Setup of a local P2P electric energy market based on a smart contract blockchain technology

Igor Perekalskiy, Sergey Kokin , Dmitriy Kupcov
Ural Federal University, Yekaterinburg, Russian Federation
s.e.kokin@urfu.ru

***Abstract*— in an era of the widespread introduction of information technology, the broadest possibilities are opening up for the implementation of additional services for prosumers in the electricity market. The traditional electric power system of Russia allows customers to receive electricity only from large power plants, which leads to centralization and monopoly. Currently, the concept of distributed generation is gaining popularity. The idea is that small electric power generators are distributed throughout the local power network. The introduction of such an electrical network will improve the reliability of the system. However, such a network needs effective management and an electricity metering system. This paper proposes the use of distributed network blockchain technology as a solution to these problems. The proposed double-chain blockchain model will provide for the electric energy trading within the local electricity market, without third-party intermediaries, with a sufficient level of security and automation for all participants.**

Keywords*— *blockchain; smart grid; distributed computing; energy internet; distributed ledger

I. Introduction

The electric network today is undergoing a revolutionary transition to a sustainable, decentralized and intelligent system that includes the creation of a microgrid [1]. A microgrid is a cluster with distributed generators, loads and energy storage devices within a clearly defined electrical boundary. Such systems offer higher reliability and flexibility due to the integration of various energy resources [2]. New technologies are emerging to provide for the functioning of such systems. The concept of creating P2P energy markets is becoming implementable.

The setup of such local markets provides the conditions for consumer involvement in electric energy trade operations. This will surely promote the reduction of the cost of electricity through the use of renewable energy sources by the market participants.

However, the setup of such a market requires a reliable and cyber-stable system capable of ensuring the fairness of all transactions, at the same time ensuring the stability of the energy system as a whole. Blockchain technology can be an effective solution to meet these needs. Blockchain is a decentralized and distributed digital book of records (database) that records data (information) in encrypted form, in blocks that are inextricably linked to each other and are protected cryptographically. Each of the Blockchain network members keeps copies of the records. The recorded data is constantly synchronized and cannot be changed by a single node without the consent of all other nodes in the network, which makes blockchain the system suitable for managing immutable data. In addition, all changes made to the data are subject to authentication by all participants. By this, blockchain technology is able to provide secure data management, which is crucial for the establishment of a secure trading system. In recent years, P2P systems and blockchain have become an active area of research. Blockchain technology was used in [3, 4, 5, 6] to create local electric energy markets inside residential neighborhoods and microgrid. In [7], a method of energy exchange was proposed for small clusters of consumers who have power generation of their own. In such a case, there is no need to regulate the pricing policy and the process of reaching agreements by the third parties. [8] suggests carrying trade operations based on the DGC mechanism for the exchange of rights between individual consumers. In [9], the authors proposed a real-time bidding process, where several “agents” are assigned to collect bids from generators and consumers. Even so, there is still a risk of a hacker attack due to the centralization of database management. Moreover, the issues of security of energy transactions and of the network threats are generally omitted in the abovementioned studies.

This paper offers a Blockchain-based method for building a local P2P market. The Blockchain technology provides for the distributed storage of the data on the electrical energy transactions in the network. The decentralized nature of the data storage ensures the security and integrity of transactions, transparency and reliability of the data. The paper is structured as follows: part II provides an overview of Blockchain technology. Part III describes the architecture of the suggested distributed P2P trading platform. Part IV analyses the features of the proposed solution.

II. Blockchain Technology Overview

Blockchain is a decentralized data management system where data is stored in an encrypted block chain and distributed in a peer-to-peer (P2P) network. The concept of Blockchain is integrated into the electronic payment system

978-1-7281-9479-0/20/$31.00 ©2020 IEEE

Bitcoin proposed by Satoshi Nakamoto [9]. Key characteristic features of Blockchain are as follows:

- Support for building consensus throughout the network;
- Data storage in the form of a linked chain of blocks;
- Chain synchronization throughout the network;
- Decentralization of data storage;
- Consistent, verifiable and reliable data management.

