Decentralized Application for Electric Vehicle Charging at Charging Station

Abstract—**The penetration of electric vehicles (EVs) entails the deployment of more charging station (CS) infrastructure to realize the charging requirement issues of the EVs. But, limited installation of charging infrastructure and data security issues require a secure and efficient CS selection mechanism for EVs. Towards this goal, we proposed an Artificial Intelligence (AI) and game theory-based secure CS selection scheme for EVs using blockchain. Blockchain and AI-based proposed scheme provides security and privacy during the communication between participants, i.e., EVs and CSs, for optimal CS selection. Moreover, an incorporated blockchain network with Interplanetary File System (IPFS) strengthens the reliability and cost-efficiency of CS selection by using beyond 5G network and its ultra-intelligent features. Furthermore, the blockchain and AI-based proposed scheme utilizes coalition game theory approach to recommend the optimal CS for EV and balance the fair payoff between the participants in the network. Finally, experimental results show that the proposed scheme yields better results than the conventional approaches considering the performance evaluation metrics such as State of Charge (SoC), profit analysis, and latency comparison.**

***Index Terms*—Electric Vehicles, Charging Station, Coalition Game, IPFS, Blockchain**

I. Introduction

In the recent past, there has been a huge surge in Electric Vehicles (EVs) due to depletion of non-renewable fuel resources. Moreover, EVs also have various other merits which has led to increase in use of EVs. Firstly, they have low running and maintenance costs; and better performance than fuel based vehicles. Importantly, they also have near to zero harmful emissions making EVs a successful replacement for normal vehicles.

Nevertheless, with drastic rise in number of EVs, there has been an 18% increase in the overall EV cars' share in the year 2023 in India itself. With the explosive growth and scattering number of Charging Stations (CSs) it is quite difficult to allocate charging to all EVs approaching CS on timely basis. Along with that, it is also uncertain for all EVs to get their desired energy demands satisfied on a particular CS. In order, to assign charging to all EVs optimally, energy trading also needs to be implemented.

Various researchers, have proposed works for allocating EVs to CS. Qarebagh [1] *et al.* presented a scheduling algorithm for EVs at CS, this sytem helped reduced the charging time by considering the length of cars and limit of CS. However, they have executed the scenario only for a few number of cars at CS and it does not addresses the problem of charging high number of EVs optimally. Later Li [2] *et al.*, proposed a two-stage charging allocation system using coordinated charging case. They have calculated charging behaviour based on location and capacity of EV, based on this data they can assign charging facilities to EV and improve economy distribution along with EV safety. Further to ensure the balanced charging between EV amd CS in terms of customer satisfaction, Arias *et al.* [3] considered a medium-voltage and low-voltage level network for real-time implementation of EV charging coordination and scheduling using mixed-integer linear programming model. In-spite of various researches and studies for coordination of EVs to CS efficiently; safe and fast charging of EVs is still a major issue which can also hinder customers from buying EVs as their is a risk of data exploitation by CS.

Zhou [4] *et al.* presented a blockchain and edge computing based vehicle to grid energy trading system. It provides a solution for demand-supply issues at CS by providing two-way energy trading capabilities. Edge computing is incorporated to increase block creation probability. Yahaya *et al.* [5] proposed a smart contract and reputation based energy trading system along with load balancing for smart communities. Proof of Work (PoW) mechanism ensures security and further shortest route algorithm is implemented to reduce traveling distance for energy trading. Later, Sahu *et al.* [6] discussed a blockchain based EV charging port allocation framework. Here, the charging time of EVs and availability at CS is considered and based on that scheduling of EVs is carried out, the following system proposes to significantly reduce the waiting time of EVs at CS.

Through the aforementioned research works, it can be claimed that researchers have been using blockchain to solve the issues of security and charging allocation at CS. However, more number of cases have not been considered to successfully implement their works in real-time scenarios. Also, there is no such novel work representing decentralised application for EV charging assignment and energy trading. The EV users do not have access to a user-friendly mechanism to charge or trade energy for their EVs at CS and therefore, the above mentioned research works do not serve the purpose of solving issues related to EV charging. Therefore, we have proposed a decentralised application for EV charging and trading having various facilities like charging based on energy demands, reducing waiting time, providing charging based on type of EVs, energy trading with EVs available at CS or an outsider EV and also management page for CS owners.

A. Research Contributions

Following are the research contributions of this paper.

