Blockchain-based Energy Trading Scheme for EVs coordination: A Smart Contract Approach

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***Abstract*—The extensive deployment of electric vehicles (EVs) globally has become an alternative to fossil-fuel or gasoline vehicles to tackle harmful greenhouse gas emissions. But, huge EV charging demand can bring challenges to the charging infrastructure by destabilizing the grid stability and affecting efficient EV charging. Thus, the aforementioned challenges can be addressed by facilitating the energy trading (ET) between EVs which can act as prosumers or consumers. Thus, we have proposed a blockchain-based secure ET scheme for EVs coordination using IPFS protocol to mitigate the data storage cost issues of the blockchain. Opportunistically, we have considered various ET scenarios to coordinate the communication between prosumer and consumer based on the waiting time and priority levels. Moreover, the data communication between EVs is considered via a 5G communication network for highly reliable and efficient ET. Finally, the proposed model is evaluated by executing the smart contract using Remix Integrated Development Environment (IDE) with various performance metrics such as gas consumption and cost (execution and transaction cost) analysis.**

***Index Terms*—Electric Vehicle, Charging Station, Energy Trading, IPFS, Blockchain, 5G**

I. Introduction

In recent times, there has been an enormous surge in electric vehicles (EVs), and it is expected to grow from 8 million units to 45 million units by 2030 across the globe. The drastic increment of EVs on the road is due to reduced non-renewable energy sources. Besides, EVs possess various benefits over traditional fossil-fuel vehicles, such as lower running costs, higher efficiency, lower energy consumption, and environment friendly as they do not emit harmful pollutants, maintaining a green environment. However, with the rising demand for EVs in the energy market, it is crucial to allocate EVs efficiently to charging stations (CSs) without any delay due to their high energy demand, which leads to an increment in their waiting time at the CS. Moreover, the installation of CSs requires a great deal of finances for their deployment, installation, and maintenance. So, to resolve the aforementioned issues of coordinating EV charging at the CS efficiently and timely, many researchers have discussed their research work to assign CSs to EVs optimally and by discussing the energy trading (ET) scheme for EVs charging [1] [2]. For instance, Li *et al.* [3] proposed an optimized charging and discharging mechanism for EVs through a reliable charging index. Their system helped in improving user satisfaction and the trustworthiness of EV charging. Further, Zhang *et al.* [4] presented a planning mechanism for CSs, where the charging behavior of EVs is analyzed along with the charging queue index to lower the cost of users and increase benefits for CS owners. Later, optimal functioning of EV at CS (proper EV charging allocation) is achieved by the authors of [5] by applying the game theory approach. The aforementioned model assists in selecting CS based on Evs' huge charging demand to overcome the competition between arriving EVs for charging.

The preceding solutions proposed by various researchers focused on effectively assigning and satisfying the energy demands of EVs. However, they can be easily exposed to different security attacks such as distributed denial-of-service (DDoS), man-in-the-middle (MITM), malware, fraud, etc. In order to deal with privacy and security issues, many authors have presented blockchain-enabled frameworks to allocate energy demands to EVs at CS using ET [6] [7] [8]. Firstly, Kakkar *et al.* [9] proposed an IoT and blockchain-enabled EV scheduling scheme at CS. Nevertheless, the authors haven't considered all the possible scenarios of various types of arrival of EVs which can impact the efficiency and reliability of the system. Then, Kakkar *et al.* [10] considered blockchain technology for ET to provide an optimum pricing scheme. It is based on a double auction mechanism to introduce the incentive mechanism for the involved participants in the ET. Further, Baza *et al.* [6] presented a blockchain-enabled ET scheme to prevent various security attacks and efficient ET maintaining the identity of the EVs anonymous. Later, a smart-contract based ET system for smart cities has been proposed, facilitating ET through local renewable energy providers. The aforementioned system yields improved latency and transaction throughput even at congestion hours in a crowded city [11].