Each block has a predefined size and stores a certain amount of data. Each block has two unique identifiers (hashes): the hash address of the current block and the hash address of the previous block. The first block of such a chain is called "genesis block" [10]. Thus, block chains are hash interlocked, and this connection cannot be broken afterwards, because once a block is created, any change inside the block will cause the hash to change and, therefore, the chain will be broken. This paper proposes a double-chain blockchain model, where smart contracts and transactions of participants are stored in two separate block chains, namely in the "contract chain" and "transaction ledger chain" Fig. 1(a, b).

The hash addresses of all blocks are located in a tree, which in turn generates a root hash as shown in Fig.1(c). Any unauthorized change in the blocks will lead to a change in the root of its hash. Consequently, unauthorized changes in the blocks will be detected and averted during the block verification process by other participants (miners).

III. DESCRIPTION OF THE PROPOSED MODEL.

The proposed market model implements a smart contract concept and suggests the deployment of blockchain nodes at each connection to the electric network. Intelligent metering devices (smart meters) will serve as such nodes for consumers.

A Seller is an entity capable of acting both as a power consumer and as a power generator. Each seller has a power generation of his own, including, for example, generation from renewable energy sources (photovoltaic energy, wind energy, bioenergy, etc.).

Each node will have a smart meter that controls all operations of transmission or receipt of electric energy from the sellers by analyzing the power flows. A smart meter will also ensure all switching operations based on the power flow data. As long as the user completely covers his needs with his own renewable energy sources, he is powered by his own generation. Should the smart meter detect a lack of power, the node will request for the purchase of energy from the external market and ensure its receipt. Should a household have excess energy, the corresponding node will enter the market and sell the energy. Thus, a smart meter provides a bi-directional flow of energy between the consumer and the network.

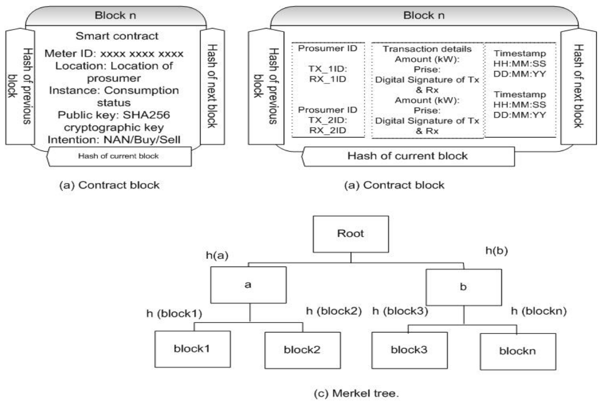

Fig. 1. Architecture of a contract block chain: (a) block containing data on smart contracts, (b) block containing data on transaction ledger, (c) a tree of n blocks generating a root hash.*A smart meter* measures and monitors data on energy consumption by consumers in real-time and uses wireless technology to send readings of household meters to energy providers [11]. The data is sent to the smart contract chain that processes this data and upon checking all the specified conditions, updates the blockchain with the corresponding recommendation for the purchase or sale, after checking all the conditions specified. Table. 1.

TABLE I. SMART CONTRACT

```
Class SmartContract
{
Public smartmeter.ID;
Public smartmeter.position;// Smart meter location
Public smartmeter.instance;// Household's current power requirements of the household
Public smartmeter.maxpower.value; // Household's maximum disposable power availability.
Public smartmeter.currentpower;// Current Power Flow Measurement.
Public smartmeter.public_key; // Smart Meter Public Key
Private smartmeter.private_key;// Smart Meter Private Key
 KeyPublic smartmeter.goal;// set function
Public smartmeter.tamper;//
}
function status() {
if smartmeter.instance < smartmeter.maxpower.value;
smartmeter.goal =='Buy';
else if smartmeter.instance > smartmeter.maxpower.value;
meter.intention=='Sell';
else if smartmeter.instance == smartmeter.tamper || meter.suspicious.usage ;
alert==" Possible invalid operation detected" ;
else smartmeter.instance= smartmeter.currentpower;
endif
}
function main() {
status();
message=encrypt(smartmeter.intention,alert, private_key);
}
```

