An Energy Blockchain, a use case on Tendermint

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***Abstract*—The recent advances in distributed energy systems require new models for exchanging energy among prosumers in microgrids. The blockchain technology promises to solve the digital issues related to distributed systems without a trusted authority and to allow quick and secure energy transactions, which are verified and cryptographically protected. Transactions are approved and subsequently recorded on all the machines participating in the blockchain. This work demonstrates how users, which are nodes of the energy and digital networks, exchange energy supported by a customized blockchain based on Tendermint. We focus on the procedures for generating blocks and defining data structures for storing energy transactions.**

Keywords—blockchain; transactive energy; microgrids; energy market; peer to peer.

I. INTRODUCTION

The intermittent production of energy from renewable sources is still growing. If not managed optimally, it can compromise the stability of the electrical system. One solution could be the storage of this energy and the balanced peer-to-peer exchange between end users. This latter measure can be realized using a properly designed blockchain [1].

The blockchain is a distributed ledger of transactions, which is structured in blocks and stored in the network nodes. Blocks are connected to each other in a chain and are validated before being inserted in the distributed ledger. In a nutshell, the blockchain can be represented by a chain of blocks that contains and manages multiple transactions. Each node can see, control and approve all transactions and is part of a network that allows traceability of all transactions. Each node, in turn, is also an archive for all transactions and thus of the history of each transaction that, just to be approved by the network, is available on all the nodes of the network and is thus unmodifiable (unless the same modification is carried out in the whole network and only after the approval). In addition to immutability, the other important feature of the Blockchain Network is the use of cryptographic tools to ensure maximum security of each transaction [2]. By using a blockchain, it is possible to reduce transaction costs through, for example, a standardization via "smart contracts" and automatic order execution without the presence of a third party to act as guarantor, allowing direct exchange of energy between users of the network quickly and safely [3]. A Smart Contract is a contract, suitably coded, which automatically verifies the occurrence of certain pre-defined conditions and executes actions when the conditions between the parties are fulfilled and verified [4]. Each new transaction before being integrated into a block of the blockchain is validated by specific nodes, which are rewarded for their work [5]. The blockchain is a distributed ledger, namely a ledger that is not physically located only on one single server; it is located on multiple machines at the same time, all perfectly synchronized on the same information. The use of the blockchain technology in energy management introduces:

1. *Transparency*, because each block added to the blockchain is accessible by all participants. It becomes a permanent and unchangeable reference to that specific transaction;
2. *Trust*, based on cryptographic functions, the blockchain works in distributed and untrusted environments;
3. *Efficiency*, as it requires fewer intermediaries than the traditional energy trading system, thus simplifying processes, infrastructures and increasing operational efficiency;
4. *Control and security*, because, thanks to encryption, data protection is better and less risky (fraud). Furthermore, decentralization prevents market abuses through monopolies and requires lower costs and regulatory oversight.

This document explains how to record energy transactions, occurred in a microgrid, using the Tendermint platform [6].

The use of Tendermint blockchain for the exchange of energy users allows transactions to be carried out quickly and securely, as the latter are made up of encrypted data and are verified, approved and subsequently recorded on all the machines participating in the blockchain.

The same "information" is present on all nodes and therefore becomes unmodifiable unless through an operation that requires the approval of the majority of nodes of the network and that in any case will not change the history of that same information. The blockchain is the digital paradigm that allows to guarantee the immutability of the data because it is able to guarantee its history.

II. State of Art – Energy Blockchain

The widespread of renewable and distributed generation leads rethinking the management of energy flows on the power system. As demonstrated in [7], the blockchain technology in the energy field has today become a realistic perspective, particularly for microgrids, where energy production is intrinsically distributed. The decentralized structure of a blockchain is perfectly adapted to the control of production processes within a microgrid. It is understood that this technology can guarantee the traceability and security of energy transactions. In [8], the authors reviewed several projects on energy blockchain, developed on different platforms. The project initiated by the PWR Company involves the installation of batteries in homes for the storage of electricity and the subsequent sale of this energy to other users in a microgrid to limit balancing problems on the network. The project currently relies on the Ethereum platform but will be replaced by another blockchain developed by PWR, which will include the use of an energy cryptocurrency, the PWRToken (1 PWRToken = 1 MWh) [8].

