Blockchain Technology Application in Improving of Energy Efficiency and Power Quality

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Abstract— **This article presents one of the many uses of blockchain technology in the power grid, especially for improving energy efficiency and power quality. As a key element, it will show you how to use the blockchain technology to store in a decentralized way the data collected by existing intelligent sensors or which can be mounted in the power system. The purpose of this article is to present the point of view of the need to improve the energy system generated by the many problems arising from its age and its incompatibility with new production and consumption technologies.**

Blockchain implementation will be low and medium voltage, where the most affected are final consumers (whether household or industrial) that have started to have new energy-efficient technologies but have an unpredictable consumption that cannot be anticipated, thus increasing network losses.

The article also contains data on energy efficiency in a decentralized energy system through the use of new IT technologies and, in particular, by involving consumers who will have a double role as part of the blockchain.

Index Terms—**Blockchain, Power Grid, Energy Efficiency, Power Quality, Micro Grid, Smart Grid, Electric Vehicles (EV), IoT (Internet of Things),**

I. Introduction

Since the 1980s, and with the advent of the Internet, digitization has begun to make its presence felt. Thus, the ability and capacities of electricity consumers have increased and have begun to participate in both parts of the sector (production and the energy market). [2]

Energy infrastructure, especially electricity generation, has been created from the idea that the origin, allocation and use of energy is costly. In recent years, other energy trends have emerged so that solutions for decentralization of energy sources and energy consumption have now been sought, and data collection from sensors has become more economically accessible. Thus, a new idea emerged, namely the development of a new energy system in view of the current energy system scheme is no longer present. [2],[4]

The central question of the decentralized energy system is related to data coordination and processing, if it should be done in a decentralized or centralized architecture, the advantage of centralized architecture is that it is a solution which is much more feasible and easier to implement.

Electric energy is essential to increase productivity and ensure a high quality of life; therefore, the relationship between electric power and economic growth is crucial. However, the consequence of the current worldwide prevent the depletion of resources and promote economic growth at the same time is the application of the concept of energy efficiency through energy management systems. [5]

Also because of the existing infrastructure, in this article we will relate to energy efficiency and power quality, the most important aspect of which is the economic one. Also, as you already know, energy is one of the factors of production, energy efficiency helps to improve energy production but also to economic efficiency. Moreover, the efficient use of electricity as well as changes in the energy sector will play an important role in any strategy to achieve an economically efficient society, because energy efficiency refers to the physical / technical performance of the user's energy equipment, household (lighting, heating, cooling and electrically driven equipment). [4]

In the last chapter we will discuss and analyze the implementation of blockchain technologies and their use in an energy system to improve the qualiy of energy use. For years, there has been talk of finding new technologies to reduce costs and increasing reliability in the use of the power system, but so far, they are bound by technological limits, but in research, risk is part of evolution. All the ideas are at the simulation stage in the laboratory or implemented into a MicroGrid for obtaining truthful and accurate information. A big step back is generated by people's skepticism, lack of knowledge, and the most important cause is the lack of money. The cost of using blockchain for energy system efficiency is far too high due to the cost of IT components and software, as well as by the lack of experience of those who need to use them. [4]

II. Blockchain Technology

A. Definition

Blockchain is a distributed database in which data is stored and stored in blocks, and data stored in the current block have references in the previous block, all forming a growing chain of blocks and they are created by members called miners using their own equipment IT and its own power to validate transactions / data and are rewarded for individual effort. [1]

Blockchain technology has two great advantages, making it

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an attractive solution for recording data or transactions, namely:

- Cryptographic immutability and verifiability - this is due to the impossibility of changing records stored in data blocks once validated by the miners, which ensures the security of transactions. Blockchain technology combines two existing technologies (hash functions such as SHA256 and Merkle trees) to ensure its verifiability and immutability. [2]
- Distributed consensus - That is, when making a transaction on a peer-to-peer network, it is necessary for this transaction to be approved by foreign individuals who are part of the same network, this allows the removal of the approval of a mediator or an organization in a centralized system. [2]

Cryptographic immutability and verifiability

In a more detailed look at the technology used to achieve inflection and technology verifiability, hash functions are an algorithm that processes arbitrary data and output data with a fixed bit chain known in the IT world as hash. To further detail, the hash functions are a one-way mapping function, and after running this algorithm, output data is obtained, but the process is irreversible, and it is impossible to get back the input data from which everything was started.