As per the above-mentioned surveyed literature, various researchers have included blockchain framework to secure the process of EVs coordination using ET mechanisms. However, all the scenarios corresponding to ET between EVs, along with the priority levels and waiting period of EVs, haven't been considered to perform the ET between EVs. Therefore, we have proposed a blockchain and Interplanetary File System (IPFS) architecture for a trustworthy and cost-effective ET system between EVs in which they can act as prosumers or consumers to accomplish the ET securely and efficiently. Moreover, we have considered the synchronization of EVs while applying for ET with different scenarios with priority EVs. The scenarios are formulated using various parameters such as energy demand, priority level, waiting period, and available energy of EVs for trading. Additionally, we have implemented a 5G network to enable the high availability and scalability of communication between prosumers and consumers for ET.

A. Research Contributions

Following are the research contributions of this paper.

- We have proposed a blockchain-based ET scheme for EVs secure and efficient coordination by combining the IPFS and 5G communication network.
- We have formulated various ET scenarios based on waiting time and priority levels of the consumers for executing the ET in fair and trustworthy manner.
- The communication between ET entities is considered through a 5G network which offers a high data rate, low response time, and high availability environment for EVs.
- The performance evaluation of the proposed model is analyzed considering various factors such as gas consumption and cost (transaction and execution cost) analysis along with the security analysis of the smart contract using the Echidna tool to ensure the ET without any threat.

B. Organization of the Paper

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

II. System Model and Problem Formulation

In this section, we discussed about the system model and problem formulation of the proposed scheme.

A. System Model

We have presented a framework for a secure EVs ET scheme with the amalgamation of 5G and IPFS so that prosumer and consumer can communicate with each other based on the various scenarios for the fulfillment of EVs energy demand. Now, EVs arrive at the CS with some available energy which can vary based on their destination that finalizes their energy demand for charging. Further, EVs at the CS are classified based on their charging demand, i.e., low energy requirement EVs (having high available energy) and high energy requirement EVs (having low available energy) can be assigned to the charging queue ζ_q^c. They are further categorized based on the priority levels, i.e., 0, 1, or 2 $\in \{p_0, p_1, p_2\}$. EVs such as high authority, government cars, emergency cars, etc., can register for priority levels 1 or 2. However, EVs with high priority (1 or 2) can easily preempt the other of low priority, which can increase their waiting time and delay their traveling plans, demotivating them from participating in the charging. Thus, EVs can opt for the ET mechanism for energy fulfillment over a 5G wireless network based on their energy requirement, i.e., EVs with low energy can act as consumers and EVs with high energy can participate in ET as a prosumer for fulfilling the energy demand of consumers in the charging queue ζ_q^c. So, based on the consumer's priority level, we have considered various scenarios to accomplish the coordinated ET between EVs.

To accomplish ET between prosumers with lower energy demand and consumers with higher energy demand, we have focused on various scenarios based on the priority level of EV and the waiting time of EV. The waiting time for approaching EV is calculated based on the charging time of the EV ahead of it. Also, the consumers can view the trader's queue (having available energies of the trading vehicle) before applying for ET to check for energy availability according to the demand. The priorities for the consumers are considered in the order of $p_2 > p_1 > p_0$ for high authority vehicles applying for the ET with the prosumers. So, consumer EV with priority 2 is privileged the most for ET, consumer of priority 1 can be eligible for ET, and priority 0 is considered the lowest priority for ET with the prosumer. Therefore, arriving EVs, i.e., prosumer and consumer, can get involved in the ET over blockchain network to ensure the trustworthiness and privacy of the EVs with IPFS and 5G wireless network. The IPFS protocol with the blockchain improves the cost-efficiency of the ET between EVs (prosumers and consumers) with the ultra-intelligent features of the 5G network, which encompasses high data rate, availability, and reliability.

