Blockchain Based Energy Trading Model for Electric Vehicle Charging Schemes

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Abstract. The electricity market is undergoing a transformation with increasing number of electric vehicles (EV). This paper studies the current charging and discharging schemes for EV and the feasibility of the decentralized transactional energy market. In order to adapt the high volume of EV integration and fully decentralize the grid system, the blockchain technology is introduced to serve as an envision for the next generation grid. Furthermore, we propose a blockchain technology enabled electricity exchange market to enable EVs' autonomy in trading energy with secured distributed energy transactions. The constructed exchange market is price competitive platform where the best bid price is modelled via the jump-diffusion process to enable users to participate in the trading process. We demonstrate that our proposed distributed energy exchange system can perform the peer-to-peer transaction with the real-time electricity price aligning with the EV power demand trend without requiring a third-party intermediary.

Keywords: Electric vehicles · Distributed trading system
Transactional energy · Blockchain technology · Smart grid

1 Introduction

The large-scale integration of renewable energy sources imposes significant challenges to the existing grid systems, mainly because the power generation from renewable energy sources is intermittent and fluctuating. The uncertain power generation and load in the grid lead to unpredictable fluctuation in both the power demand for traditional power generators. Thus, the smart grid is envisaged to be the next generation power grid which combines the stand alone microgrids and large-scale electric power plants [1]. It enables two-way flows of electricity and information to create an automated and distributed advanced energy delivery network that is capable of preserving the stability and resilience of the grid system [2]. However, the fast increasing adoption of EVs brings both challenges

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and opportunities to the power grid. On one hand, the massive load demand caused by the integration of EVs into the power grid burdens the power transmission substation and severes the randomness and voltage stability. On the other hand, EVs can be used as mobile energy storages with the bi-directional charging and discharging features to provide ancillary services to the grid system, such as load flattening, peak shaving and frequency fluctuation mitigation [3]. It is, therefore, the vehicle-to-grid (V2G) and grid-to-vehicle (G2V) concepts have introduced that act as the provision of energy and ancillary service from an EV to the grid system [4].

In order to minimize the impact of random behavior from the EV integration, various centralized control scheduling techniques are proposed to provide the ancillary services. In [5], it proposes an optimal scheduling and load curtailment problem for the microgrids to support the islanded operation mode where the parallel computation is used to run the optimisation problem. The proposed scheme ensures the minimal amount of load curtailment while maintaining the reliable operation. Moreover, a stochastic program that incorporates the risk management in [6] is proposed to provide frequency regulation service with the aid of EVs and an aggregator. In [7], an aggregation-based optimisation model for EV charging strategy was proposed with the consideration of stochastic features of the charging procedure in arrival time and state-of-charge (SOC). However, the aforementioned schemes rely on predictions of energy consumption and a day-ahead profile based on historical power consumption and user profiles. In [8], the proposed scheme also lacks of individual decision making process and undermines the autonomy of the individual grid participants. In [9], a distributed trading platform is proposed based on blockchain to support decentralized market approach with facilitate distributed optimization and control. In [10], the authors concluded that a more sophisticated dynamic grid infrastructure can advance the small-scale generators and overall resilience. In [11], a transactional energy is proposed where a sequence of energy transactions for a delivery of a quantity of defined energy product in a specific time interval and location to simplify business for all parties including generators and Distributed System Operator (DSO). Thus, the distributed energy trading platform is based on the clear and frequent communication of offers and transactions among the electricity consumers and operators respectively.

Based on the aforementioned studies, the trading energy in the distributed system is capable of achieving demand response by providing incentivizes EVs to supply and consume electricity of their own self-interest [12]. The advantage of the market-based trading concept is that it reduces the dependency of agents on the DSO or aggregator, as energy supply and demand are matched directly between network peers which results in a more competitive environment. In this regard, this paper proposes a blockchain based transactional energy trading model for the smart grid components, including EVs. This model simulates the trading depth and energy market profile with the best price guide economic concept and allows EVs to charge and discharge autonomy in the grid.

The remainder of this paper is as follow. In Sect. 2, it presents the state-of-the-art in blockchain enabled energy market compositions. In Sect. 3, the concept model is introduced for the distributed energy market with components in smart grids and then further propose the trading model for energy transaction. Then, the simulation results for a local area trading platform with EV market and the concept model evaluation are presented in Sect. 4. Section 5 includes and identifies future research opportunities.

2 Existing Works on Blockchain Enabled Smart Grid

The blockchain is a shared and trusted distributed ledger technology that permits the recording of any digital asset transaction between parties over a decentralized encrypted network which is initially developed as a mechanism to record financial transaction [13]. It confirms transactions in real time and ensures the integrity of transactions through the secured encryption techniques. Henceforth, the blockchain has generated broad interest in other business sectors including the energy trading where all energy traders are the peers in the blockchain network.

The blockchain technology enables a trustless network to eliminate the operation cost of the intermediary participation, which will realise a quicker, safer and cheaper way in the transactional energy market. In [14], a novel mechanism for trading the energy based on the blockchain technology was proposed to adapt the decentralised and competitive environment for the locally produced energy, but the blockchain is solely used as a data storage warehouse to record transactions. In [15], the authors further analyzed the economic evaluation of the market mechanism for local energy trading.