Other interesting works are those carried out by LO3 Energy: TransActive Grid and Brooklyn Microgrid. The TransActive Grid platform, developed on Ethereum, aims at various business models through the use of smart contracts. It allows peer-to-peer energy transactions, control of network balancing, emergency management and other uses. The second project, the Brooklyn Microgrid, represents an application of the TransActive Grid project, which foresees the creation of a P2P market of energy produced in surplus by the photovoltaic systems of the users of the Brooklyn community [8] [9]. The used technology is based on a transactive network, namely based on active transactions in both directions, rather than one-way. Within this network, each, with his home, constitutes a node. To become part of it, in addition to the physical connection, it is also necessary to stipulate contracts (smart contract) with the neighbors, by selling or buying a share of energy. The difference, compared to traditional energy supplies where the private individual purchases from a large company, is the peer-to-peer nature of the transactions. In addition to the environmental advantage, since the energy exchanged is produced from renewable sources, there is an economic advantage, as buying the energy locally instead than from a large company, the money spent in the transaction ends directly in the pockets of those who live in that area [8] [10]. The implementation of a transactive network, therefore, creates several challenges, such as establishing compensation prices for energy and exchanging money between users. The blockchain technology and the use of smart contracts promise to solve such challenges, in some cases with special cryptocurrencies that are dedicated to energy exchange.

In [11], the authors propose a type of smart contract based on a transactional energy auction without the supervision of a third party, implemented on Ethereum.

The system requires smart meters at both sellers' and buyers' premises and assumes that they can send/receive messages from the blockchain and that determines how much energy has been sold and purchased in a given period. Initially, a new contract is entered on the blockchain; the seller advertises the amount of energy that can enter the network, the buyers check the blockchain and send their offers, the contract performs the auction and determines the winner, namely who among the buyers receives the energy. Once the transaction is established, it becomes part of the blockchain and the resulting currency is exchanged between users.

In one of the most recent works on the energy blockchain, the installation of smart meters memorizing the values stored in blockchain allows the voluntary participation of each prosumer to "Demand Response" (DR) programs. DR is enacted through smart contracts that define the basic energy profile of prosumers. The energy measures, the expected energy profile, and the adjustments for "Demand Response"[1] events are the main elements of study. For each value stored in a block, by the intelligent measuring device, the corresponding smart contract evaluates the difference between the expected energy curve and the actual measured energy values. If significant deviations are found, actions are taken to rebalance demand with production. Therefore, smart contracts act as a decentralized control mechanism [12].

A further challenge is also to provide ancillary services and to establish a precise role for those nodes that perform this function. Microgrid producers may pay for voltage regulation that maximizes their production or, vice-versa, the Distribution systems Operator, DSO, might be willing to pay for the supply of reactive power, to maintain the quality of the voltage. The participation of the microgrid nodes in ancillary services, such as voltage regulation, as well as improving the management of the network, can, therefore, determine more revenues for the prosumers. The continuity of energy supply and the willingness to accept energy interruptions constitute a good to be traded, with its specific value. However, from a

[1] Events through which the prosumers of the smart grid can respond to the market signals increasing or decreasing their energy consumption, aiming at responding to the peaks of offer or demand, increasing flexibility, stability and efficiency of infrastructures and energy resources.

technical point of view, the problem poses some important challenges. First of all, it is well known that an energy transaction between a generator and a load located at two different nodes in general does not correspond to the physical situation that appears using power flow tracing methods [14]. After starting the virtual transaction, it is therefore necessary to perform a technical feasibility check to verify whether the transaction considered is or is not practicable in the system.

In addition to energy districts, the energy blockchain technology can be implemented on industrial operating systems with the aim of developing new applications for the optimization of the distributed energy system, as for example in [1], in which the authors propose the implementation of a blockchain on a "PREDIX" software framework (a software developed by General Electric for the collection and analysis of industrial machine data).

The system monitors the production of an eco-district and assigns green certificates to producers. The latter can be purchased by consumers through transactions certified by the blockchain implemented on the monitoring system itself.

III. PROBLEM DESCRIPTION

During an energy exchange, even if the generator and the load are close, the energy injected by the generator will not necessarily supply that particular load. While this fact in the current energy market has little or no influence on the determination of energy distribution costs, in a more restricted context, where energy is exchanged between neighboring nodes, it becomes relevant. Other technical aspects to take into consideration are the profiles of voltages, reactive flows and power losses, which vary at each transaction.