B. Problem Formulation

The proposed blockchain-based ET scheme initiates the energy demand request of arriving EVs at the CS. Then, based on the waiting time and priority levels of the EVs, they can apply for ET in which EVs with high energy requirement υ_h as consumers and EVs of low energy requirement υ_l as prosumer based on their willingness for ET. So, prosumers $\{\gamma_1, \gamma_2, \ldots, \ldots, \gamma_g\} \in \gamma_G$ with the surplus energy β^{γ_G} can communicate with consumers $\{\delta_1, \delta_2, \ldots, \ldots, \delta_d\} \in \delta_D$ with their energy demand α^{δ_D} to trade energy and in return, prosumer get the incentive ϕ from the consumer which varies based on the charging levels of EVs and their distance from CS which is discussed in the various scenarios of ET. The above-mentioned associations between EVs are represented as follows:

$$\pi_{\Theta_T} = \begin{cases} \upsilon_l & \text{If EV is prosumer} \\ \upsilon_h & \text{If EV is consumer} \end{cases} \tag{1}$$

$$\sum_{G=1}^{g} \gamma_G^{\beta^{\gamma_G}} \xrightarrow{\upsilon_h} \sum_{D=1}^{d} \delta_D^{\alpha^{\delta_D}} \tag{2}$$

$$\sum_{D=1}^{d} \delta_D^{\alpha^{\delta_D}} \xrightarrow{\phi} \sum_{G=1}^{g} \gamma_G^{\beta^{\gamma_G}} \tag{3}$$

where g number of prosumers can trade energy υ_h with d number of consumers for obtaining the incentive of ϕ. Thus, ET is performed by considering the priority level of consumers willing to trade energy with the prosumers in the charging queue ζ_q^c based on the waiting time considering various scenarios. Firstly, when the calculated waiting time of the EV entering the charging queue is greater than the threshold value, then they can apply for ET to save time and cost that may arise due to waiting in the queues for a longer duration. Secondly, when the waiting time of EVs exceeds the threshold time, and an EV of priority level 0 is also present in the charging queue, then EVs of priority 0 get the opportunity to trade with the prosumer. But, the third scenario involves consumers with priority level 1 or 2 willing to trade energy with the prosumers as there are higher priority level

EVs already present in the charging queue, in such scenario consumers with priority level 2 preempt the other EVs and get an opportunity for trading with the prosumers, and they can get the higher incentive than the aforementioned scenario for trading purpose. After that, EVs with priority 1 can be assigned to the ET mechanisms with the prosumers.

Moreover, we have considered a fourth ET scenario in which if energy demand of the consumers is not fulfilled due to the exceeding value of waiting time of EVs with priority level 0 due to the preemptive ET of EVs with priority level 1 or 2 in the charging queue. In that case, consumers of priority level 0 can trade energy with the EV, which is at a distance of 2km or less from the CS, but they have to pay higher incentives than the aforementioned scenarios as the prosumer has to travel some distance to the CS for ET. The association of priority level with the consumers and with the ET is mentioned as follows:

$$\{\delta_1, \delta_2, \ldots, \ldots, \delta_d\} \rightarrow \{p_0, p_1, p_2\} \tag{4}$$

$$\{\gamma_G^{\beta^{\gamma_G}}, \delta_D^{\alpha^{\delta_D}}\}(p_0) < \{\gamma_G^{\beta^{\gamma_G}}, \delta_D^{\alpha^{\delta_D}}\}(p_1) < \{\gamma_G^{\beta^{\gamma_G}}, \delta_D^{\alpha^{\delta_D}}\}(p_2) \tag{5}$$

The energy data transactions involving trading energy and incentive between prosumer and consumer need to be stored securely in a distributed and immutable platform which can be achieved with the blockchain. But, blockchain can't perform the data transactions with the cost-efficient that can be attained with the IPFS protocol, a content addressing protocol that offers low data storage cost for energy data transactions of the EVs. But, to accomplish the data storage in IPFS reliably, foremost, the smart contract needs to be running to verify the identity of the EVs. Based on the verification, it allows them to access the IPFS for data storage. Once EVs get the privilege and opportunity for data storage in IPFS, energy data transactions can be performed over blockchain securely.

III. The Proposed Model

Figure 1 focuses on the blockchain-enabled ET scheme for secure EVs coordination with 5G wireless network. The proposed scheme is classified into three layers such as Data Acquisition Layer, Energy Trading Layer, and Distributed Ledger Layer.

