ion battery was charged to 60% of its capacity, and the supercapacitor was sized to accommodate the energy equivalent to the remaining 40% of the battery capacity. The entire charging process was carried out at a predetermined current value, with the added protection of a battery protection circuit and a supercapacitor balancing circuit, resulting in a total charging time of less than 40 minutes. Further investigation into the Battery-supercapacitor hybrid device (BSH) revealed unique advantages, including superior performance, cost-effectiveness, safety, and environmental friendliness in various applications [4]. Notably, the assessment of State-of-Health (SoH) became vital due to the impact of aging on supercapacitors' performance, which could potentially lead to their failure. A novel online diagnostic method for detecting supercapacitor aging issues was developed, requiring only voltage and current measurements and reducing the need for numerous sensors compared to other methods [5].

The structure of this article is as follows: Section 2 outlines implementation details of the energy storage system and fee collection system using RFID. Moreover components required and circuit diagrams are also detailed in this section. Section 3 provides a concise overview of simulation results and hardware prototype while the concluding remarks are presented in the final section.

II. IMPLEMENTATION

In this work, a hybrid energy storage system is proposed, comprising 60 percent supercapacitor banks and 40 percent Li-Ion battery packs. This innovative system incorporates enhanced battery protection and supercapacitor balancing circuits, replacing the conventional single Energy Storage System (ESS). As a result, it significantly reduces the charging time of electric vehicles. Notably, the power generated during braking is directed exclusively to the supercapacitor, minimizing losses during regenerative braking and reducing strain on the battery pack due to fewer charge and discharge cycles.The charging process is intelligently managed: when the vehicle is plugged in, it first charges the supercapacitor bank. Once the supercapacitor is fully charged, a signal is sent to the controller, allowing the battery bank to start charging. During a drive, if the battery bank is not fully charged, energy from regenerative braking is used to replenish the supercapacitor bank. During periods of high power demand, both the battery bank and supercapacitor work in tandem to meet energy requirements. While supercapacitors are more expensive than battery packs, this system compensates for the high cost by using a small battery, which needs replacement more frequently. This initial cost is offset by lower ongoing operating costs for the vehicle. The entire workflow energy storage system is illustrated in the Fig. 1.

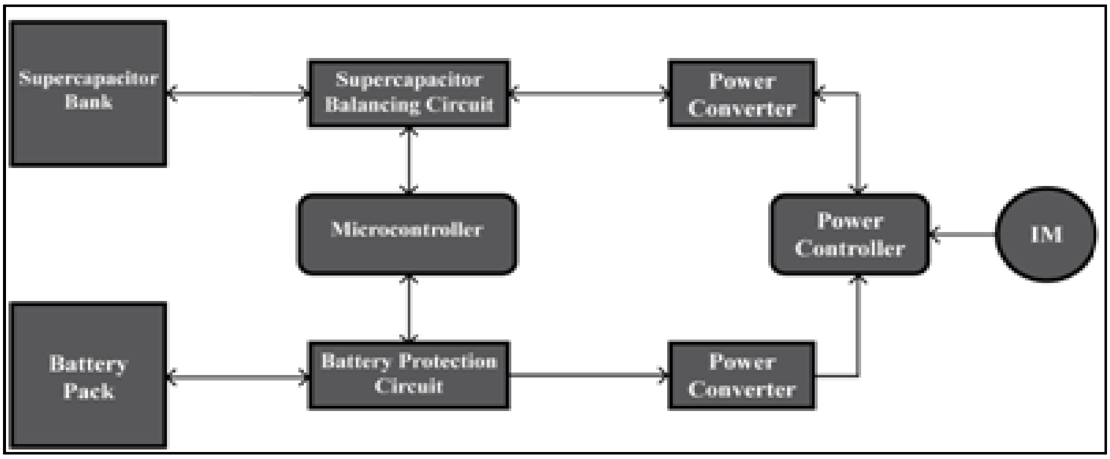

Fig 1 Block Diagram of Energy Storage System

Additionally, an automated fee collection system is integrated into public charging stations, enhancing user convenience. Users attach an RFID tag linked to their bank account or a dedicated charging wallet near the vehicle's charging port (as shown in Fig.2). The charging gun, equipped with an RFID scanner, reads the tag in each vehicle and verifies the available balance. The charging system then sets a maximum energy limit based on the user's balance, deducting the amount for energy consumed if charging is interrupted. This method simplifies payment processes and eliminates the inconveniences associated with traditional payment methods.