Smart contracts are used as functions with built-in cryptographic keys. They are designed to represent, verify and monitor users on the blockchain network and ensure energy trading operations with minimal human intervention [12, 13]. We single out smart contracts into a separate block chain with the name "contract chain", Fig.1 (a). The chain of contracts is designed to inform the user of the energy consumption status, as well as to detect any malevolent attempts to interfere with the metering and control system by the user or by the network and declare such a contract void.

Implementation of the proposed model will ensure a sufficient level of security and increase the reliability of monitoring the network. This paper proposes an algorithm for the implementation of smart contracts.

Upon installation of a smart meter, each smart contract generates a public key and a private key, public key being sent to the network. The smart contract collects data from the user and from the network and constantly sends encrypted reports to the smart meter of the user. These reports are decrypted using the private key of the corresponding user, as described in the algorithm above. Based on these reports, the user or the smart meter takes appropriate actions.

IV. P2P MARKET MODEL

We suggest using a double-chain blockchain model. This will eliminate the problems arising from the management of smart contracts and transaction data in the same blocks of the records.

The proposed model consists of:

- "Contract chain" for managing and verifying smart contracts;
- "Ledger chain" for managing and verifying transactions with the energy available from the user and from the other users.

Records are distributed over the network, making it impossible to tamper with the data in the ledgers without being noticed. This is ensured by the basic blockchain functioning principles: consensus, decentralization [14, 15].

Trade Operations.

Each node n updates the current generated power P_{Gen}, the storage capacity S_{Bn} and the required power consumption P_{Cn} data once in every T seconds. The required power for the user is calculated in equation (1).

$$D_n = P_{gen} \cdot T - P_{Cn} \cdot T + S_{Bn}, \ \ D_n \leq P_{Lmax} \qquad (1),$$

Where

P_{Lmax} (in kW) stands for the maximum power transmittable by the participant's connection line.

When the value of D_n is positive, the smart meter gives a command to sell energy to the network for this particular time period. When the value of D_n is negative, the smart meter gives a command to buy energy from the network.

Based on the received data, the smart meter generates a request signed with its private key and transmits it to the network through a smart contract. This model is shown in Fig. 2. Upon verification in the Ledger Chain, the user is granted access to the P2P market.

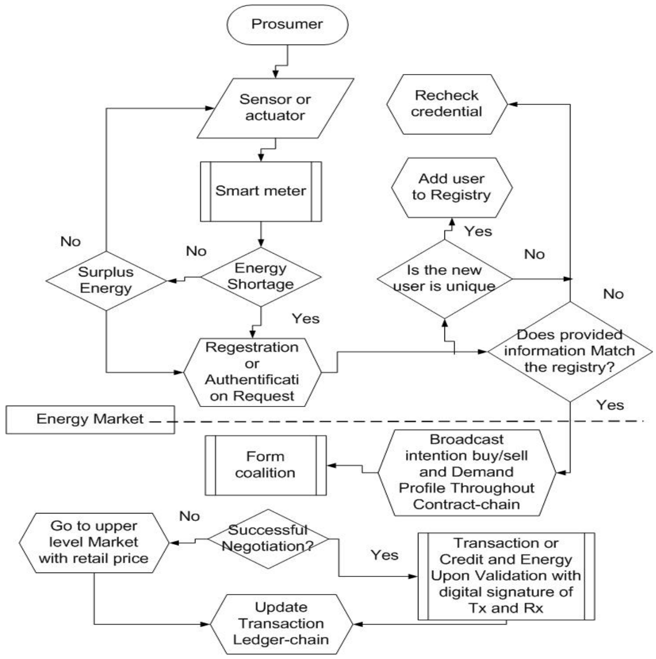

Fig. 2. P2P Market Operation Algorithm

Pooling.

