P2P Trading using DERs: A Holistic View of Global Practices and Pioneering Efforts in India

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***Abstract*— Quite notably, over the years, the Distributed Generation (DG) concept has evolved and the role of Renewable Energy (RE) has become increasingly important in shaping the developments. In the form of Distributed Energy Resources (DERs), RE sources also help in reducing burden on the utility by providing an alternative source which is most relevant for a distribution network. With increasing penetration of DERs at the distribution-level, electricity distribution is rapidly transforming into a two-way business where consumers (as prosumers) are selling power back to the utility. All such interactions can be streamlined in the form of Peer to Peer (P2P) trading of energy and a decentralized network between "peers" participating in a local energy market can be created thus transforming into a virtual power plant. If used properly, DERs at the distribution-end can not only reduce losses but can also help the utilities in managing demand more efficiently by engaging people who own these generating assets. Blockchain serves the P2P framework well, creating an efficient platform for energy trading between peers without any requirement of an intermediary. This paper presents a review of the existing major projects on P2P trading using DERs. The aim of this paper is to report different price bidding strategies and auction mechanisms employed to create a win-win approach for both prosumers and consumers. Societal aspects and institutional development required for using Blockchain for P2P trading have also been discussed. In the end, a prototype model for P2P trading of rooftop solar energy, developed by the authors, is introduced.**

***Keywords*—Distributed Energy Resources, Peer to Peer trading, Blockchain, Pricing Mechanism, Social Aspects and Institutional Development**

I. Introduction

The new paradigm of smart grids is being adopted on a wider scale. The elementary premise of such a paradigm is enabling active participation of consumers. Distribution utilities-based interventions like Demand Response (DR) and Demand Side Management (DSM) involve consumers and allow them to optimize their energy usage so that they experience reductions in their electricity bills [1]. Many Distributed Energy Resources (DERs) like rooftop solar Photovoltaic (PV) systems and Electric Vehicles (EVs) are being introduced into the distribution network [2]. These systems provide grid-services and support the utilities in avoiding network augmentation. Distribution utilities are also lately encouraging them. The consumers can now also produce power on their own and hence are fast-changing into 'prosumers'.

Solar PV generation is being integrated with the distribution grid, popularly in the form of rooftop DG systems [3]. Governments in many countries have framed regulations to allow connectivity of these systems to distribution networks. There are mechanisms to compensate or incentivize the consumers that adopt such systems for optimizing their self-consumption. Net-metering and feed-in-tariffs are two such mechanisms that compensate the consumers for their power. EVs are distributed energy storage units that can provide grid-regulation services, if their cycle life is considered in such exercises [4]. Increasing adoption of DERs is making the distribution grid active and bi-directional power flows are becoming common. The flow of money is also getting dynamically changed and the stakeholders and actors in such a scenario are also getting modified.

The emergence of localized electricity market makes sense and is pertinent in the present situation. Decentralization of generation and control is leading to a scenario wherein transactions associated with power purchases also need to be modified accordingly. The actual flow of power among a set of prosumers and between prosumers and consumers should be tracked to settle the transaction between the correct players and ensure a just compensation. Accordingly, the prosumers and the consumers can now be enabled to actually 'sell' their excess electricity to their neighboring consumers and 'buy' excess from their neighbors, respectively. Thus, the paradigm of Peer to Peer (P2P) power trading is emerging and hence the management of transactions with trust and security becomes important. Blockchain-based frameworks thus assume importance in this regard. Bidding by the peers and the auctioning of bids to clear the market are important processes of the power trading process.

This work reviews the developments across the world in P2P trading using DERs. The paper begins with a description of a list of major projects, pilots and various initiatives in P2P trading across the globe, in section II. Section III details the various price-bidding strategies and auctioning mechanisms adopted in the projects listed. The various aspects of such a digital technology in view of societal, economic and institutional development are described in section IV. Section V gives a glimpse of a pioneering initiative being taken by the authors with an actual distribution utility in India. The objective of such an initiative is to promote the scaled-up adoption of rooftop SPV systems in the country. Section VI gives the conclusions. A holistic view of the integral components of a blockchain based P2P trading set up and the understanding required for institutional development, in view of the socio-economic aspects, has been contributed by the paper. The examples of real-life projects and the initiative spearheaded by the authors is also a part of the analysis. All these points and the highlighting contributions are summarized in this section.