In a blockchain, the hash functions are used to achieve the data content of a block with a fixed length of the bit chain, since the hash functions are quick to make up and deterministic; for the same input data, the same output data is obtained. if the input data is changed even slightly, then completely different output data is obtained. [1], [2]

In terms of Merkle trees, they are used to structure block records and allow efficient verification of the authenticity of chain data. In a simple Merkle tree, all data is retained in leaf nodes. The method used is a simple one, namely that each record is then hashed, and the parent node is placed over the leaves by combining the lower-level node pairing hashes and calculating a new hash as shown in Figure 1.

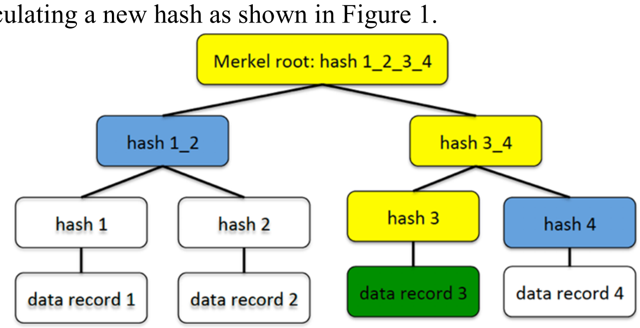

Fig. 1 – A simple Merkle tree [1]

Each blockchain block contains the upper-level hash of the tree named Merkle root and together with all the transactions contained within that block. Each block contains the previous block hash of the previous block, so the new block of the string is calculated according to the predecessor block so that it is inseparably linked to the previous one. [1], [2]

Thus, by using a principle such as the Merkle trees, it ensures that no change or replacement of transactions goes unnoticed. They also provide an easy check of current string records using the so-called Merkle proof. Having a higher-level hash (Merkle root in Figure 1), the data node (record data 3 in Fig.1) and the set of hashes used to integrate the current data into the rest of the tree (hash 1_2 and hash 3 in Fig.1), a Merkle proof always allows an interested party to verify the data held (eg: record data 3 in Fig. 1) if it is correct and uniquely integrated in the chain without this interested party having knowledge of each individual node. [2]

Distributed consensus

It is a process that leads to an understanding between people in the peer-to-peer network. This understanding is required in Blockchain Technology to validate a block and if it can be added to the block of blocks, this being done by miners, being rewarded for adding a block in the chain, and therefore competing against each other.

This understanding is achieved through a distributed consensus algorithm (DCA) [1]. Each blockchain platform uses its own version of DCA:

1. Proof of Work (PoW), this version works by setting target values that should not be exceeded by the hash value of a particular block for it to be accepted in the blockchain. This target value is adjusted in such a way that on average in a network node there is a block of such value within a certain time interval. Then in the node where such a block is found it can add it to the chain. This method creates competition between miners who want to be the first to find an acceptable hash value.
2. Proof of Stake (PoS) is a version that works by randomly choosing from a bunch of other nodes that have kept the unwrapped currency for a long time, the node that will create the next block.
3. Proof of Burn (PoB) is a version of DCA whereby the choice of the next node that will create the next block is chosen from a amongst of nodes that have shown that they burn some of their coins by sending these to a verifiably unspendable address.

Those who perform a hash task and implicitly create a block are rewarded with a payment composed of the charges each participant blocks to secure their transactions and a preconfigured amount of network cryptocurrency. [1],[7]

Those who perform a task to determine the hash and implicitly create a block are rewarded with a payment composed of the charges each participant blocks to secure their transactions and a preconfigured amount of network cryptocurrency. [2]

As a mode of operation, the blockchain is maintained and operated by a blockchain network that is a peer-to-peer network of computers that stores data in a redundant way, which gives it continuity in the event of a single-point fault or the case of intentional attack. In the case of a blockchain network, an internal procedure is required whereby all its nodes ensure a consistent state of the blockchain copy. [1]

The conclusion is that blockchain databases are distributed, decentralized, are a multiple-access database that has cryptographic security of recorded data. Still, the nature of this database requires a pellicular environment operation, such as a dedicated network of members to support it and requires a transaction cost.