Smart contracts provide for the purchase of electricity C_i^{buy} from a temporarily formed pool of households that have surplus power $S_i^{sell} \in N_{br\,(i)}$, thus available power $AP_i^{s\ sell}$ covering household demand over the time period t_{Lim}. Each seller's contract S_i^{sell} has its own prices according to (2).

$$Pr^{sell}_{Si\ sell} = generation\ cost + \alpha \cdot C_i^{buy} \qquad (2)$$

where α indicates the number of customers. As seen from (2), the price increases with the number of interested buyers in the pool.

For buyers, the estimated price is calculated using (3).

$$Pr^{sell}_{Si\ sell} = consumer\ price - \beta \cdot S^{sell}_{price} \qquad (3)$$

The variable β shows that the more sellers in the pool, the lower the price of energy. Equation (2, 3) balances the trading mechanism, effectively eliminating overpricing. Pools are formed as described in Table 2, lines (1-7).

FORMATION OF THE POOL AND INTERACTION THEREIN.

1 **for each** $S_i^{sell} \in N_{br\,(i)}$
2 **if** $AP_i^{s\ sell} \geq D_i^{buy}$
3 seller group[j] = S_i^{sell} ;
4 coalition[i] = *seller_team* $\cdot C_i^{buy}$;
5 **else** go to the higher level market.
6 **endif**
7 **endfor**
8 **for each** i in coalition
9 **if** $Pr^{buy}_{Si\ buy} \geq Pr^{sell}_{Si\ sell}$
10 buy energy and start a trading mechanism.
11 **else if** $Pr^{buy}_{Si\ buy} < Pr^{sell}_{Si\ sell}$
12 reject the offer or buy from the main network.

```
13    else offer a counter price Pr^cnt_i
14    When Pr^cnt_i < Pr^sell_Si sell < Pr^reail_i
15    end if
16    if Pr^cnt_i < generaton cost
17    reject the offer and look for another seller.
18    else
19    accept the offer and start the trading mechanism.
20    end if
21    end for
```

A. Consensus-building process

Buyers can either accept, decline or offer a counter price for the energy. After the conditions described in lines (9-15) of Table 2 are met, the buyer and the seller can negotiate and transfer energy and money between each other. A smart meter controls both incoming and outgoing flow of energy from the microgrid. If the negotiations were unsuccessful, participants go to the market of a higher level, i.e. consumer is offered conditions that are more favorable automatically. Each transaction is included in the Ledger chain and is synchronized throughout the P2P network.

B. Simulation results

The proposed blockchain mechanism of electric energy trading mechanism will provide for the following benefits:

- Cybersecurity. The key feature of the blockchain technology is ensuring data integrity, as well as detecting any unauthorized interference. Blockchain will become a unique tool to resist network attacks, for example, the input of false data in microgrid;
- Elimination of the monopoly on electricity production. The proposed trading model establishes a decentralized market where consumers trade energy among themselves without intermediaries;
- Transparency. The transaction ledger is stored and synchronized throughout the network. Each server node can verify any transaction through a consensus mechanism. In addition, all transactions are subject to verification, therefore, transparency will be ensured in the entire trading system, which will prevent any possible fraud attempts;
- Security. Smart contracts and transaction records are stored in immutable blocks that provide protection against energy theft and facilitate secure energy and money transactions.

V. Conclusion

This paper proposes a model of a P2P trading platform for selling electric energy directly between network participants without intermediaries. The implementation of this model will ensure security, transparency, and decentralization of data storage and data management. The proposed P2P market model constitutes an alternative to the traditional electricity market, eliminating the monopoly in the energy sector. Blockchain technology, which offers a serious level of information security and an effective data management mechanism, is ideally suited for the deployment of such a market model. This paper proposes the implementation of a double-chain blockchain model to avoid excessive data processing and offers algorithms for creating smart contracts and pools during transmission of electric energy. Smart contracts and "Smart meter" metering devices together will provide for the uninterrupted power supply and ensure automated control.