A. Data Acquisition Layer

The primary layer in the proposed model is the data acquisition layer which contains energy data $\omega^d \in \delta_{\omega^d}, \gamma_{\omega^d}$ corresponding to EVs ω approaching CS ψ, and EVs participating in ET (δ and γ). The EVs in the charging queue ζ_q^c need to enter their energy requirement, priority levels p_l (i.e., $\in \{p_0, p_1, p_2\}$), and the unique identification string of EV for registration and trading purpose. As EVs energy requirement bifurcates them into prosumer and consumer while applying for ET based on the threshold energy,i.e., χ. EVs with energy ($\upsilon > \chi$) tends to participate in ET as a prosumer and EVs with energy ($\upsilon < \chi$) participate as consumer in the ET.

In ET, prosumers can specify their surplus energy β^{γ_G} and consumers can request for ET with the energy demand of α^{δ_D}. Moreover, outsider EVs at a distance of 2km or less from the CS can also play the role of prosumers based on their willingness to perform trading with the consumers of waiting time exceeding the threshold time due to the preemptive nature of other high priority EVs. Thus, outsider EVs η_o can apply to trade energy with the consumers waiting at the CS by considering the distance Δ to the CS, which is determined using the longitude and latitude of outsider EVs $(\theta^{\eta_o}, \vartheta^{\eta_o})$ and CS $(\theta^{\psi}, \vartheta^{\psi})$ and prosumers (outsider EVs) get the incentive to perform ET based on their distance. Thus, the prosumer and consumer corresponding to the energy data communicate to accomplish the ET reliably without delay.

$$\omega^d = \{\upsilon_\delta, \upsilon_\gamma, \delta_{\omega^d}, \gamma_{\omega^d}, \chi, \beta^{\gamma_G}, \alpha^{\delta_D}, \Delta\} \tag{6}$$

$$\Delta = \sqrt{(\theta^{\psi} - \theta^{\eta_o})^2 + (\vartheta^{\psi} - \vartheta^{\eta_o})^2} \tag{7}$$

Now we focus on various ET scenarios in which participants (prosumer and consumer) along with their energy data ω^d can apply for ET based on their waiting time and priority levels.

B. Energy Trading Layer

ET layer is the most crucial layer for successfully executing and fulfilling the energy requirement of EVs based on the energy data acquired from the data acquisition layer. ET between prosumer (trader's queue ζ_q^t) and consumer (consumer's queue ζ_q^e) is achieved by considering the waiting time and priority levels of the arriving EVs at the CS. We have considered several ET scenarios to explain how prosumers can trade energy with the consumers, and prosumers receive the incentive for transferring the energy to the consumers. Before discussing the ET scenarios, we have considered a scenario that initiates the ET between EVs to further focus on the other ET scenarios, assuming that the number of consumers is greater than the number of prosumers in the ET.

1) ET Layer-Case 1: The first scenario for initiating the ET arises when the waiting time of EVs Φ_ω exceeds the threshold waiting time $\Phi_{\omega'}$. The waiting time of any arriving EV in the charging queue ζ_q^c is determined using the charging time of the prior EV already charging at the CS. If the waiting time of EVs is found to be less than the threshold waiting time, then EV can charge at a CS. But, with the waiting time of EVs exceeding the threshold, they can opt for ET based on the energy demand of consumers needs to be fulfilled by the prosumers. Thus, the above-mentioned associations is represented as follows:

$$\pi_{\Theta_T} = \begin{cases} \Phi_{\omega^g} & \text{If waiting time greater than threshold} \\ \Phi_{\omega^l} & \text{If waiting time less than threshold} \end{cases} \tag{8}$$

$$\{\omega(\Phi_{\omega^g}, \alpha^{\delta_D}), \omega(\Phi_{\omega^l}, \upsilon)\} \xrightarrow{EV-CS,ET} \{\psi, (\gamma_G, \delta_D)\} \tag{9}$$

Now, EVs can exit the charging queue ζ_q^c to apply for ET after checking some of the conditions related to the energy requirements. Moreover, before exiting the charging queue, the prosumer can access and view if any consumer is willing to perform the ET and the consumer can also check the trader's queue for ET. So now EVs willing to perform the ET can arrive at a CS with some priority levels in which we need to prioritize the trading fairly.