B. Blockchain in Energy Sector

The concept of blockchain implemented in the energy sector has been accepted by industry and academia, and both are convinced that this technology has the potential to facilitate the transition to Smart Grid but also to make innovative changes in the sector. Energy has emerged as a decentralized electricity network that has become a feasible idea in recent years with the integration of electrical storage devices and electric vehicles into the future power grid. In the world of energy, there has been a growing debate about studies on new control schemes for both energy storage and demand for response programs. [1], [2]

Another example of blockchain use was to eliminate fraudulent behavior in emissions trading, so an Emission Trading Scheme (ETS) was created with a blockchain that provides confidence and security for transactions and incorporates a reputation system to encourage long-term ETS investment.

In the last few years, the idea of using blockchain technology in the energy sector is being viewed with increasing interest. An example would be the integration of electric vehicles (EVs) with the Blockchain Technology so that EV can use the blockchain to find the closest charging station, while the power stations can bid to have the opportunity to load the EV. This example has been conceived as a help mechanism for finding the best price and the best location for both EV users and electric stations, while offering EV security and privacy.

A very active and sought-after research area is the use of the IOT blockchain, especially in energy efficiency in intelligent homes or for energy efficiency through smart metering. In this case, blockchain can play an important role in data control and support in making large-scale decisions in IoT using smart contracts as a means of automated communication and enforcement rules between devices. [2], [4]

The P2P (peer-to-peer) trading system allows any unit of generated electricity to be recorded in a blockchain allowing the owner of this generated energy to sell it to others. This concept allows those who generate electricity or those who consume it (be they big or small) to assume the ownership of their product, choices or preferences rather than relying on the energy network that plays the role of intermediary. Some studies on P2P energy trading are focused on creating the P2P energy market by demonstrating that block-based energy trading without intermediary is possible and beneficial to those who generate it but also to buyers. [1], [2]

A platform prototype has been created that focuses on user anonymity and privacy while removing a possible failure point. On this platform, the central pricing algorithm was removed, instead providing users with encrypted channels to facilitate direct price negotiation between the seller and the buyer. [1]

Figure 2 shows the three types of energy grid trading (microgrids, energy harvesting networks and vehicle-to-grid networks), it is essential that they present a unique energy trading framework, and those who succeed in building a block of energy to secure energy transactions. [7]

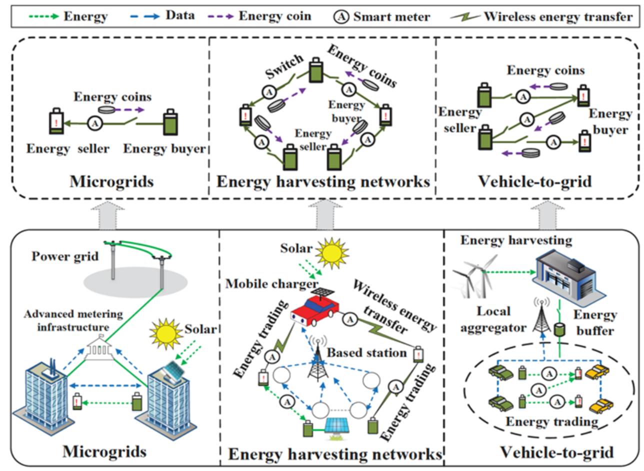

Fig. 2 - A typical scenario of energy trading in IoT [6]

The unified framework for energy trading contains 3 joint entities such as: [2], [6]

- Energy nodes: smart buildings, smart sensors and EV play different roles in P2P energy trading such as buyers, energy vendors, or neutral nodes.
- Energy aggregators: They have the role of energy brokers to manage events related to providing wireless communications services for IoT nodes. In Figure 2 there are 4 entities that act as aggregators: a transaction server, a credit bank, an account pool, and a memory pool.
- Smart meters: Integrated into each IoT node to calculate and record the amount of energy traded in real time. Energy buyers pay the amount of energy purchased directly to the seller based on smart meters.

