Blockchain for Smart Grid Flexibility

Handling Settlements between the Aggregator and Prosumers

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***Abstract*—This paper shows how the Ethereum blockchain can register settlements between an aggregator and prosumers in a smart grid. By providing flexible use of electricity to the aggregator, customers get rewarded. The flexibility is valuable for the aggregator since the power infrastructure may be used more efficiently. Blockchain is an exciting technology for handling settlements which, however, also has some clear limitations. For example, the cost per transaction on the public Ethereum blockchain is too high compared to the value of the actual transactions. A private blockchain is an alternative but removes some of the original benefits of using the public blockchain. The paper concludes that blockchain is a promising technology, and a private blockchain is more suitable for transactions containing minimal amounts.**

Keywords-smart grid; blockchain; Ethereum; smart contract; aggregator; flexibility; Smart-MLA.

I. INTRODUCTION

Smart grids [1] are electric power grids supported by electronics that keep track of power consumption and production. Typically, smart meters [2] keep track of energy flow between producers, consumers, and prosumers. Smart meters normally connect to a service maintained by the Distribution System Operator (DSO).

Prosumers refers to the combination of producers and consumers, with production coming from energy sources like solar panels. On sunny days, the energy production of a household or a building may exceed the consumption. Then the prosumer may sell excess energy to the grid. At other times, the household gets its electricity from the grid, as shown in Figure 1.

The price of energy varies throughout the day. The energy price is calculated based on demand and supply forecasts, and the pricing intervals typically differ from one hour down to ten minutes.

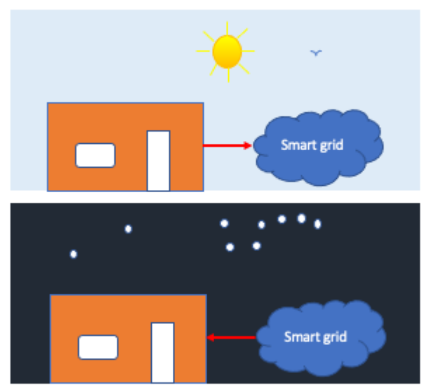

Figure 1. Prosumers

Flexibility occurs when a household or building can delay the use of electricity to a timeslot when the price is lower. A typical example is the charging of electric vehicles. Charging requires a rather large consumption over a relatively short period. If the customer chooses the optimal time, charging will be less expensive.

The next step is to transfer the flexibility to an aggregator. In this case, the customer defines some constraints, e.g., the electric car should be fully charged at 7 am. The aggregator then selects the optimal time slots when the actual charging takes place.

The flexibility is essential for grid management since it can reduce the chances of overloading the grid and delay investments in upgraded electric power infrastructure.

The customer is rewarded for giving up control, either by favorable pricing or a discount on the electricity bill.

Blockchain technology has the potential to have a significant impact on the energy sector. Numerous use cases have been proposed, including wholesale and retail energy trading [3][4].

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The purpose of this paper is to present the Smart Multi-Layer Aggregator (Smart-MLA) project and how blockchain technology can handle settlements between the aggregator and its customers (prosumers).

Section II discusses the flexibility project, followed by a section explaining Blockchain technology. Section IV presents some related work, followed by a section showing our approach for the project. Finally, Section VI concludes and provides some input on future work.

II. The Smart Multi-Layer Aggregator

The Smart-MLA project [5] is an ERA-Net Smartgrid Plus research project with academic and industrial partners from Denmark, Norway, Romania, Sweden, and Turkey. The aim is to develop and demonstrate a cloud-based multi-layer aggregator solution to facilitate optimum demand response and grid flexibility for energy systems to utilize up to 100% renewable energy. The project implements three layers of flexibility aggregation, as shown in Figure 2.