II. P2P Trading Projects Across the Globe

It is evident that the future grid is moving towards more DERs and with a gradual shift towards prosumers, their interactions with utility grid and amongst each other are set to increase. There exist a lot of value streams that can be tapped from the distribution system upon the introduction of DERs, especially in the residential sector [5]. The penetration of rooftop solar PV [6], plug in EVs [7], establishment of DSM [8] and combination of PV with storage [9] will bring a lot of benefits for both the utility and consumers.

With the emergence of local electricity markets, P2P trading is taking shape through several pilot projects, the most famous running commercially in Brooklyn [10]. In the Australian National Electricity Market [11], P2P trading is used to provide better pricing mechanisms for local demand and supply. Open utility, a British start-up, and Good Energy, a renewable energy based power company in Britain came together to build UK's first online P2P marketplace for electricity sourced from renewable energy, as reported in [12]. Vandebron, a Dutch company, allows prosumers/consumers to buy electricity directly from farmers having renewable sources of energy like wind and solar PV in the Netherlands [13]. The sonnenCommunity, consisting of a group of users and operating in Germany, Austria, Switzerland and Italy[14], provides constant power supply using batteries (called sonnenBatterie), ensuring a surplus power pool to trade within the community. A proof of concept with different case studies is explained in [15] using blockchain technology for secured transactions, thus, providing security and privacy. POWER TAC (Power Trading Agent Competition), a rich competitive simulation of future retail power markets [16] developed a wholesale marketplace using artificial intelligence for managing energy trading. Surplus energy exported to the grid can be replaced by a virtual currency called NRGcoins [17] in local electricity markets, a smart contract based mechanism to incentivize green energy. The price of the coin is not constant and changes with the demand and supply conditions. Greenwash and Energy saving Trust [18] provides nearest green energy to the consumers at a higher rate. In the Lazarettgarten Microgrid [19] in Germany, a local energy market using Solar PV and energy storage system has been developed. The Microgrid aims at developing the market mechanisms and the necessary regulatory framework required for future projects. In partnership with Allgauer Uberlandwerk, they are also developing the Allgau Microgrid project [20] focusing on integration of local microgrids with the existing marketplace. LO3 energy with Yates, is planning to develop transactive energy trading models to promote RE in Australia [20]. In Texas, in partnership with Direct Energy [21], they aim to reduce high renewable curtailment in the local energy market. Kepco in Japan [22] is planning to test the feasibility of blockchain for trading surplus energy with other peers in the network of 10 households having their own generating sources like solar, wind and storage. Vector [23] is currently performing trial-runs on the existing network of 500 consumers including residential, school and communities that focuses on trading through blockchain. Powerpeers, in collaboration with Vattenfall [24] proposed a mechanism where each peer can choose a specific peer in the network to buy or sell the electricity generated. P2P Trading using blockchain was implemented in an Eneres project of 1000 households [25] in Japan. In Amsterdam [26], a private and permissioned blockchain platform is being used for a high number of transactions per section in trading power. Spectral Energy has made new tokens named 'Joulitte' [26] that are used for transactions between 16 different buildings. Direct energy exchange is possible between prosumers and consumers in Lyon, a city in France. In this case, smart contracts are doing accurate calculations of the power losses during transmission. In Australia, Philippines and South East Asia, Energo Labs is planning to set up a 100 MW based decentralized energy system, as they did in China. They plan to exchange power, payments and information in real-time using two different tokens i.e. WATT token (1 kWh of energy storage) and TSL (Cryptocurrency). Energy Bazaar [27] in India, has developed an energy exchange especially in rural areas with smart software agents, better forecasting and game theory based techniques using blockchain.

Apart from solar PV, EVs are also being used as DERs in many P2P trading projects. Innogy has developed a platform for the interaction of EV owners including those having private charging infrastructure. This platform is capable of automated billing and provides incentives to EV owners [28].The impact of the charging process in peak hours on the power system, during P2P trading of two different kinds of EVs in Belgium is presented in [29]. In USA, the Oxygen Initiative [30] is conducting trials on charging infrastructure operation to be dependent on peak and non-peak hours. They are planning to use this platform in the toll settlement and car pool payments process. A California-based company, eMotorwerks also started their EV charging project in July 2018 giving smart Wi-Fi with EV chargers control over EV charging from anywhere with the help of a mobile App [31]. Alliander, in Netherlands, started a pilot project on dynamic smart contracts for each individual so that EV owners can choose and pay for the desired energy at every station. This platform focuses on providing transparency in the energy price and smart contracts [32]. Another example is Car eWallet [33], based in Germany that has built a platform for mobility services like energy trading, parking, car sharing etc. using Hyperledger Technology. Payments in this platform can be either done manually or automatically depending upon the EV owner's choice. PROSUME is also working on EVs on a decentralized platform [34]. EV owners are able to charge at residence, commercial and public charging stations with the platform built by Every [35], an Australian company. Power Ledger, a well-known operator is also working on peer to peer trading using EVs and its applications using Blockchain [36].