C. Blockchain into the energy network

For this purpose, a project has started that has a different approach to blockchain integration into the energy grid. Within this project, participants are encouraged to export electricity and thus help balance demand and supply from the network. For each kWh that a household user with a surplus of electricity exports to the grid, and if that kWh is consumed by another user, then the one who injected into the grid will receive that amount of energy that will be rewarded financially.

This system works using smart meter data and data from street-level substation. Each of these substations sees the total consumption and generation of the house / dwelling group connected to it and the smart meter data that provides information from each end user / consumer for the same period as the substation. [1] This information determines whether the amount of energy exported by a user has been consumed by another user belonging to that group.

Thus, the person who exported energy is remunerated in accordance with the amount injected into the network. At the same time, the data provided by the smart meter and the substation are compared to verify the integrity of the data. [7]

Another example of how to implement a blockchain on an IoT platform is in the case of an autonomous local marketplace of a roofed company that has smart and flexible devices, EV, smart meters that can measure a bi-directional energy flow (see Figure 3).

Blockchain can distinguish the electricity produced by each equipment by facilitating the trading of electricity between different devices. Starting from user preferences and willingness to pay, autonomous trading agents form an integral part of all intelligent devices, they can decide the optimal bidding strategy to trade energy on the platform. [2]

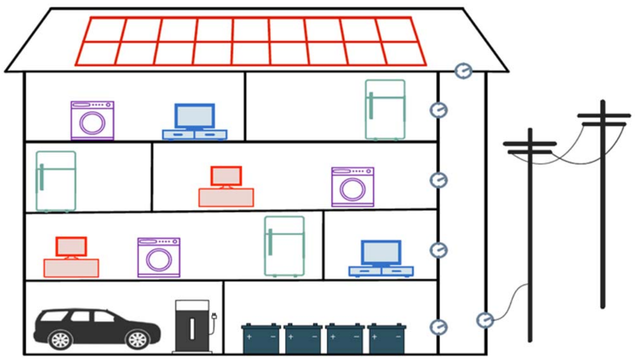

Figure 3 - Housing society electricity trading platform [7]

Despite the potential to save money, it is unclear whether a consumer will want the electrical consumption books, washing machine or EV to be published in a public register.

III. Energy Efficiency and Power Quality

A. Introduction

The management of electrical power systems in general, of efficiency and power quality in particular, has become a concern for network operators (system) when it has been found their need to ensure operational safety, power supply security and economic optimization. [8]

Both act to the customer's benefits and bring competitive advantages to the company: power quality creates advantages from the differentiation of electricity distribution services and has a significant influence on the market shares of an power distribution operator (on the unregulated market), and the efficiency in using electricity has a great influence on the profitability of the company and thus creates a cost advantage. [9]

Electricity distribution systems must meet certain requirements related to the electricity supply to consumers and their fitting into the power system. The most important requirements are: ensuring continuity in the electricity supply to consumers, safety in operation, ensuring the qualitative parameters of the electricity supplied to consumers, economic efficiency of investments, additional requirements imposed by the impact on the environment.

B. Power Quality in Power System

The power quality is one of the important factors that determines the economic efficiency of both consumers and electricity grids. Deviations of the power quality parameters from the accepted values can cause damage to all participants in the power system. It is influenced by both the production, transport, distribution and supply systems, as well as the activity of the consumer. Due to their characteristics and the specific stresses that arise, they are the source of disturbances in the form of interruptions, voltage drops, unbalances, overvoltages, voltage and frequency variations. [9]

The most important damages to a user's activity are generally caused by interruptions in power supply to the electricity system. It should be noted that the duration of the interruption in the power supply is different for both the supplier and the user. Long-term interruptions can be: planned or unplanned (accidental).

Planned interruptions are imposed by the network operator, generally for maintenance or network structure interventions. Often, planned interruptions are designed to ensure superior performance of the user's power supply. An interruption is considered to be planned if the user is informed in advance, usually 15 days in advance. Under special conditions, notification must be made at least 24 hours in advance. As in the case of planned disruptions, induced damage can be limited by specific measures adopted, it leads to lower associated costs compared to an unexpected interruption of the same duration. [8]

C. Study case

For the case study, the city of Bucharest with the highest density of electrical equipment was chosen, referring to the number of consumers served and its surface. The city of Bucharest is divided into 4 large network areas that include both medium and low voltage power grids. The users of the distribution grid, the majority of the consumers (final customers), are connected directly to the public utilities networks of the eight distribution companies, in this case the concession license is the socket of E-Distribution Muntenia.