- This paper proposes a blockchain and AI-based secure CS selection scheme for EVs. The blockchain and IPFS-enabled proposed scheme focuses on availing reliable and optimal CS for EVs with high efficiency and reliability along with the beyond 5G wireless network.
- The blockchain and AI-based proposed scheme leverages coalition game theory to ensure the optimal CS selection

for EVs by providing a fair and balanced payoff for the participants, i.e., EV and CS, in the coalition game.
- The performance of the proposed scheme is simulated and evaluated against various performance metrics such as State of Charge (SoC), profit analysis, and latency comparison.

B. Organization of the Paper

The rest of the paper is organized as follows. Section II discusses the system model and problem formulation of the proposed scheme and Section III highlights the elaborated proposed scheme. Next, Section IV presents the performance evaluation of the proposed scheme. Finally, the paper is concluded with future work in Section V.

II. Related Works

Various researchers have presented their works pertaining to EV charging allocation and energy trading using smart contracts and blockchain. For instance, Lin *et al.* [7] proposed a smart CS management system, to ensure charging is meet to large number of EVs with privacy protection. An AI module is also used to determine renewable energy generation and load consumption to optimally calculate real-time charging and discharging of EVs. Further, Di *et al.* [8] discussed optimal EV scheduling at CS based on blockchain. They also calculate cost based on distance consumption, user reputation and time of use electricity price. The proposed model aims to reduce user waiting time and grid pressure. Liu *et al.* [9] presents an incentive based intelligent system to schedule EVs charging for local load balance. To prevent identity data leaks of EVs, CS, and utility data centre a blockchain based mutual authentication system is designed.

Various charging allocation/ scheduling schemes have been considered for EVs at CS to reduce charging overhead. However, with increasing EVs it is not always feasible to complete all the energy demands efficiently on time. Therefore, many researchers have considered applying vehicle to vehicle energy trading to satisfy all energy demands. For example, Sun *et al.* [10] proposed a regional vehicle-to-vehicle (V2V) energy trading system based on fog computing to resolve the social well-being maximization problem by balancing profits of both discharging and charging EVs. Xue *et al.* [11] presented a blockchain based energy trading scheme based on sharing mode of EVs in smart grid. The system aims to provide a non-tamperable, peer to peer and trusted blockchain system, it helps in feature matching of EVs and generating transactions. Energy trading of EVs with smart grid is also a possible solution using blockchain. Authors in [12] presented CS to vehicle energy trading scheme, further to present sybil attacks a common prefix link-able anonymous authentication scheme is designed.

In the aforementioned research works, various researchers have considered blockchain for privacy protection in scheduling EVs to CS optimally and to carry out energy trading among EVs and smart grids. However, no research aims to provide a combined solution for allocation and energy trading to provide a time effective charging solution. Furthermore, no energy trading and charging web application has been proposed for better user accessibility. Thus, we have proposed a decentralised application for EV users having various features like registration of EVs based on type of EV(emergency, high-authority or normal), charging allocation based on energy demands(low demand, high demand), energy trading option with low demand EVs or outsider EVs at time of hime traffic hours. Further, a user management page is provided for CS officials to carry out charging allocation efficiently. The total bill to be paid for energy trading is also calculated based on energy levels and type of EV.

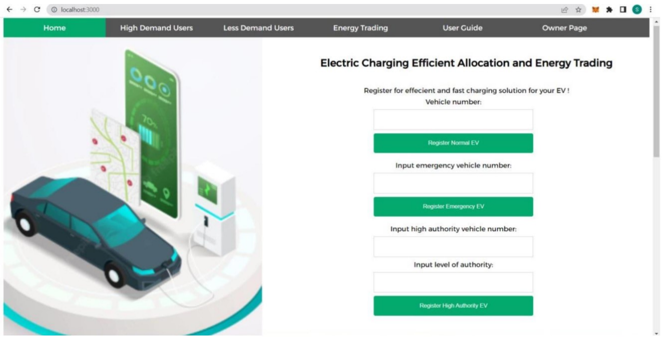

Fig. 1: Home Page of DApp

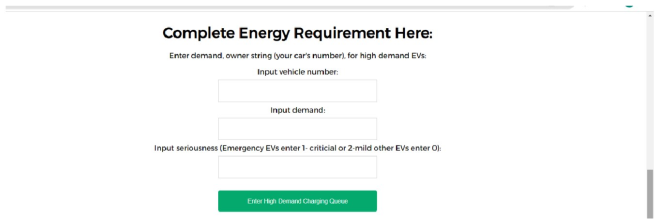

Fig. 2: Entering Queue for Charging Section

III. The Proposed Application

A. Home Page

The home page (α) as can be seen in Figure 1 is the primary page the EV users gets to see when they notice the DApp. Here, the EV users have to firstly register their EVs based on their vehicle type. It can be emergency, high-authority or normal EV. The registration can also be monitored by CS staff by authenticating the data through user management page.