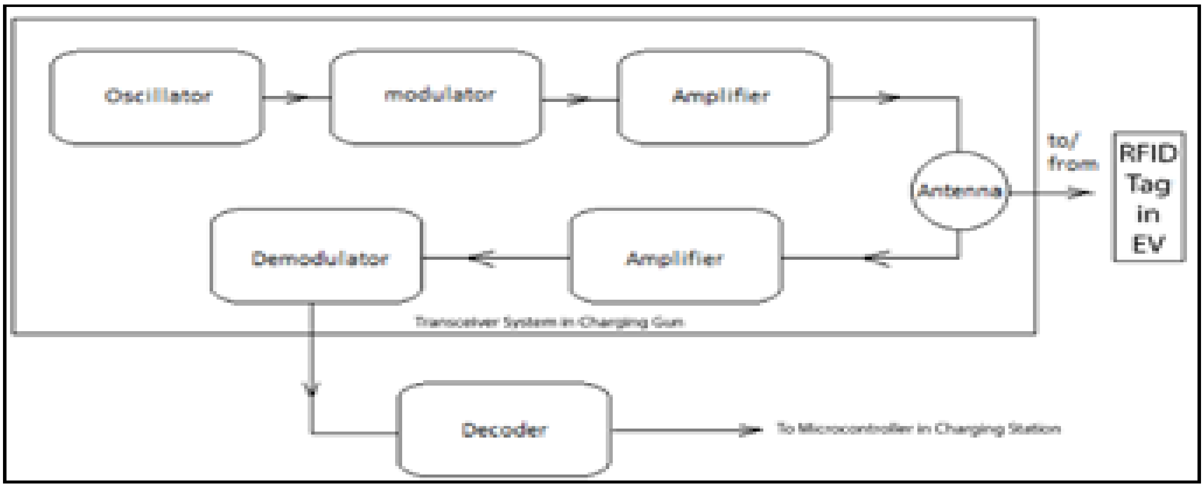

Fig 2 Schematic View of Fee Collection System Using RFID

A. Components Required

The following are the key components required for implementation.

➢ *Arduino:*

- Arduino is an open-source hardware and software platform, as well as a user community, known for designing and manufacturing single-board microcontrollers and microcontroller kits for digital device development.
- Arduino boards come in various designs, each using different microprocessors and controllers. They offer sets of digital and analog I/O pins for interfacing with expansion boards ('shields') and other circuits, with some models featuring Universal Serial Bus (USB) for program loading.
- Arduino boards can be programmed using C and C++ languages through the Arduino language, inspired by the Processing language and used with a modified version of the Processing Integrated Development Environment (IDE).

➢ *ACS712 Current Sensor:*

The ACS712 Current Sensor offers several features and benefits.

- It provides a low-noise analog signal path and has adjustable device bandwidth through the FILTER pin.
- With a fast 5 µs output rise time in response to step input current, it offers an 80 kHz bandwidth.
- The total output error is 1.5% at TA = 25°C, and it comes in a small footprint, low-profile SOIC8 package.
- It has a 1.2 Mega Ohm internal conductor resistance and 2.1 kVRMS minimum isolation voltage.
- The sensor operates on a 5.0 V single supply and has an output sensitivity of 66 to 185 mV/A.
- It produces an output voltage proportional to AC or DC currents, is factory-trimmed for accuracy, and exhibits an extremely stable output offset voltage.

➢ *RFID Module:*

- A versatile multi-communication RFID module.Interfaces with various microcontrollers using SPI, I2C, and UART protocols.
- Operates at 13.56 MHz and reads/writes UID/RFID cards.
- Utilizes mutual induction and radio frequency for communication.
- Effective for security and commercial applications, offering error detection and encryption support.

➢ *JQC3F-05VDC-C Relay Module:*

- A device for opening or closing contacts to control electrical operations.
- Detects undesirable conditions and issues commands for circuit breaker operations.
- Versatile and suitable for advanced applications.
- Convenient for integration into various reader designs.