References

[1] Distributed generation in Russia: a competitor to large energetics or a way to lay hands on consumers' pockets? [Online]. Available:: https://www.eprussia.ru/epr/217/14807.htm [Accessed: 21-Feb-2020]

[2] X. Zhou and T. Guo, "An overview on microgrid technology," IEEE Conference Publications, Conference Proceedings, pp. 76–81. DOI: 10.1109/ICMA.2015.7237460

[3] Ali Dorri, Salil S. Kanhere, Raja Jurdak, and Praveen Gauravaram., "Blockchain for IoT Security and Privacy: The Case Study of a Smart Home," 2017, doi: DOI: 10.1109/PERCOMW.2017.7917634.

[4] G. C. Lazaroiu and M. Roscia, "Smart district through IoT and Blockchain," 2017, pp. 454–461, doi: 10.1109/ICRERA.2017.8191102.

[5] P. K. Sharma, S. Rathore, and J. H. Park, "DistArch-SCNet: Blockchain-Based Distributed Architecture with Li-Fi Communication for a Scalable Smart City Network," IEEE Consumer Electronics Magazine, 2018, doi: 10.1109/MCE.2018.2816745.

[6] E. Mengelkamp, J. Gärttner, K. Rock, S. Kessler, L. Orsini, and C. Weinhardt, "Designing microgrid energy markets," Applied Energy, Jun. 2017, doi: 10.1016/j.apenergy.2017.06.054.

[7] N. Liu et al., "Online Energy Sharing for Nanogrid Clusters: A Lyapunov Optimization Approach," IEEE Transactions on Smart Grid, vol. 14, Jul. 2017, doi: 10.1109/TSG.2017.2665634.

[8] Real-time multi-agent support for decentralized management of electric power," ResearchGate. [Online]. Available: https://www.researchgate.net/publication/4247646_Real-time_multi-agent_support_for_decentralized_management_of_electric_power. [Accessed: 21-Feb-2020]. DOI: 10.1109/ECRTS.2006.22

[9] Nakamoto, Satosh Bitcoin: A peer-to-peer electronic cash system 2008.

[10] R. Hanifatunnisa and B. Rahardjo, "Blockchain based e-voting recording system design," 2017, pp. 1–6, doi: 10.1109/TSSA.2017.8272896.

[11] M. R. Asghar, G. Dan, D. Miorandi, and I. Chlamtac, "Smart Meter Data Privacy: A Survey," IEEE Commun. Surv. Tutorials, vol. 19, no. 4, pp. 2820–2835, 2017, doi: 10.1109/COMST.2017.2720195.

[12] A. Kosba, A. Miller, E. Shi, Z. Wen, and C. Papamanthou, "Hawk: The Blockchain Model of Cryptography and Privacy-Preserving Smart Contracts," 2016, pp. 839–858, doi: 10.1109/SP.2016.55.

[13] 13. H. Watanabe, S. Fujimura, A. Nakadaira, Y. Miyazaki, A. Akutsu, and J. Kishigami, "Blockchain contract: Securing a blockchain applied to smart contracts," 2016, pp. 467–468, doi: 10.1109/ICCE.2016.7430693.

[14] R. Deng, G. Xiao, R. Lu, H. Liang, and A. V. Vasilakos, "False Data Injection on State Estimation in Power Systems—Attacks, Impacts, and Defense: A Survey," IEEE Trans. Ind. Inf., vol. 13, no. 2, pp. 411–423, Apr. 2017, doi: 10.1109/TII.2016.2614396.

[15] Generalized FDIA-Based Cyber Topology Attack with Application to the Australian Electricity Market Trading Mechanism , [Online]. Available: https://www.researchgate.net/publication/314270516_Generalized_FDIA-Based_Cyber_Topology_Attack_with_Application_to_the_Australian_Electricity_Market_Trading_Mechanism. [Accessed: 21-Feb-2020]. DOI: http10.1109/TSG.2017.2677911