Further, once the registration of an EV is done by entering the unique identification number that is their EV number (as on number plate); the EV users have to enter their energy demands. The energy demands are to be entered on the home page based on your demand type (less energy requirement or high energy requirement) as shown in Figure 2. The threshold for energy demand bifurcation is already listed on the page and users are added to their respective high demand or less demand queues based on their types of demand. For an emergency EV, the users also have to enter the seriousness type (1 for critical and 2 for mild), other EV users have to enter zero. Nevertheless, even if a non-emergency EV enters their seriousness type as 1 or 2, the data is further validated and only then you are allotted priorities of an emergency EV.

$$\beta \xrightarrow{register} \theta, \iota, \kappa \tag{1}$$

$$\gamma(\delta, \zeta) = \begin{cases} \gamma 1 \text{ if } \zeta >= Thresholddemand \\ \gamma 2 \text{ if } \zeta < Thresholddemand \end{cases} \tag{2}$$

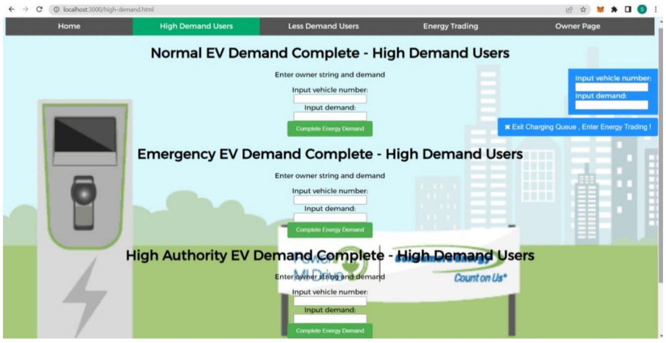

Fig. 3: High Demand Users Page

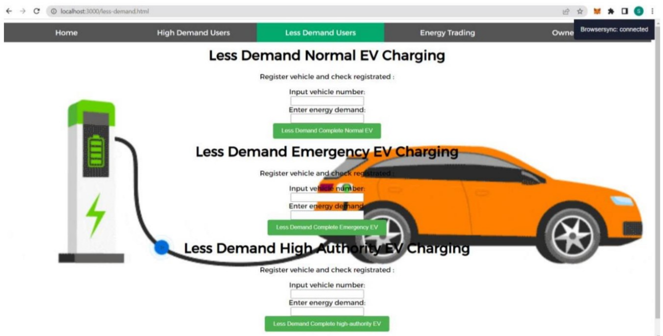

Fig. 4: Less Demand Users Page

The equation (2) represents the registration function denoted by β as stated above. The normal EV represented by θ, emergency EV represented by ι, and high-authority EV represented by (κ) have to register themselves at the CS. The equation (3) represents the enter queue function denoted by γ where EV users have to enter vehicle number (δ) and energy demand (ζ) to enter respective high demand queue (γ1) and less demand queue (γ2) for charging.

B. High Demand Users Page

The EV users who have their demands greater than threshold are added to the high-demand queue. Therefore, to further get allocated for charging, the users need to enter their energy demands on high demand users page as shown in Figure 3. The users have to enter their demands based on their type of EV along with their unique EV number. The allocation of charging point is done to EV based on set priority. If there is an emergency EV in the queue, it gets allotted to charging first, followed by an EV that is high authority. Later, the EVs with waiting time greater than threshold waiting time gets allotted to charging preempting the EVs ahead of them. If there is no EV vehicle with waiting time greater than threshold then the normal EVs are allotted to charging based on First Come First Serve (FCFS) basis.

Moreover, if an EV user enters their energy demand midway and it's not their turn to get allotted to charging station. Then, the EV user gets the notification that it's not their turn along with the reason and the EV that gets allotted to charging is displayed. In some scenarios, when an EV is not able to get allotted to charging even if its waiting time has been exceeded due to presence of one or more higher priority EVs (emergency or high-authority) then they can apply for energy trading. Secondly, the high priority EVs can also apply for energy trading when there are more than one higher priority EVs then that EV, and it might not get allotted to charging as soon as it approaches the CS. To enter energy trading the high demand users have to enter their unique identification number in the blue tab and give their approval to exit the charging queue.