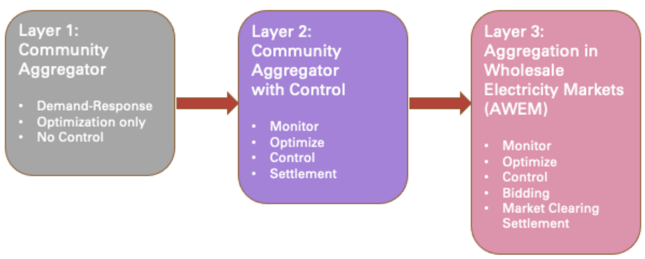

Figure 2. The Smart-MLA layers

On the lowest layer (shown in Figure 3), flexibility occurs within a household or a building. The main objective of this layer is to improve the awareness of the prosumers on the merits of flexibility at the prosumer level. Here, the customer sets constraints and the preferred scheduling for flexible appliances. Then, the proposed algorithm [6] optimizes the operation of the flexible appliances and comes up with the difference between the cost of using user-preferred and optimal schedules. The solution considers both production capacity (solar panels) and storage capacity (batteries) to obtain the best possible result.

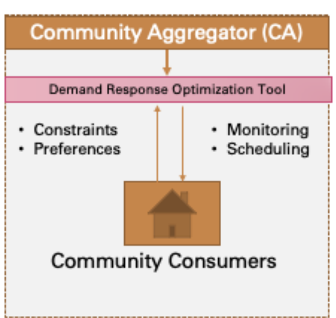

Figure 3. Smart-MLA layer 1

On the second layer (shown in Figure 4), the customer transfers the control of charging electric vehicles, heat pump, and other appliances to the aggregator. When the aggregator controls many households/buildings connected to the grid, the aggregator may optimize the power consumption for the whole smart grid.

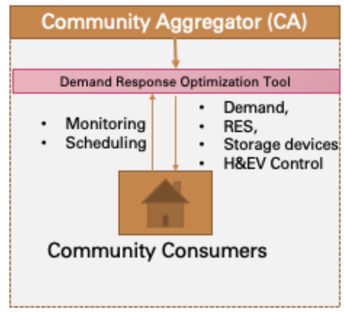

Figure 4. Smart-MLA layer 2

This layer includes settlements between the aggregator and the prosumers. In this layer, the grid is used as an on-demand delivery service that may also buy back excess energy and reward the prosumer for transferring flexibility. The settlements are between the prosumers and the aggregator, as shown in Figure 5. The settlements are registered on the blockchain.

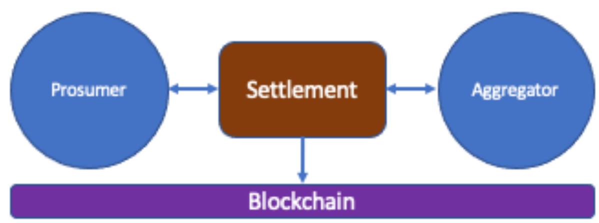

Figure 5. Settlements on layer 2

The flexibility aggregated from the prosumers will be traded in the local flexibility market in coordination with the Distribution System Operator (DSO) on the upper layer. The aggregator uses an iterative process based on schedules, prices, and bids for flexibility, as shown in Figure 6.

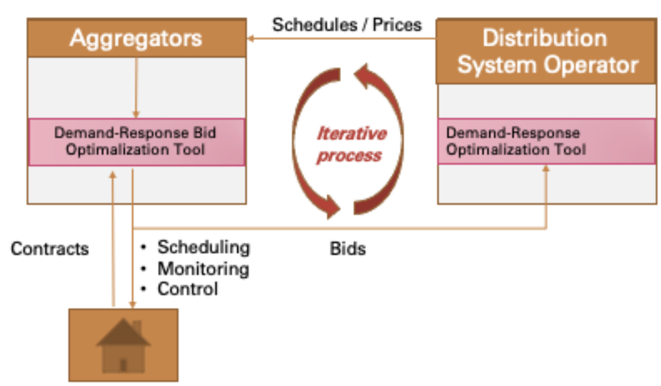

Figure 6. Smart-MLA layer 3

Further details on the three-layer aggregator flexibility can be found in a separate paper [7].

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The settlements are made between the aggregator and the prosumers, and the aggregator and the DSO, as illustrated in Figure 7.

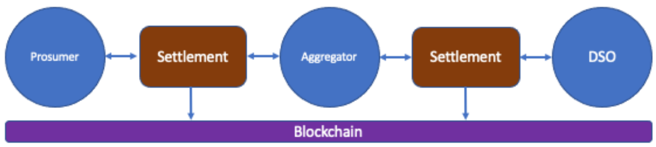

Figure 7. Settlements on layer 3

Both types of settlements are registered on the blockchain. The settlements include the amount of energy, time, period, and the two entities involved in the transaction.