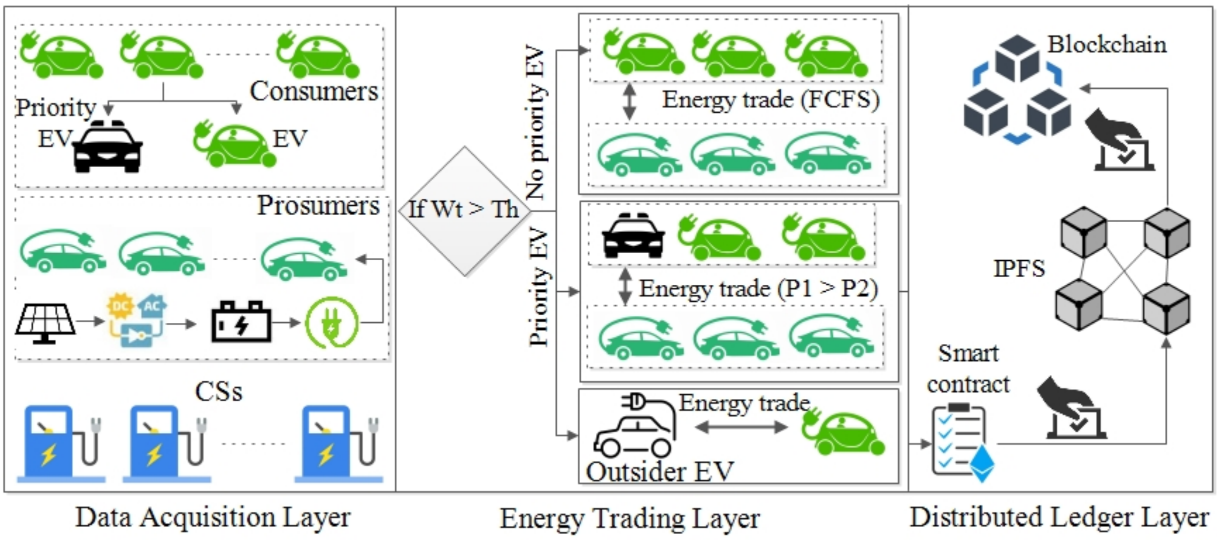

Fig. 1: The proposed ET scheme for EVs coordination.

2) ET Layer-Case 2: The next ET scenario encompasses consumer EVs with priority p_0, p_1, and p_2 willing to perform ET with the prosumers. Now, we need to prioritize the ET between consumers (priority EVs can be an emergency, ambulance, or high authority vehicle) based on the priority level, i.e., $p_0 < p_1 < p_2$. Now, consumer EVs with priority 2 can participate in the ET by preempting other consumers of priority 0 or 1. Then, after approving the ET initiation between the prosumer and the consumer of priority 2, the consumer of priority 1 can be privileged to perform the ET with the prosumer. Finally, a consumer with priority 0 is considered for involvement in the ET with the prosumer. Thus, ET between the prosumer associated with the surplus energy β^{γ_G} and consumer with the energy demand of α^{δ_D} can be performed based on the considered priority and prosumers get the incentives (considering per unit rates p_r from the consumers which is decided based on their priority. It means prosumers get more incentives from the higher authority vehicles, which is expressed as follows:

$$\gamma_G^{\beta^{\gamma_G}} \xrightarrow{ET} \delta_D^{\alpha^{\delta_D}}(p_0, p_1, p_2) \text{ and } \delta_D^{\alpha^{\delta_D}} \xrightarrow{\phi} \gamma_G \tag{10}$$

$$\phi^{\gamma_G}(p_2) > \phi^{\gamma_G}(p_1) > \phi^{\gamma_G}(p_0) \tag{11}$$

Hence high priority consumer EVs can apply for ET, but they have to pay additional incentives to the prosumers. As their preempting nature allows them to preempt other EVs by paying additional incentives to the prosumers based on their priority levels. Now, there can be another case with consumers of the same priority requesting for ET. Then, the first come first serve (FCFS) scheduling algorithm is utilized so consumers can get involved in the ET based on their timestamp.