$$\chi(\theta,\iota,\kappa) \xrightarrow{\delta,\zeta} \begin{cases} \zeta = granted \\ \zeta\ != granted \end{cases} \tag{3}$$

$$\tau(\theta,\iota,\kappa) \xrightarrow{\delta,\zeta} Exitchargingqueue \tag{4}$$

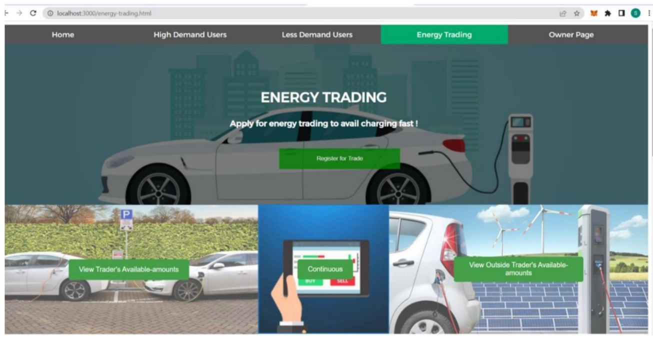

Fig. 5: Energy Trading Page

C. Less Demand Users Page

The less demand users ($lambda$) have to enter their energy demands based on their EV type in a similar way as stated above. Moreover, the less demand users are allotted for charging before the normal high demand users. This in done in order to provide less demand EV users with a benefit of less waiting time and therefore, lower charging cost to complete their less energy demands. The order of allocation to charging point is as follows: firstly an emergency high demand EV gets charging followed by high authority high demand EV, next the EV with waiting time exceeded than threshold waiting time are allotted to charging and then, less demand emergency and high-authority EVs are allotted to charging point. Lastly, followed by less demand normal EVs and then high demand normal EVs.

$$\lambda(\theta,\iota,\kappa) \xrightarrow{\delta,\zeta} \begin{cases} \zeta = granted \\ \zeta\ != granted \end{cases} \tag{5}$$

This order for charging allocation is set in order to solve social problem as a less demand EV will have to wait for long time in the queue and still won't get charging sometimes due to presence of high demand EV users and high authority users. The less demand EV users have sufficient energy available with them can further apply for energy trading, acting as prosumers for energy trading process. Less demand EV users earn incentives and therefore, will join as traders in the process. To enter energy trading less demand users have to register as trader in the energy trading page as further explained in next part.

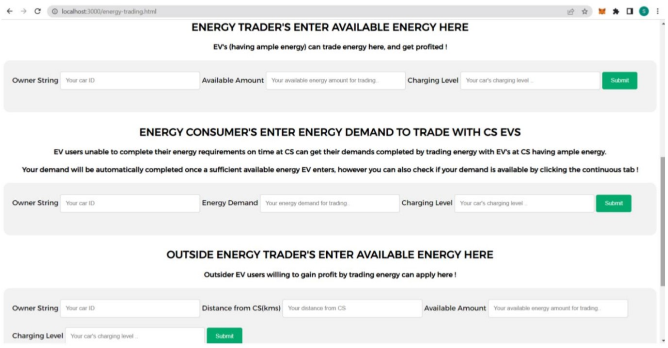

Fig. 6: Energy Trading Data Entry Section

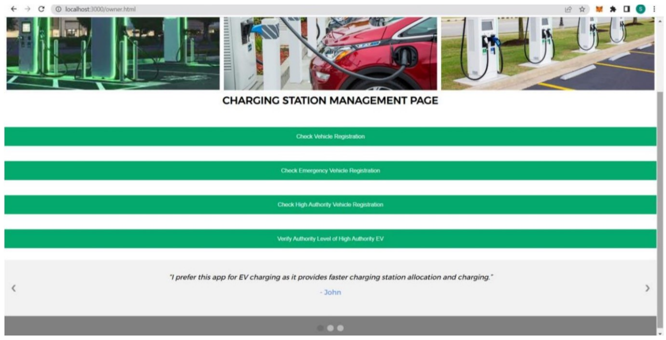

Fig. 7: User Management Page

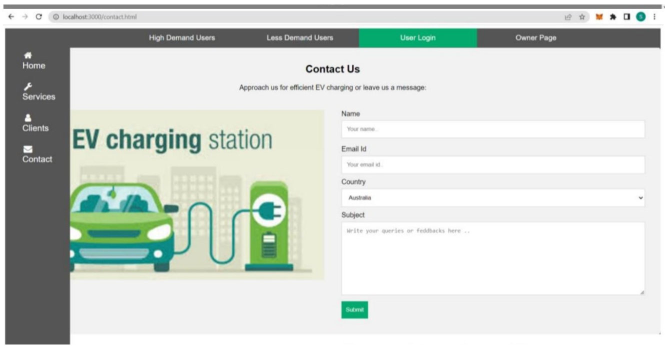

Fig. 8: User Guide with Different Sections

D. Energy Trading Page

The energy trading page is designed for those EV users who are not able to avail charging on time. Firstly, the less demand users or an outsider EV wiling to trade energy has to register themselves through register for trade tab. Moreover, if an EV wishes to get their demands completed through energy trading, then they can check the EVs available for trading through trader's list(on CS trader's list and outsider EVs list available for trading) and then decide to apply for energy trading as shown in Figure 5.