With regard to voltage profiles and reactive flows, two different scenarios can be envisaged: one in which the distributor provides the aforementioned services and one in which the users of the microgrid are the ones supplying them. In both cases, an appropriate remuneration system can be estabilished, which will form part of the block related to the transaction. With regard to the attribution of energy losses to a given energy transaction, however, the situation is more complex. Taking into account a passive system, it is possible to state that losses increase when the network load increases, but for active systems this is no longer true.

By applying the proportional sharing rule for tracing power flows to a suitably modeled microgrid, it can be noted that the expected power flows for P2P energy transactions do not correspond to the physical situation. The reactive flows strongly influence the operation of the network, especially when the voltage regulation service is provided by local generators. Furthermore, the missing correspondence between virtual and physical transactions makes it difficult to correctly allocate energy losses.

Although distribution costs can be accurately calculated in each branch, they cannot be exactly attributed to simultaneous "transactions" that insist on the same path, due to the non-linear coupling of flows from different generators on the same branch [15]. The authors in [14] propose two different indicators to manage the losses allocation problem:

1) The PSR index, which is able to provide an accurate assessment of power losses to be associated with energy transactions between a specific generator/ load pair, by applying the power flow tracing and then the proportional sharing rule;
2) The Global index, which on the contrary, provides only a rough estimate of power losses attribution, but is very simple to evaluate. In this case it is assumed that power losses increase or decrease proportionally according to loads variation.

As already said, loss assignment is not an easily solvable problem, due to the non-linear coupling of reciprocal terms that appear in the expression of power losses, when considering the power flow tracing from the generators to the loads. Therefore, it is possible to argue that the reciprocal terms could be equally shared between the active transactions on a given branch. Any economic rewards for the distributor, to compensate the cost of network maintenance, could also be included in the blockchain.

Once the distribution of the power flows and the distribution costs are evaluated, it is possible to integrate them into the blocks forming part of the blockchain. For the case here considered, the Tendermint blockchain is used, with some dedicated modifications.

IV. APPLICATION

Tendermint is a blockchain that allows the secure and consistent replication of an application on different machines. Safe because it works even if 1/3 of the machines fail arbitrarily (capacity known as Byzantine-BTF fault tolerance) and consistent because each machine sees the same transactions and are in the same state [16].

The advantage of using Tendermint, as compared to the other blockchains, is the possibility of using any programming language to write the code of the App to process the transactions to be included in the blockchain blocks. Tendermint consists of two main technical components: a consent engine (Tendermint Core) and an interface application (Application BlockChain Interface - ABCI). Tendermint Core ensures that the same transactions are recorded on each node, while the interface application allows to communicate with Tendermint Core by processing transactions in any programming language. Figure 1 shows a simplified diagram of how Tendermint works.

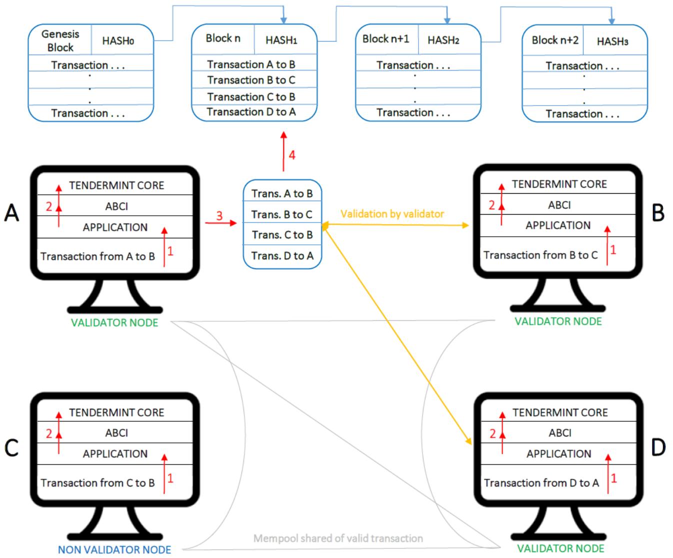

Fig.1: Tendermint operating principles

Every time a user decides to execute a transaction, the latter is sent to the App (see 1 in figure 1) which performs the validation. Once this is done, a valid or non-valid message is returned to Tendermint Core (see 2 in figure 1). If the transaction is valid, it will be included in the mempool of validator nodes. At this point, a validator node proposes a block containing several valid transactions, sends it to the other nodes of the network (see 3 in figure 1) and, following validation by the other validators, the new block is inserted in the blockchain (see 4 in figure 1). The validators are the consensus participants, who, in turn, propose a block containing transactions, which can either be inserted into the blockchain or not.