The performance standard for the power distribution service regulates the quality of the electricity distribution service and establishes the performance indicators in the provision of distribution service. According to the performance standard in a calendar year, for the development and maintenance work, the distribution operator does not cause a user more than: 4 planned interruptions of up to 8 hours each in the urban area and 8 planned interruptions with the maximum duration 8 hours each, in the countryside. [10]

From this point of view according to the data presented in Table 1 we can say that the requirements imposed by this standard are respected in relation to the number of planned interruptions for each network area, considering that each event does not affect the same end customers. Operating maneuvers refer to the maneuvers performed by the energy dispatcher needed to return to the normal operation scheme following the remediation of some incidents or the exploitation of the power equipment. These are done with the end-users' agreement at night time intervals to reduce the impact on them.

Table 1. Situation of planned interruptions for 2018

Type of activity	Network area MV-LV Bucharest							
	EAST		NORTH		SOUTH		WEST	
	Event Number	Average interruption time	Event Number	Average interruption time	Event Number	Average interruption time	Event Number	Average interruption time
Operational maneuvers	92	52	86	27	79	50	62	38
Maneuvers for investment works	6	45	10	32	8	99	14	115
Maintenance maneuvers	15	118	6	144	6	42	2	313

In the case of planned interruptions, only one interruption is considered, even if during the announcement period for the execution of the work on the electrical networks the user has suffered several interruptions followed by temporary overvoltages. The duration of this interruption is equal to the sum of all the lengths of the long interruptions recorded during the period announced for the work

Table 2. Situation of accidental interruptions for 2018 (T > 3 min)

Event type	**Case**	**Network area MV-LV Bucharest**			
		E	**N**	**S**	**W**
With defective component	Non-selective protection	1	1	-	-
	Fire	2	-	-	-
	Others	13	7	3	7
	Flood/Infiltrations	1	1	2	-
	Electrical Fault	397	229	345	246
	Mechanical failure	-	-	1	-
	Pets	4	1	-	-
	Unidentified	2	3	1	-
	Incorrect protection	-	1	-	-
	Third parties	13	29	23	12
	Remaining without power from system	4	-	4	-
	Defects in third party installation	2	-	-	1
Total		**439**	**272**	**379**	**266**
No defective component	Stealing	1	-	-	-
	Fire	-	1	-	-
	Others	23	22	43	19
	Flood/Infiltrations	2	1	1	-
	Electrical Fault	4	3	3	3
	Pets	2	4	-	-
	Unidentified	-	6	11	10
	Incorrect protection	-	2	-	-
	Third parties	1	-	3	-
	Remaining without power from system	16	-	7	-
	Defects in third party installation	9	8	3	7
	Producer defects	-	-	-	4
	Request client interruption	5	10	3	2
Total		**63**	**57**	**74**	**45**

E-EAST, N-NORTH, S-SOUTH, W-WEST

Interruptions are considered to be unplanned if the user is not informed in advance. Most of the interruptions are unpredictable, unplanned events, caused by defects in system components, lightning strikes in power plants, unauthorized interventions (destruction), incorrect maneuvers in the system. Accidental interruptions in power supply due to permanent or temporary defects can be classified as: a long-term interruption (duration> 3 min) caused by a permanent fault and a short duration (duration ≤ 3 min) caused by a fault transient. [8]

In the case of unplanned interruptions, if two or more long interruptions have the same cause and succeed at intervals of no more than three minutes, they will be grouped and considered as a single interruption equivalent to the duration equal to the sum of the durations of the discontinued interruptions.

In Table 2 it can be noticed that accidental disruptions in the long-term power supply resulting in defective elements have a much greater share for each zone than for non-defective elements. In Table 3, in the case of short interruptions, the above situation is repeated.