The less demand users after registering themselves as traders can enter their available energy demands, charging level and unique identification number and act as traders. EV users with higher charging levels can provide charging faster and therefore, are paid higher incentives than EVs with lower charging levels. The charging levels are taken for one to four. Similarly, an outsider EV can enter their following data along with an additional data stating their distance from the CS is to be entered. If the distance is less than or equal to two kilometers from CS, then those EVs can act as traders for the particular CS.

Additionally, consumer EV users can enter their energy needs, charging level, along with unique identification number and apply for trading as shown in Figure 6. The EVs will be assigned a prosumer EV and their total bill along with incentives to be paid will be displayed on presence of an EV with energy demand greater than or equal to consumer EV's energy needs. If their is no such prosumer EV in the trader's list then the following consumer EVs will be able to continuous queue. Here, the EVs will be assigned a prosumer based on availability in FCFS order for normal EVs. However, the emergency and high-authority EVs are given a higher priority for getting a prosumer in the continuous queue as well and hence, have to pay higher incentives then normal EV users. However, if an EV users does not wants to wait for their energy needs to be available then they can directly apply for energy trading with an outsider EV. Here, they will have to pay slightly higher incentives as the outsider EV has to travel a particular distance to provide consumer EVs with charging.

The EV users who are taking part in energy trading as consumers can check if there is an availability of their energy demands by clicking the continuous tab. Nevertheless, there is an auto-matic check setup to match the energy needs and available demands of EVs whenever a new EV enters the process of energy trading. But, if a user wishes to check that by himself; they can do it through continuous tab available on the page.

$$\beta(\delta) \xrightarrow{TradersRegister} \Psi \tag{6}$$

$$\Psi(\delta,\zeta 1,\upsilon) = \begin{cases} Accept \text{ if } \zeta 1 >= Thresholdavailableenergy \\ Deny \text{ if } \zeta < Thresholdavailableenergy \end{cases} \tag{7}$$

$$\Psi(\delta,\zeta 1,\upsilon,\varpi) = \begin{cases} Accept \text{ if } \zeta 1 >= Thresholdenergy \ \&\varpi >= 2km \\ Deny \text{ if } \zeta < Thresholdenergy \end{cases} \tag{8}$$

$$\Psi 1(\delta,\zeta 2,\upsilon) = \begin{cases} Trade \text{ if } \zeta 1_1^n >= \zeta 2 \\ Deny \text{ if } \zeta 1_1^n < \zeta 2 \end{cases} \tag{9}$$

E. User Management Page

The user management page (μ) or the owner page as shown in Figure 7 is designed for the CS staff or officials to validated the registration information entered by EV users. The CS staff can validate whether an EV is emergency or high-authority. They can also view basic information like whether an EV entering their CS is registered or not as shown in the equation (3). These data helps in proper functioning of the system and blocking malpractices that might occur while registration.

$$\beta 1 \xrightarrow{CheckRegistration} [\theta,\iota,\kappa](\delta) = \begin{cases} \text{True if } \delta = registered \\ \text{False if } \delta ! = registered \end{cases} \tag{10}$$

F. User Guide Page

The user guide page (ν) is designed to make the DApp more approachable and accessible to the EV users. The users can view the services (ξ) provided by CS (like energy trading, charging allocation based on EV types), they can view our clients (π) i.e., different CS that have been using this DApp as shown in equation (4)(in-order to create a sense of trust among new users). And importantly, they can contact us (ρ) for any of their difficulties using the application through the contact us section as shown in Figure 8. The contact us page is implemented using PHP post action to the email of DApp manager. The user has to enter name ($\rho1$), ID ($\rho2$), country ($\rho3$), and subject ($\rho4$) for submitting the query to the DApp manager as represented in equation (5).

$$\nu \rightarrow \xi, \pi, \rho \tag{11}$$

$$\rho(\rho1, \rho2, \rho3, \rho4) \rightarrow submit \tag{12}$$

IV. Performance Evaluation

V. Conclusion

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