The insertion in the blockchain occurs only if more than 2/3 of the validators execute the pre-commit[2] of the same block in the same round. If this does not happen, the block passes to the next round [16].

When Tendermint is started for the first time on a machine, the following files are generated:

one where the blockchain can be configured (specify the blockchain nodes, add validators or non-validators nodes, the application address, etc.), another one containing the public key of that node and finally one containing the private key of the same node.

Considering the simulated micro grid in [15], it is possible to create a blockchain whose nodes are the users of the microgrid itself and include in the energy transactions between the various nodes, in addition to the amount of energy exchanged, the losses on the network following the transit of energy and any management costs to be paid to the DSO. A user who decides to exchange a certain amount of energy with another user of the same microgrid, sends the transaction to the App that performs the feasibility analysis of the considered energy exchange, evaluates the losses, the related costs and processes the complete transaction. The latter is then stored in the Tendermint mempool, inserted in a block and, following the validation mechanism described above, a new block is inserted in the blockchain.

We propose to perform energy exchanges among the users of a microgrid through a decentralized approach, without the need of third parties. In this case the Blockchain is used as a shared database of energy transactions between the users. Users of the microgrid use their mobile App to communicate with their smart meters. Starting from measurements collected by smart meters, the App forecasts energy production and consumption and can define the best matching between energy needs and offered energy. An advanced application may include extra information on the blockchain besides energy transactions. Forecasts of produced energy and sell orders as well as forecasts of consumed energy and purchase orders would also be included in the blockchain.

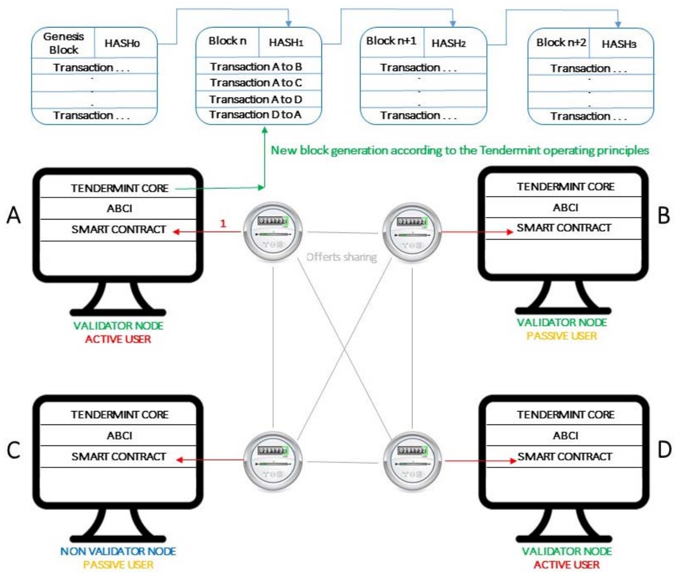

Fig.2: Architecture of our distributed system based onTendermint

2 The pre-commit is a voting mechanism performed by the validators to determine whether or not to insert the new block in the blockchain.

As shown in Fig. 2, the application gets the production or consumption profile from the smart meter, produces forecasts, and sends their purchase or selling offer. Users can select, for example automatically through a mobile App, the offer that best fits their needs. After this, the smart meter sends the transaction request to the smart contract running on node (see 1 in figure 2).

The smart contract performs the feasibility analysis of the transaction. If the result is positive, the procedure for entering the blockchain of the transaction (through the procedure explained above) starts and a message is sent to approve the transaction to the smart meter which in turn informs the user. If the result is negative then a non-approval message is sent to the smart meter and the user can select another offer. Smart contracts automate their energy trading actions, therefore users only set thresholds for their purchase or sale prices.

V. CONCLUSIONS

The possibility to use any programming language for creating applications for the considered application makes Tendermint an easy-to-use tool that is easy to understand and useful for a wide variety of distributed applications.

Further developments of this work concern the simulation of energy transactions between the various users of a micro grid and the possibility of developing an application for verifying the technical feasibility of transactions. Moreover, the application allows to view not only the transactions on the blockchain, but also the sales offers and purchase proposals of the various prosumers.

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