➢ *ZMPT101B AC Voltage Sensor:*

- A compact single-phase AC voltage sensor module.
- Handles AC voltages up to 250V at 50Hz/60Hz.
- Allows analog output adjustment through an onboard multiturn trimpot.
- Recommended operating voltage is 5VDC.

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B. Circuit diagram and Working

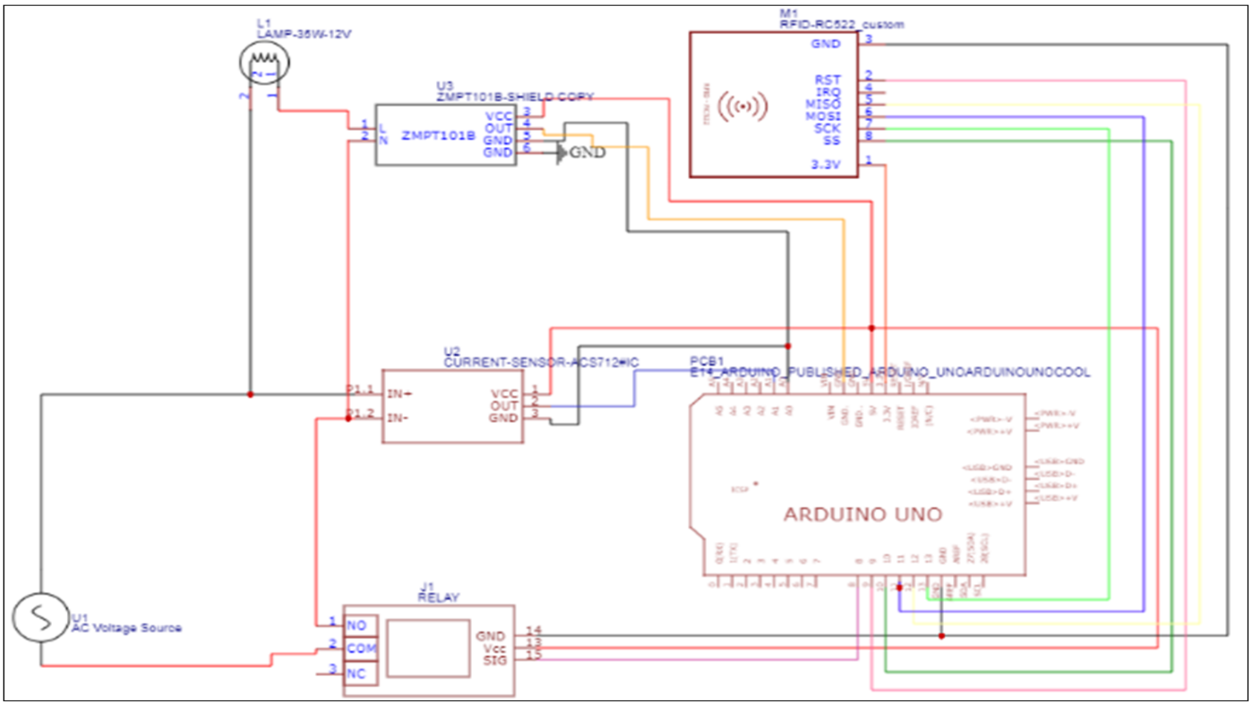

Fig 3 Circuit Diagram of RFID System Hardware

In the automated fee collection system using RFID technology we use a RFID reader or sensor, which is fixed on the charging gun at the charging station and the RFID Tag is affixed on every vehicle's charging port. Whenever a vehicle is plugged in to charge the reader scans the tag and checks with the database whether it is a valid tag or not. Once it's confirmed that it is a valid tag the system checks whether there is sufficient balance in that specific tag and if it validates the conditions the system microcontroller sends a signal to the Relay Module to activate it thus initiating the charging of the vehicle.A current sensor and a voltage sensor are incorporated in the system which is used to measure the current and voltage respectively and using the algorithm calculates the real power used for charging and with it the energy consumed is calculated and finally the amount for the consumed energy is deducted from the wallet or bank account linked with the specific RFID Tag and it's updated in the database. For the prototype version of this system Arduino is used as the microcontroller, ACS712 as the current sensor, ZMPT101B as the voltage sensor and a Relay Module for switching. Here no database is incorporated instead the specific tags are mentioned in the code.