The use of smart contract in blockchain technology is driven by open-source agreements, which also provides the potential to balance supply and demand in the transactional energy market. Furthermore, in [16], the authors provided the insight of the smart contract to allow the automation of multi-step processes to self-execute the distributed and heavy workflows, which is envisaged in the energy industry and the Internet of things.

In summary, the uncontrolled EV charging/discharging may lead to instability of the overall grid system operation. Therefore, it is critical to deploy the effective scheduling algorithm for efficient distributed grid operations on the blockchain based trading platform.

3 Blockchain Based Energy Trading Model for EV Charging Schemes

The transformation to the decentralized transactional energy market can be achieved based on the small-scale energy generators and EVs, in which they may produce, consume, and sell excess electricity capacity like a commodity. It does not require hierarchical system structure, no information exchange, instead, it offers the energy transaction and the agreements on transactions. Hence, all the loads, such as the residents, offices and plants, in the grid are connected to both the retail for end users and wholesale market for large generator offers.

This paper proposes a blockchain based energy trading model that allows prosumers to trade energy in the grid. The proposed model enables the autonomy of prosumers in blockchain power exchange platform, which can inject and draw energy order to the smart grid public blockchain trading platform.

3.1 System Model

In blockchain based energy trading model, we define components as all the power generators and power load components that connected to the retail markets. Each component is capable of publishing and transmitting the charging or discharging order to the smart grid public blockchain trading platform. For EVs, the charging and discharging process can be realized by a programmable charge installation. This is to enable the instant on/off switching of the power transmission as instructed by EVs (assuming the sophisticated design of switches). The energy providers in the public blockchain power exchange platform are the conventional large power plants, distributed micro renewable generators, the storage which compose the electricity provider side and EVs. Besides, the power loads, for example the residential area, hospital, and also EVs are all connected to the public blockchain power exchanging platform.

The information exchange in the blockchain platform is at 30-min intervals. And the components are capable of deciding the price for their produced energy to incentivize users to balance the supply and demand, in the meantime, to reduce the power generation and consumption peaks. The conventional power generators are connected to the wholesale market which trades with large power demand offers, depicted in Fig. 1. Besides providing the wholesale market in the conventional grid system, transactional energy offers a vision for the coordination of retail customers using large numbers of frequent tranching transactions executed automatically by blockchain enabled platform, therefore reducing the centralized features of the next generation grid system [17]. The information exchange is the same for a large generator, distributed energy resource, renewable energy generators such as wind and solar, EV, microgrid, energy trader, broker, exchange, aggregator or system operator. The transactions can be executed between retail and wholesale markets which equalizes the opportunity for all components. Furthermore, the transactions must also account for the transmission and distribution limits and other physical constraints on the grid.

We first define the EV status matrix X as:

$$X_{i,t} = \begin{cases} 1, \text{ if } EV_i \text{ is connected at time } t \\ 0, \text{ otherwise} \end{cases}. \tag{1}$$

The power demand of EV depends on the battery residual (SOC_{ini}) in each EV and the expected SOC (SOC_{exp}) after charging. Hence, it can be formulated as follows:

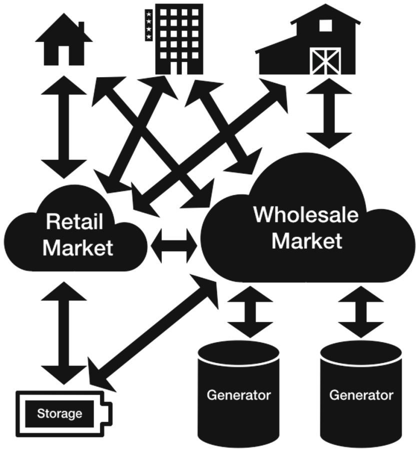

Fig. 1. Transactional energy market system model with retail and wholesale markets in smart grids where arrow represents the price offers and transactions.

$$P_{EV}(t) = \sum_{i=1}^{I} \left(X_{i,t} \left(SOC_{exp}(i) \pm SOC_{ini}(i) \right) \right). \tag{2}$$

Then, we can define the total residential load as the sum of EV charging/discharging demand and load profile without EV in order to formulate the EV charging problem.

$$P_{total}(t) = P_{load}(t) + P_{EV}(t), t \in T, \tag{3}$$

where P_{load} is the power load generated or consumed by the load within the microgrid network. With the overall utility function for the local area, we can apply optimisation techniques to achieve the objective, such as load flattening, peak shaving and privacy preserving.