3) ET Layer-Case 3: After discussing the ET scenarios from the above-mentioned cases, we can infer that it is not always possible to have required available energy in the trader's queue to fulfill the energy demand of consumers. Moreover, consumer EVs with priority level 0 may have to wait longer due to the request of the other high priority consumer EVs for ET. Thus, they can be assigned to the consumer's queue when there is insufficient available energy in the trader's queue and get assigned to trading automatically when a trader EV with sufficient available energy enters the trader's queue. Then, consumers in the consumer's queue can trade energy with outsiders' EVs. Towards this goal, it is beneficial to consider EVs at a distance from CS to participate in ET as traders or prosumers. For that, foremost, EVs (outside of CS) are required to register for ET and have to enter their distance Δ from a particular CS. Therefore, they can act as traders or prosumers if the distance is less than or equal to 2 km. In this scenario, consumers have to pay higher incentives $\phi^{'}$ based on the per unit rate $p_{r^{'}}$ and than the aforementioned scenarios as prosumers have to travel some distance to reach the CS which acquire additional cost for them. Thus, we can represent the ET between consumer and outsider EVs as follows:

$$\eta_o(\Delta, \beta_{\eta_o}) \xrightarrow{ET} \delta_D^{\alpha^{\delta_D}}(p_0) \text{ and } \delta_D^{\alpha^{\delta_D}} \xrightarrow{\phi^{'}} \eta_o(\Delta) \tag{12}$$

where $\phi^{'}$ signifies the incentive provided by the consumers of priority level 0 to the outsider EVs for ET in an efficient and profitable environment. Algorithm 1 explains the ET accomplished between g number of prosumers and d number of consumers considering various scenarios for fulfilling the energy demand of consumers and time complexity required to enable the ET is defined in O(g) and O(d).

C. Distributed Ledger Layer

The distributed ledger layer is the final layer of the proposed model. It contains energy data transactions required for ET between prosumer and consumer that needs to be executed and performed in a distributed and protected manner by combining blockchain and IPFS. Foremost, energy data transactions should get access to IPFS to maintain the cost-efficiency of the system. For that, the identity of the EVs along with their data needs to be verified and authenticated by the smart contract. Once a smart contract allows to perform and store energy data transactions through IPFS, EVs energy data can be accessed through the IPFS. Now EVs receive the hash keys from IPFS based on the validation, which

Algorithm 1 ET algorithm for EV coordination

Input: δ_D, γ_G, ζ_q^c, ζ_q^e, ζ_q^t, Δ, Φ_ω, $\alpha^{\delta}D$
Initialization: ϕ = 0
procedure $EV\_Trading(\delta_D, \gamma_G, \upsilon, \alpha^{\delta}D, p_l, \Delta)$
  for $r = 0, 1, \ldots, \zeta_q^c.length$ **do**
    for $s = 0, 1, \ldots, p_l.length$ **do**
      if $p\_l[s] == 1\ or\ 2$ **then**
        Assign charging to p2 EV first
      else
        Charging will be allotted in FCFS order
      end if
    end for
    if $\Phi_\omega[r] > \Phi_{\omega'}$ **then**
      Assign charging after priority level 1 and 2
    else
      Charging will be allotted in FCFS order
    end if
    if $\zeta_q^c[r] < \chi$ **then**
      Assign charging to EVs (high available energy)
      Apply for ET and gain incentives
    else
      Assign charging consumer p0 EVs
    end if
  end for
  for $j = 0, 1, \ldots, \zeta_q^c.length$ **do**
    if $[\Phi_\omega[j] > \Phi_{\omega'} \& (p_l[0, 1, ..k] == 1or2)]||[\Phi_\omega[j][newEV] >= \Phi_{\omega'}]||[p_l(newEV) == 1or2\ \&\ (p_l[0, 1, ..k] >= p_l(newEV))]$ **then**
      Can apply for EV Trading
      for $i = 0, 1, \ldots, \zeta_q^t.length$ **do**
        if $\alpha^{\delta}D <= \zeta_q^t[i]$ **then**
          $\zeta_q^t[i] = \zeta_q^t[i] - \alpha^{\delta}D$
          EV assigned for ET
          if $\upsilon[i] > \upsilon$ **then**
            $\phi = (\upsilon[i]/\upsilon) * p_r$
          else
            $\phi = p_r$
          end if
          Break
        else
          $\zeta_q^e.push(\alpha^{\delta}D)$
        end if
      end for
    else
      Continue in charging queue
    end if
  end for
  for $i = 0, 1, \ldots, \zeta_q^e.length$ **do**
    for $j = 0, 1, \ldots, \zeta_q^t.length$ **do**
      if $\zeta_q^e[i] <= \zeta_q^t[j]$ **then**
        $\zeta_q^t[j] = \zeta_q^t[j] - \zeta_q^e[i]$
        $\alpha^{\delta}D\ of \zeta_q^e[i], satisfied$
        Break
      else
        Wait for trader with sufficient power
      end if
    end for
  end for
  if $\Delta > 2$ **then**
    Outsider EV not eligible for ET
  $1 < \Delta < 2$
    $\zeta_q^t.push(\upsilon)$
    $\phi' = \phi' + p_{r'}$
  $\Delta < 1$
    $\zeta_q^t.push(\upsilon)$
    $\phi = \phi + p_{r'}$
  else
    Enter valid distance
  end if
end procedure