III. BLOCKCHAIN BASICS

Blockchain technology was initially developed to handle cryptocurrency safely and transparently [8]. Bitcoin was the first cryptocurrency using blockchain as a platform. The blockchain is a decentralized, immutable ledger. The ledger is implemented as blocks of data chained together [9], as shown in Figure 8. Cryptographic techniques ensure that it is impossible to change the block's content when put on the blockchain [9]. The first block is called the genesis block.

Figure 8. The blockchain

Each block contains a link to the previous block and also a hash value of the previous block. Each new block is encrypted (including the hash value of the previous block). A block cannot be altered after it is added to the blockchain. In that case, the whole blockchain becomes invalid [9]. Figure 9 shows the layout of the blocks and the block header.

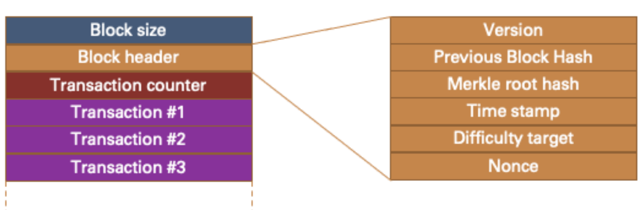

Figure 9. The blockchain header

A "Merkle" tree [9] secures the integrity of the transactions stored in the block. First, a hash value is calculated for each transaction. Hash values are then calculated for each pair of transactions, and the process is repeated until the root of the tree appears. Finally, the Merkle root hash is stored in the block header. The construction of the Merkle tree is illustrated in Figure 10.

The block is added after validation. The validation is done by so-called miners who solve a mathematical problem and get rewarded (with cryptocurrency) for solving the problem [9].

A new block is distributed to many nodes in the network. A majority consensus protocol secures the integrity of the blockchain. Therefore, an attack needs to succeed with a majority of the nodes in the network, which is nearly impossible.

If one or more nodes fail, the data is still obtainable from the other nodes. Thus, if there should be an inconsistency, the majority will win.

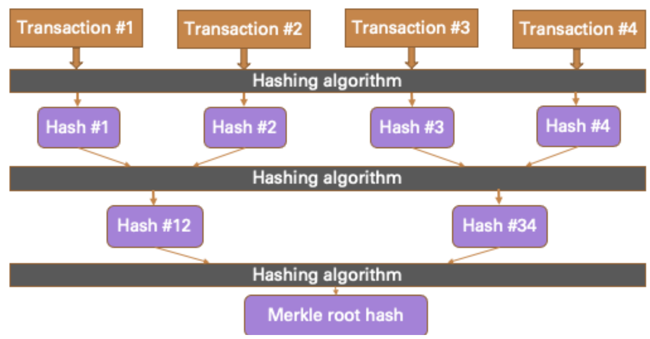

Figure 10. The Merkle tree

A blockchain may be public or private. Everyone has access to the public blockchain and can examine the transactions that have been made. The blockchain is semi-anonymous; the user is identified with a binary address. A private blockchain may require permission to examine the transactions.

IV. BLOCKCHAIN IN SMART GRIDS

In recent years, the centralized power grids have experienced significant changes and challenges as follows [10]:

- The production is unpredictable and variable due to an increase in renewable energy sources.
- The power transmission and distribution become more controllable and fault-tolerant due to network digitization.
- Prosumers (entities that both produce and consume energy) have the active dual role of both producer and consumer.
- Loads become more interactive and dynamic.

Blockchain as a decentralized and distributed technology secures suitable applications in the transition to smart grid infrastructure. The utilization of the blockchain in smart grids could offer various advantages to the electrical power system with increased security, improved data privacy, data transparency and immutability, removal of third-party control and trust, ubiquitous solution, and greater data accessibility. A lot of research has been done about blockchain technology applied to the power sector [11]. The integration of blockchain and renewable energy sources, energy storage devices, and electric vehicles into the electrical grid has been a broad research area [12]. Blockchain technology brought agreeable advantages and

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created much interest in applying this technology in smart grids [13]. Blockchain applications in the smart grid could be divided into three parts of the smart grids as follows [14]:

- Power generation: Blockchains and smart contracts can allow a generating unit to directly trade with a consumer or a retail energy supplier via autonomous trading agents, cutting out the middleman [15]. Blockchains could also provide innovative trading platforms for integrating small-scale renewables, distributed generation, and flexibility services [16].
- Power transmission and distribution: Blockchains enable independent power grid nodes, without prior trust in each other, to reach an agreement on the optimal power flow solution through simulation experiments on the 39-bus New England transmission system [17]. Blockchains also guarantee the origin of the energy from the voltage distribution across the network [18].
- Power consumption: Emerging blockchain technologies ensure the seamless and secure implementation of a decentralized demand-side management approach following optimized demand profiles, including battery devices, electric vehicles' charging [19].

Among the examined research, a focused topic is about electric vehicles' connection to the smart grids. The random charging of these vehicles may give a heavy burden to the power grid. To solve this problem, blockchain technology is introduced. An electric vehicle integration scheme is proposed based on blockchain technology for reducing fluctuations in the grid [20]. It is suggested that a platform that integrates electric vehicles and charging stations enables a negotiation between them over blockchain [21]. It explains using blockchain technology to make electric cars find a close-by charging station [22]. To improve voltage stability of the grid while minimizing charging costs for electric vehicle users, an adaptive blockchain-based electric vehicle participation scheme is proposed to schedule electric vehicles charging/discharging demand to flatten the impact of consuming/injecting excess amount of energy at the level of the transformer substation [23]. The preservation of vehicle owners' privacy is also considered by a smart contract that allows vehicles to signal their demand and receive offers by charging stations using predefined regions without revealing their exact location [24]. The integration of electric vehicles with blockchain technology may secure the best location and price for electric vehicle users and ensure security and privacy [25]. It proposes a secure and efficient vehicle to grid energy trading framework based on blockchain and edge computing [26].

The following section will show how blockchain is used in the Smart-MLA project to handle settlements between the aggregator and the prosumers.

V. Blockchain in the Smart-MLA Project

One of the aims of the Smart-MLA project is to demonstrate the use of blockchain technology for settlements. The reason for including blockchain was an increasing interest in using blockchain for applications other than the pure cryptocurrency transfer. In Smart-MLA, the communication is between the aggregator and prosumers connected to the smart grid and between the aggregator and the DSO.

Ethereum [27] is a further development of blockchain technology introducing smart contracts. Smart contracts [28] are self-executing programs stored on the Ethereum blockchain that run when some predetermined conditions are met. It provides the possibility to do more than transfering amounts between actors. For example, smart contracts can be used for bidding processes between prosumers and the aggregator and between the aggregator and the DSO.

Smart contracts are written in the Solidity programming language [29], an integrated part of the Ethereum blockchain technology.

The demonstration of blockchain technology for settlements has been done as a set of activities:

- Setting up a local blockchain using Ganache and Remix
- Writing to and reading from the blockchain using web3
- Setting up a test blockchain using the Ropsten test network
- Using Nethereum to build applications using the .NET framework
- Making a test API for settlements

A. Local Blockchain

The local blockchain was implemented by using Ganache. Ganache provides a free Ethereum test blockchain network and is part of the Truffle blockchain development framework [30]. Figure 11 shows the Ganache graphical user interface (GUI) with ten accounts set up on the local blockchain.

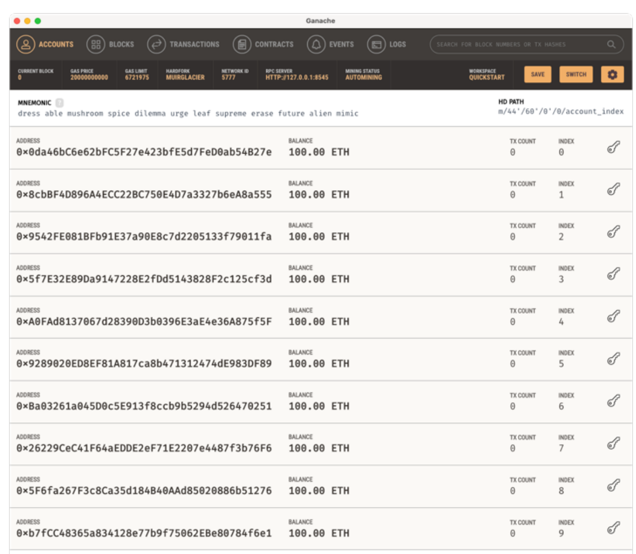

Figure 11. Ganache GUI

Ganache can be accessed from the Remix integrated development environment (IDE) [31]. Remix facilitates the writing, compilation, and deployment of smart contracts written in the Solidity language. The combination of Remix and Ganache was used to test the smart contracts. The smart contract validates senders and receivers, uses tariffs to compute correct amounts to be transferred, and checks if the sender has the necessary amount available.