3.2 Energy Trading Model

For a electricity exchange order published in the trading platform, the demand is formatted as an input to send to the electricity exchange stand book Std_{in} which is a public order book for all participants in the trading market in the form of a vector which can be denoted as follows:

$$\overrightarrow{O_i} = (\gamma, Id_i, \sigma_i, Q_i), \tag{4}$$

where the Id_i is the unique identifier for the charging/discharging initiators where they can be EVs or other components, the σ_i is the unit price that the participant is willing to pay for the electricity order, the Q_i is the electricity demand quantity of this order, and γ is a matrix indicating whether it is a electricity buy or sell order:

$$\gamma = \begin{cases} 1, \text{buy order} \\ 0, \text{sell order} \end{cases}. \tag{5}$$

Then for each inserted order, the matched order should be applied to the current stand book (Std_{in}) to generate the matched trades. And all non-error output (each matched trade order) should be directed to the Std_{out}. The trade information format is expressed as follows:

$$\overrightarrow{T_i} = (Id_{sell}, Id_{buy}, \sigma_m, Q_m), \tag{6}$$

where the Id_{sell} and Id_{buy} are the matched electricity buy and sell order identifier respectively, the σ_m is the matched price in pence and the Q_m is the matched quantity for the order. Following the receipt of an order message, and after receiving any matches in the book and outputting any generated trade messages, the solutions should display the current full order book in the above format.

In order to process the transactional energy orders smoothly and ensure the participant benefit, it is crucial to provide the guide price for this demand. We infer from the stock price model based on [18] to construct the best charging guide price S_t with a jump-diffusion process, because the electricity trading market is price competitive which is similar to the stock market. For $S_t<\bar{S}$, where $\bar{S}$ is the highest price for the order, it can be denoted as follows:

$$S_t = S_0 \exp\left((\mu - \frac{\sigma^2}{2})t + \sigma W_t\right), \tag{7}$$

where the percentage drift μ and the percentage volatility σ. Based on the limit scope of this paper, the percentage drift and volatility can be set to constants, and the W_t is a Wiener process. Thus, for a given highest price value S_0, we can obtain the best price S_t by taking derivatives to both sides which is shown as the following equations.

$$\mathrm{d}S_t = \mu S_t \mathrm{d}t + \sigma S_t \mathrm{d}W_t, \text{with } S_0<\bar{S}, \tag{8}$$

and we can obtain the expectation and variance for S_t, where the expectation can be used as the guide price in the trading process.

$$E(S_t) = S_0 e^{\mu t}. \tag{9}$$

The price function S_t is subject to the highest and lowest price, and fluctuates according to the users' bidding price. It works as the guide price for all participants where all of them are suggested not exceed the guide price. Moreover, they still have the autonomy to decide their trading price between the lowest price and the guide price. It is a closed double auction market with price-time precedence and discrete marketing closing time. Therefore, no central entity is needed to implement the market trading.

4 Simulation Results

To evaluate the performance of the proposed blockchain based energy trading model, a residential area substation transformer with $P_{max} = 250$kVA power capacity is used which serves the size of 100 households. We assume that on average each household would have owned one EV. Moreover, the EV charge connection status is modeled as two parts, where the first time segment is from 06:00 to 18:00 and the second time segment is from 18:30 to 05:30 (+1). In this model, the initial battery residual (SOC_{ini}) for EVs is randomly generated. In order to evaluate the performace of the designed trading market, we generate the electricity buy and sell orders from EV integrated smart grid network. Then the system simulate the exchange process with the order input to calculate the overall price fluctuation with respect to the real-time price.

The price of electricity exchange market is variated according to the guide price order execution where the drift of the best bid price has been assumed to be a constant. To keep the setup tractable for exposition, we assume the simplified scenario: the best bid price exhibits a zero drift $\mu = 0$ prior to the submission of the iceberg order. The original price fluctuation interval is set to be $\sigma_i \in (10, 30)$ subject to the local area, henceforth, the order price σ_t is modified for certain hours during the day to simulate the retail electricity prices σ_{ave} in distribution networks, which are displayed in Fig. 2. As we can see from the figure, the electricity price is higher during 6:00 to 8:00, 11:00 to 13:00 and 17:00 to 19:00, which conforms to the higher power demand P_{EV} for EV charging period as depicted in Fig. 2.

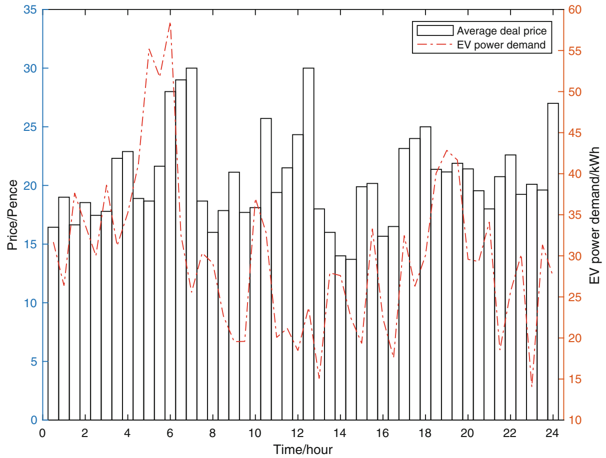

Fig. 2. Average generated trading price in a day.

5 Conclusions

In summary, this paper presents an initial proof-of-concept of energy trading on the blockchain platform. It decentralizes the central controller based smart grid system and increases the autonomy of the grid participants. We provide insight into the economic evaluation of a blockchain-based market design and its technical implementation. In the future work, we will formulate the overall utility function and optimization techniques to achieve the ancillary services.

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