they can carry forward to perform and execute the energy data transactions with blockchain in a secure and immutable manner. Energy data stored on the blockchain includes consumer energy demand, surplus energy of prosumer, trader's or prosumer's list containing available energy, and waiting time. It also contains elementary consumer EV data, such as priority levels and incentives. Additionally, blockchain provides an immutable and trustworthy platform for secure ET between EVs and also consider the scenario of outsider EVs or prosumer for ET. Furthermore, the proposed model is deployed and implemented using a 5G network which eliminates the latency issues to a great extent and also has a higher capacity for uploading data effectively on a blockchain platform due to the high data rate and lower response time.

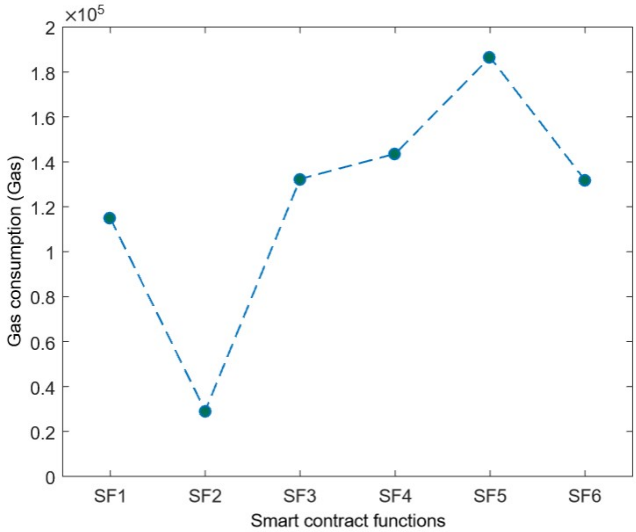

Fig. 2: Gas consumption analysis.

IV. Performance Evaluation

In this section, we have analyzed and simulated the performance evaluation of the proposed blockchain-based ET scheme for efficient and secure EVs coordination by executing the smart contract. The experimental results are simulated using the Remix Integrated Development Environment (IDE) platform that works on the Ethereum blockchain network by executing and running the smart contract of the formulated ET scenarios in the high-level Python object-oriented language to analyze the gas consumption and cost (execution and transaction cost) of the functionalities used in the smart contract to introduce the coordination between EVs.

A. Gas consumption analysis

Figure 2 represents the gas consumption for the smart contract of the proposed model on Remix IDE. For that, we have considered various smart contract functions required to execute ET between EVs efficiently. SF1 is *registerforetrade* function that requires EVs to enter their unique identification string/address for registering and participating in the ET. Next, the SF2 function (*istrader*) assists in helping CS authorities to check for the validity of traders or prosumers in the trader's queue and SF3 (*traderslist*) provides the trader's queue along with their surplus energy and charging levels that consumers can view for ET and new traders or prosumers can also be added to the list with this function.