Future P2P trading projects with various business models using blockchain have been described in [37]. Consumers will be able to prioritize buying and selling bids from specific neighbors/family/friends. Historic information on bidding price and better forecasting will also be possible in future [10].

III. Price Bidding Strategies and Auction Mechanisms

Traditional grids are undergoing a rapid transition and a series of modifications for integration of large-scale RE sources like solar PV systems and wind-turbine generators and even energy storage, which essentially means increasing penetration of DERs into the grid. To achieve DER integration with the grid, a transactive energy system is required as it allows a balance between demand and supply with a competitive economy rule and offers a control mechanism that has value as a major component of the electrical infrastructure. These values have a potential to create a win-win situation for all the players by considering both price and incentives. It is essential for energy to be the base for smart contracts in which auction mechanisms are carried out. This paper aims to bridge the knowledge gap, often observed in this regard, by reporting the mechanisms used for auctioning of the price bids, as below:

a) Discriminatory k- Double Auction:-

To understand this method, let us assume that the price at which consumers bid for buying energy from prosumers is Cp. Similarly, the price at which prosumers sell their excess energy is Pp. Once the price bids for both consumers as well as prosumers are obtained, they are ordered in descending order and ascending order respectively. Next, the mechanism checks for the condition for trading to occur i.e. the trading will happen only when the buying price is always greater than or equal to the selling price ($Cp \geq Pp$). If the conditions get fulfilled, the trade occurs at the price P calculated as in (1) below:

$$P = kCp + (1-k)\, Pp \tag{1}$$

Here, k is a predetermined constant which always lies in the closed interval [0, 1]. This process is entirely discriminatory as P or the trading price is always between every winning prosumers-consumer pair. There is no single market price which is present in any of the auction intervals and therefore, P is always different for each trading of prosumers-consumer pair.

b) Uniform k- Double Auction:-

Uniform k- DA mechanism is similar to the discriminatory K-DA mechanism. Here, all the winning consumers and prosumers trade at a common clearing price. Let us assume that the consumers are buying the energy from prosumers at a price Cpy. Similarly, the prosumers are selling the energy at a price bid of Ppy. Once the price bids for both consumers as well as prosumers are obtained, they are ordered in descending order and ascending order respectively. Y is considered as the largest breakdown index taking the condition $Cpy \geq Ppy$ into consideration. In view of this mechanism, the final trading price P is illustrated by the Y^{th} consumer and prosumers. Therefore, a distinct per unit transaction trading price for all winning consumers and prosumers at each 30-minute interval is obtained. If the conditions get fulfilled, the trade occurs at the price P which is calculated as in (2):

$$P = k\, Cpy + (1-k)\, Ppy \tag{2}$$

There are four components for having an ideal auction mechanism: Balancing of budget, economic efficiency, individual rationality and incentive capabilities. However, it should be noted that it is not possible for any auction mechanism to fulfill all these four conditions at a time. These are explained as:

a) Balancing of Budget: - To satisfy the load balancing on the network, the market operator is not allowed to gain any subsidy or profits when the transactions are happening between consumer and prosumers. In other words, the amount paid by the consumer should go directly to the prosumers, without any profit to the distribution operator in the system. A perfect example of budget balancing is Discriminatory k-DA and Uniform k-DA described above. Some other mechanisms such as Vickrey-Clark-Groves (VCG) and Trade Reduction (TR) do not provide budget balance due to the necessity of providing subsidies to the distribution operator.

b) Economic Efficiency: - This parameter is totally dependent on the social and economic aspects of the market as a fixed amount of energy is given only to those who value and use green energy the most. Specifically, K-DA is economically efficient due to the fact that no consumer or prosumer(s) is prohibited from exchanging energy in the network. However, TR is not economically efficient as specific consumer and prosumers can only take part in the energy exchange mechanism.

c) Individual Rationality: - For this condition to get fulfilled, no consumer or prosumers payment shall result with the negative values/ loss from trading in the network. Therefore, trade can only happen if and only if the trading price follows $Cp \geq P \geq Pp$ where Cp is the buying price and Pp is the selling price. Both the discriminatory and uniform k-Double auction mechanisms fulfill this condition.

d) Incentive capabilities: - Both the discriminatory and uniform K- DA mechanisms do not carry incentive capabilities because all the peers in the network submit their values different from true valuations.