III. RESULTS AND DISCUSSIONS

A. Prototype Hardware

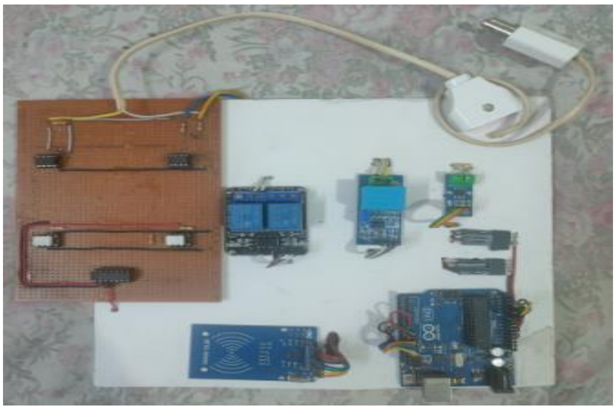

Fig 4 Hardware of Prototype Model

The prototype developed is as shown in Fig 4.

B. Simulation results

The simulation result obtained from Simulink software are detailed in Fig 5 ,Fig 6.6 and Fig. respectively. From the detailed experimentation, the following inferences can be made. In the New European Drive cycle(NEDC) for the simulated vehicle the state of charge(SOC)is 79.92% and the distance driven is 3.21Km. The top speed is reached. Till the first 800 s the drive cycle has many identical speed patterns of acceleration. The instance of a top speed of a vehicle of 120kmh is at the end of the drive cycle. From the current pattern, there are indications of regeneration. Not only that peak operating point is only once hence the battery soc is more compared to WLTP. In the WLTP Drive Cycle the SOC is 66.15 % for a distance of 6.64Km. The required drive cycle is matched. From the specs it was evident that it is possible to operate the vehicle above top speed but the back emf effect will be there. These are shot times when the motor can offer the power of up to 60% of its peak rated power. This affects the SOC of the battery. From 1500 to 1800 s the vehicle is continuously operated at a power that is more than the peak. This has affected the SOC. This can be understood from the SOC graph where there is a steep decline. The interdigital capacitor (IDC))Drive Cycle has an SOC of 85.55% for a distance of 2.047Km. The Indian drive cycle has many retardations and start-stop operations. But the distance covered compared to the other two. This is mostly a start-stop operation in a city and the vehicle is driven at low speed. For the simulation incorporating both the energy storage devices, that is the battery pack and the super capacitor bank, it shows that the super capacitor SOC drastically decreases at some point when high current is drawn from it, while the battery SOC is decreasing at a slow rate. The super capacitor thus can be utilized to supply energy at high current or high power requirement situations. If these loading situations are handled by a battery pack it degrades its life cycle but they can efficiently supply the required power in constant current and power application time.