B. *Using web3*

The web3 [32] library provides access to the Ethereum blockchain from programs. The library may be used with Ganache, the Ethereum test networks (e.g., Ropsten), or the public Ethereum network.

C. *Using the Ropsten test network*

Ropsten is one of four Ethereum test networks listed on the Ethereum website [33]. Like the public Ethereum network, Ropsten requires payments for making transactions. However, coins for payment are free and requested by sending a Twitter message to the network operator.

D. *Using Nethereum*

Nethereum [34] is a .NET library that makes it possible for .NET programs to write to and read from the Ethereum blockchain. User interfaces, as well as application program interfaces, may then be written in .NET code.

E. *Test API*

Finally, a test API was made to demonstrate how settlements may be done in practice. The smart meter or an agent talking to the smart meter writes a record to the blockchain about a settlement. The blockchain can also be accessed from the billing service and other services doing statistics and monitoring. Figure 12 shows the architecture of the settlement service.

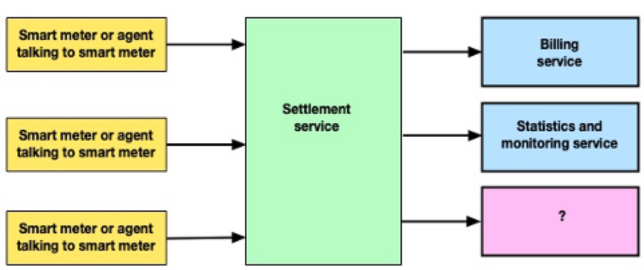

Figure 12. The settlement service

As shown earlier, the settlement records contain the amount of energy, time, period, and the two entities involved in the transaction. The smart contract checks the validity of the sender and receiver; and if the sender has the necessary amount available. The smart contract may also create a competitive environment based on bidding between the aggregator and prosumers and between the aggregator and the DSO.

VI. Conclusions and Future Work

The Smart-MLA project has demonstrated the use of blockchain for a specific smart grid application – registering settlements between an aggregator and the prosumers connected to the smart grid. The demonstration showed some disadvantages of using blockchain for this purpose.

To register a transaction on the real Ethereum blockchain requires a transaction fee. The current transaction fee on the Ethereum network is around USD 4.00 (June 2021). Therefore, if blockchain is used to register car owner transfers, the transaction fee would be negligible compared to the transaction itself.

However, the settlements between the aggregator and prosumers will be tiny amounts. Even if aggregated for each hour or even each day, the transaction fee would create a considerable overhead for the transactions.

Therefore, the public Ethereum blockchain should not be used for transactions involving minimal payments. Also, aggregation does not solve the problem since the whole idea of using blockchain was to achieve full transparency of all transactions.

The alternative is to set up a private blockchain. In that case, the fees for registering will not have a real value. But the infrastructure itself, mainly servers, will have a price tag. Blockchain is supposed to have a large number of copies on a distributed network. For a private blockchain, the number of nodes will be limited, and the blockchain will be more vulnerable to security attacks.

A traditional system of record (e.g., a relational database) could handle settlements in a much more efficient way. However, the problem with a database is the centralization of physical control combined with the ability to delete or modify records.

The blockchain excels in being immutable and transparent.

The Smart-MLA project strives to demonstrate how aggregators may benefit from customer flexibility. The smart grid may be enhanced by letting prosumers trade with each other through a stock-market exchange. Prosumers with storage capacity may compete to buy energy from other prosumers for future sales. This will create an internal market within the smart grid. The aggregator will then have to compete for excess energy produced by prosumers, optimizing the revenues for the prosumers. Today, the aggregator decides the buying price in a monopolistic way. An internal market within the smart grid would remove the monopoly of the aggregator and make a sounder competitive environment.

Acknowledgment

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