Further, SF4 is *energytrading* function that consumer EVs can use to enter their energy demand and get allocated to prosumers for trading purpose. SF5 is *continuouschecking* function that allocates prosumer EVs for consumer EVs. This function helps consumers to check if there is a new trader prosumer in the trader's queue to fulfill their energy demand. Furthermore, the function allocates consumers for trading based on the priority levels, i.e., p_0, p_1, and p_2. Lastly, SF6 is an outsider function that helps outsider EVs as prosumers participate in the ET with consumers at the CS based on distance. Moreover, it can be deduced from the graph that SF5 requires the utmost gas consumption while executing the smart contract of the formulated ET scenarios as it requires

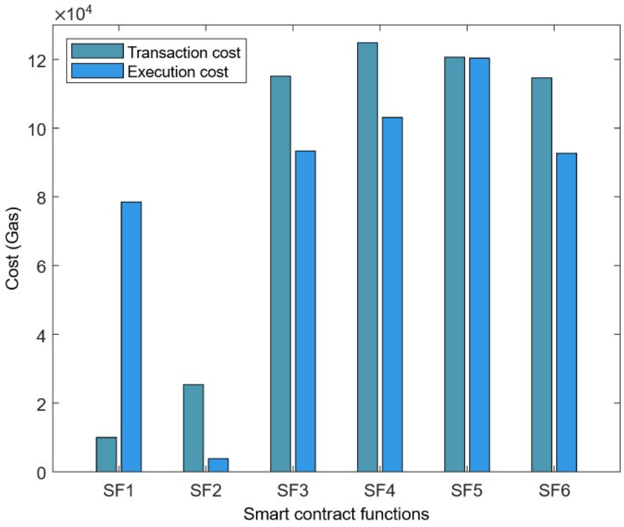

Fig. 3: Cost analysis.

Fig. 4: Security analysis of the proposed model.

prioritizing ET between EVs based on the priority levels corresponding to the consumers and also functions to assign incentives to prosumers for realizing the energy demand of consumers. In contrast, SF2 functionality acquires the lowest gas consumption than the other smart contract functions as it mainly checks the existence of prosumers or traders in the trader's queue.

B. Cost analysis: transaction and execution cost

Figure 3 depicts the comparative analysis of transaction cost and execution cost involved for executing the smart contract functionalities required to execute ET among EVs at the CS. It can be inferred from the graph that SF4 requires the maximum transaction cost, i.e., the ET function, which initiates ET between prosumers and consumers based on the energy demand of consumer EVs considering various discussed scenarios. On the other hand, SF1 tends to exhibit the minimum transaction cost, which involves the registration of the EVs to participate in the ET. Considering the analysis of execution cost, SF5 functionality corresponds to the highest execution cost as it checks for available energy of the prosumers in the trader's queue to allocate and satisfy the energy requirement of the consumers. While minimum execution cost of the executed smart contract is observed in SF2 functionality, which mainly checks if any prosumer or trader is in the trader's queue.

C. Security analysis of the proposed model: Echidna

A secure blockchain-based ET between EVs can be ensured by considering an Echidna security tool, a property-based fuzzing tool that checks and verifies any vulnerability in the smart contract of the proposed model. Figure 4 shows that the smart contract of the proposed model verified using Echidna tool has executed successfully without any threat or bug which shows that ET between EVs is performed securely in a blockchain-based network.

V. Conclusion

In this paper, we have considered the amalgamation of blockchain and IPFS to propose a secure ET trading scheme for EV efficient coordination at the CS. IPFS data storage platform works on the principle of the content-addressing protocol, which offers EVs a cost-efficient platform for low-cost data storage cost with its high availability and reliability characteristics. The charging coordination between prosumers and consumers for ET is attained by formulating the various ET scenarios corresponding to the waiting time and priority levels of the consumers. It means consumers of higher priority get the privilege to accomplish ET with prosumers foremost than the other consumers by providing them the incentives. Moreover, we have considered an additional scenario of outsider EVs (prosumers) that can trade energy with consumers at the CS to coordinate the EV charging without delay. Furthermore, the security analysis of the proposed model (using Echidna) is analyzed to ensure the ET without any vulnerability. Finally, the proposed model is simulated and analyzed by implementing the smart contract of the functionalities of the proposed model over Remix IDE in terms of gas consumption and cost comparison (transaction and execution cost).

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