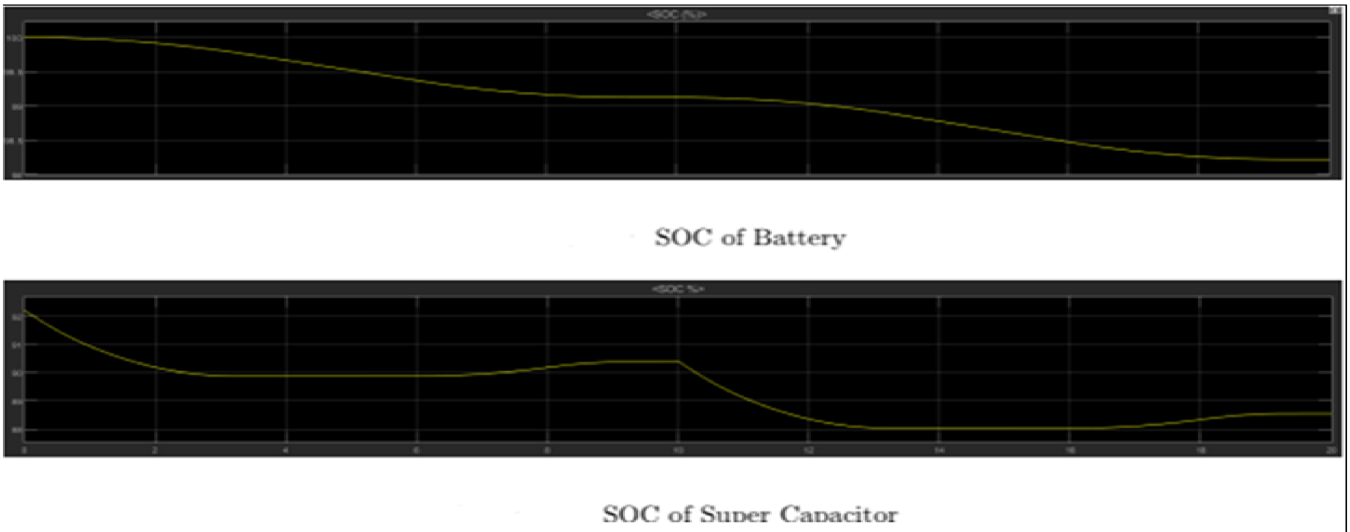

Fig 5 SOC Curves for Battery and Super Capacitor

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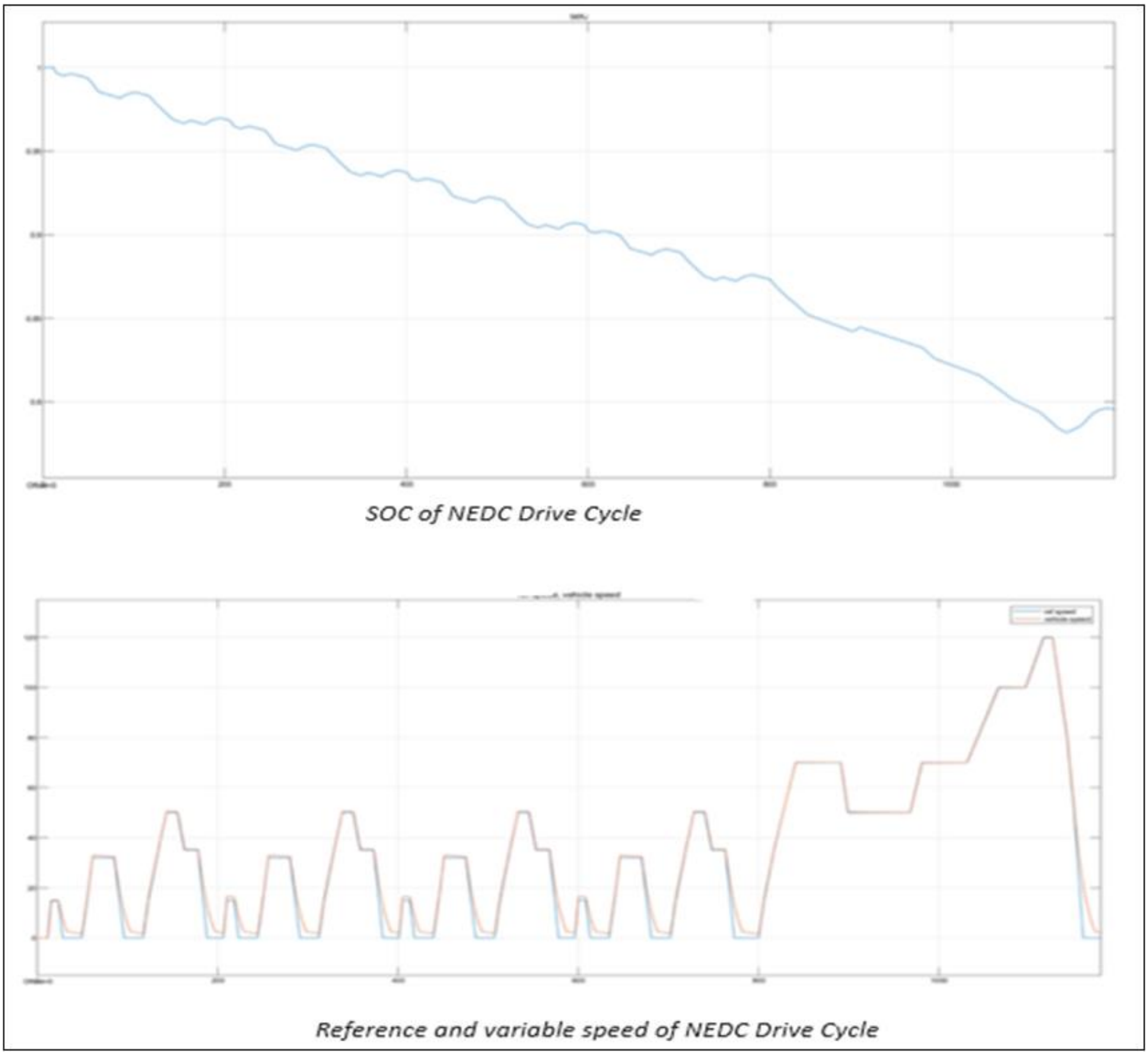