IV. Blockchain in P2P Power Trading: Societal Aspects and Institutional Development

While blockchain has been rapidly developing, policies are lagging behind [38],[39]. In India, renewable energy support is growing, for example via Renewable Purchase Obligations (RPO) [40]. However, there are institutional and social barriers to prosumers and P2P-trading. Key challenges may include grid codes, P2P policy, market policy [41], as well as policy uncertainty. In the Indian Electricity Act [42] and Electricity Code [43], prosumers or P2P-trading are not explicitly discussed. In addition, electricity trader approval is contingent on technical, capital, and credit worthiness requirements [42] which may be impractical for small-scale prosumers. It is suggested that the prosumer scope, licensing, and requirements are in need of regulatory progress.

Market reform, including wholesale competition, can also support prosumers [41]. There is a need for retail competition in India [40]. Indeed, the government has been exploring wholesale reforms, including day-ahead, real-time, and ancillary markets [44]. Such efforts may support market competition, renewable energy, and minimize procurement costs [44]. In addition to economic markets, social backdrops are vital considerations. P2P energy exchange participants may be influenced by a diverse spectrum of monetary and non-monetary returns [45]. Socio-economic incentives may include both economic and non-economic motives such as local generation and renewable energy purchases, as well as energy security [10]. In a study in rural India [45], it was found that in-cash as well as in-kind and in-tangible returns impact P2P-trading; depending on peers' social connectedness [45].

P2P networks and microgrids may also support local employment: a key potential socioeconomic benefit [10]. Utilities would also need to recruit digital tech-savvy talent [40], and skill development for blockchain and blockchain-oriented software is a key factor moving forward [46]. There are indeed increasing educational initiatives, such as Future Skills: a platform backed by the Indian Government with courses on technologies such as IoT and blockchain [47].

With a rise of new actors, incumbent roles may be changed or even displaced. To remain relevant, utilities may engage in small-scale strategic deployments to explore new value streams and roles [48]. In India, utilities would also need new, innovative funding mechanisms [40]. It is suggested that roles, funding mechanisms, incentives, and other economic and social aspects would be moulded by institutional change (and vice versa). It would be vital for governments as well as practitioners to consider socio-cultural context [45] and socioeconomic incentives [10] in such change. In order to keep pace with technological advancements while maintaining underpinnings in socioeconomic context, regulatory sandboxes may be used to inform both regulatory and industrial change via real-life testbeds [41].

V. Rooftop Solar PV: Scaling Adoption Using P2P Trading

TERI has developed a prototype on peer-to-peer (P2P) trading of rooftop solar energy using blockchain. The objective of this prototype is to demonstrate the concept of energy trading among rooftop solar system owners so as to facilitate the development of local electricity markets that will promote the adoption of rooftop solar systems, as this will incentivize the consumers by providing additional incentives of trading among themselves, in addition to selling to the distribution utility. Blockchain enables bi-directional power flow due to the various leading factors such as payment ease with the help of smart tokens (1 Token = 1 INR), monetizing the generation sources, decentralized network (no third-party required), guaranteed payment and enforcement of trade decisions. Each consumer holds a copy of the records chain and reaches an agreement on the valid state, thus providing transparency to all the consumers in the grid. These advantages will provide an upper hand for the implementation of the solar rooftop and will help in promoting the same.

VI. Conclusions

The basic premise of P2P trading and its synchronism with the broader theme of smart grids has been established given the increasing importance of RE based DERs. The various P2P DER power trading projects developed, under-developed or being-planned across the world were comprehensively reported. The various pricing schemes and auction mechanisms being deployed in these projects were discussed. Socioeconomic setting and skill development are equally important aspects for institutional development in regard to such innovative initiatives and were comprehensively discussed. Lastly, a glimpse of how a proof-of-concept demonstrating P2P trading among rooftop solar owners can scale the adoption of such systems in India was provided by discussing some details of the work being carried out by TERI with local utility partners.

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