Table 3 Situation of accidental interruptions for 2018 (T ≤ 3 min)

Event type	**Case**	**Network area MV-LV Bucharest**			
		E	**N**	**S**	**W**
With defective component	Others	53	45	24	20
	Electrical Fault	164	71	91	84
	Mechanical failure	2	2	2	1
	Unidentified	1	4	-	2
	Incorrect protection	-	0	0	1
	Third parties	2	1	2	3
Total		**222**	**123**	**119**	**111**
No defective component	Non-selective protection	1	-	-	-
	Others	56	68	73	61
	Flood/Infiltrations	-	2	-	-
	Electrical Fault	3	4	8	1
	Mechanical failure	1	-	-	-
	Unidentified	3	1	10	1
	Incorrect protection	-	3	-	-
	Third parties	-	-	2	-
	Remaining without power from system	14	-	11	-
	Defects in third party installation	2	2	1	7
	Request client interruption	-	-	4	-
Total		**80**	**80**	**109**	**70**

The distribution operator has the obligation to ensure continuity in the power supply in accordance with the performance levels set out in the performance standard for the power distribution service. The operator takes all measures to reduce the duration of interruptions and to schedule them at dates and times that least affect the user.

The distribution operator has the obligation to record all long-term interruptions as well as short-circuit interruptions of the power / evacuation path of the power and / or production sites connected to the distribution network, regardless of the voltage them.

For the period from 1 January 2019 to 31 December 2020, the number of unplanned long interruptions affecting a place of consumption and / or producer connected to low voltage electrical networks in a calendar year under normal weather conditions may not exceed : 12 unplanned interruptions in the urban environment and 24 unplanned interruptions in rural areas.

IV. Conclusions

A conclusion resulting from this study case presented in this scientific paper as well as from the scientific papers in this field is that it is necessary to use new technologies, such as blockchain technology, to solve problems which exist into power system and to improve the parameters of energy quality and energy efficiency.

Thus, as we have said, blockchain technology, through its decentralized structure, and its ability to use the computational power of peer-to-peer network members can generate a multitude of databases that are processed, verified, and created repetitively and sure. Thus, such technology can process energy-related parameters such as long-term interruptions, third party intervention, software or hardware issues, distribution or supply issues, etc.

Long-term interruptions have occurred due to electrical failures, which is to be expected because most of the interruptions are due to the failure of the power lines in the cable and less of the power equipment in power stations, transformer stations and power points. Another cause that led to disruption of power supply is third party intervention on power plants without the manager's approval. As a cause of an accidental interruption there is a cause that bears the name of others, it covers a wide range, ie it may refer to problems of SCADA or telecommunication or multiple failures occurring in a power equipment. Another cause of significant importance is the lack of power from the system, affecting a significant number of end users of thousands or tens of thousands, and therefore a rather extensive consumer area is affected.

Regarding the state of the distribution network's electricity networks, it is noted that a large part of the installations currently in operation have a long service life. For some of these assets, service life may be extended, while others may need to be replaced. It can be seen that only a small part of the total energy capacities has been rehabilitated or modernized.

Along with technological evolution It is necessary to apply consistent programs of upgrading and modernization of the existing installations, as well as to increase and make more efficient the maintenance activities for the maintenance of the electrical installations in the nominal operating parameters and the adequate monitoring and evaluation of the state of the networks.

Based on the analysis of the results recorded in the previous tables, it is necessary to conduct investigations for the detection and elimination of the causes leading to the degradation of the electricity quality indicators, as well as the implementation of a management oriented towards improving the performance of the electrical networks. Taking these aspects into account we also observe a change of the role that the households play. In energy sector: there are not simply consumers, but active owners and/or investors into energy hardware and software infrastructure, generators and sellers of energy, as well as buyers and consumers.

Regulation of businesses from energy sector through blockchain technology is currently somewhat under-developed. Furthermore, most activities from power system already or may use smart contracts over blockchain for specifying and enforcing energy trading contractors to support efficient trading, efficient and smart use when is needed to prevent problem with the parameters of energy quality.

In summary, looking at the trends within the energy sector, we suggest that the impacts expected from blockchain technology have already started to manifest in practice, and seems to be grounded in reality, through there still is a long way to go for its full-scale rooting with the energy sector. Thus, we remain cautiously optimistic that these expectations will be realized in not-so-distant future.

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