Fig 6 NEDC Drive Cycles Detailed

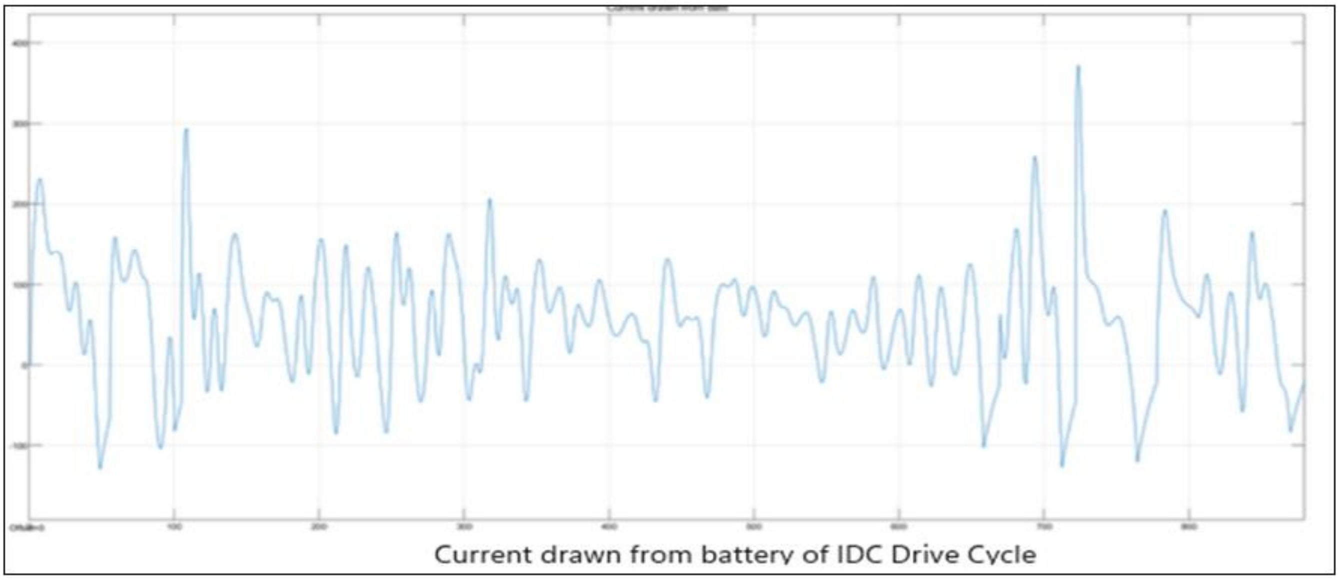

Fig 7 Current Drawn Information

IV. CONCLUSION

In this project, we propose a combination of a super capacitor bank and a Li Ion battery bank at a 60 percent and 40 percent ratio, respectively. Development of ultra-capacitor can lead to a drastic reduction in weight of the vehicle and charging times and increase in efficiency . The system is designed in such a way that it first charges the super capacitor before transferring the charge to the battery. Here, we have initially designed an EV working on battery alone as the ESS. TATA Nexon was taken as the reference, considering a well-to-wheel (WTW) analysis of the vehicle/fuel system, the power delivery and the vehicle subsystem. Its simulation model and results were evaluated. A separate battery and supercapacitor Energy Storage System was also developed which improved the overall efficiency and charging time. Upon integrating the developed ESS with the initial overall vehicular model, the EV is believed to have superior performance and efficiency. Another issue that EV users face is the difficulty in paying fees at public charging stations. To address this, we propose an RFID-based automated fee collection system that can also prevent energy credit usage by checking the balance in the consumer's wallet before charging. The proposed system was designed and the system hardware was developed

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