2017 IEEE 23rd International Conference on Parallel and Distributed Systems

M2M Blockchain: The Case of Demand Side Management of Smart Grid

Xigao Wu
College of Information Engineering, Xiangtan University
Xiangtan, China
xigaowu@163.com

Bin Duan, Member, IEEE, Yinxin Yan,Ying Zhong
Collaborative Innovation Center of Wind Power Equipment and Energy Conversion
Xiangtan, China

***Abstract*—The purpose of this paper is to explore applications of blockchain technology related to demand side management of smart grid and to present an example that blockchain is used to facilitate machine-to-machine (M2M) interaction and frame an electricity market in the context of demand request. We use blockchain technology to record data derived from power flow calculation model and electricity price customization, and use smart contract to store transaction data and transfer assets automatically. Firstly, we establish a power flow calculation for microgrid operation system of 34 node master-slave control island, and the power flow is calculated and an optimal generator work adjustment is used. Then, according to the price customization, the participation mode of priced demand response is acquired. The presented scenario includes that a power management system and a generator which can actively adjust the power generation trading with each other over a blockchain. According to flow calculation and price customization, power management system generate smart contracts automatically. The final is that two sides complete the transaction and the load state of grid has been adjusted. This work contributes a proof-of-concept implementation of the scenario. This example verifies the feasibility of the method.**

Keywords*—blockchain technology; smart contract; smart grid; flow calculation; demand response; electricity market

I. INTRODUCTION

Smart grid is the direction and trend of power industry development. The smart grid utilizes advanced information and communication technology, computer technology, control technology and other advanced technologies to achieve the coordination of power generation, power grid operation, terminal electricity and electricity market, as well as the needs and functions of the various stakeholders, which improves the reliability, self-healing ability and stability of the system while improving the high efficiency operation of the various parts of the system, reducing the cost and environmental impact [1].

Generally, power quality management needs to master all the micro-grid power and load information, which will improve the overall cost of communication [2], as micro grid belongs to different operating entities, the sharing of power and load information will lead to serious privacy problem and leakage of commercial information, therefore, there are some problems in the application of centralized optimization scheduling. In the context of Internet technology, when there is a need for value exchange activities with unfamiliar opponents, how can we prevent ourselves from being maliciously deceived, confused, and thus make the wrong decision, and in the absence of a trusted central node and a trusted channel, how should the microgrid be distributed in the network reach a consensus.

The concept of machine-to-machine (M2M), information physical system (CPS) and Internet of Things (IoT) is introduced into Industry 4.0[3,4]. M2M communication technology involves the information exchange between the various industrial devices; CPS focuses on the integration and coordination between information resources and physical resources controlled by industrial processes, which establishing a virtual copy for entity and achieving the decentralized active decision-making; Internet of Things is a dynamic network which contains unique identity, attributes, and intelligent interfaces of both virtual and realistic individuals. The core problem that the blockchain solved is how to establish a "trust" ecosystem in individual information interaction that meets the needs of all activities, when faced the information is asymmetric and uncertain. That is, when any node in the network can not trust each other in communication, how to create a consensus base for secure information interaction without worrying about data tampering.

This paper presents to calculate the voltage of each node, the power of each branch and its sensitivity matrix by power flow. According to the limit value, the demand side as decision-making subject, application of blockchain technology to achieve microgrid collaborative optimization program with active demand response of supply and demand sides, which provides a guarantee for the security and stable operation of smart grid.

II. BLOCKCHAIN TECHNOLOGY

A. Blockchain Technology Principle

A blockchain is a distributed electronic database which can hold any information (such as records, events, transactions) and set rules for updating these messages [5]. Its blocks are growing and linked through a string of hash values to the front block (using the bitcoin as an example to visualize the link, as shown in Figure 1), The hash value is obtained from the cryptographic hash function (such as SHA-256 in the bitcoin) based on the content data of the block file. An ideal

978-1-5386-2129-5/17/31.00 ©2017 IEEE
DOI 10.1109/ICPADS.2017.00113

cryptographic hash function can easily generate a hash for any input, but it is difficult to use the hash value to reverse the input. In addition, if there is any change in the original data will lead to the corresponding change of hash value [6,7]. Finally, two different inputs correspond to the same hash value is not feasible. The use of cryptographic hash is to ensure that the previous block changed, and all subsequent blocks must also be changed [6,7]. According to a pre-established consensus mechanism (a set of global agreements that allow network connectivity [8]), distributed books are verified and maintained by all participants (nodes) on the network, so centralization is not necessary. Multiple (but not necessarily all) nodes hold a complete copy of the entire database.

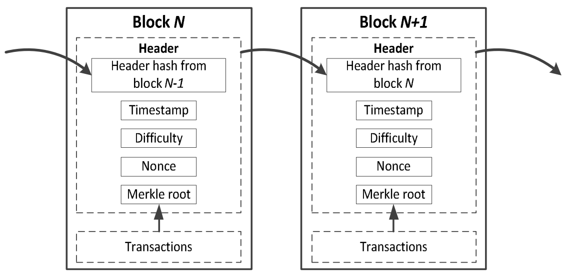

Fig. 1. Blocks linked in a chain, by reference to the previous block header hash.

Blockchain technology is relatively new, and many different structures and forms are being derived. In this paper, we use bitcoin as a case study, because blockchain technology has been used in it successfully. Bitcoin is a payment system based on no license (that is, anyone can read or write chains) blockchain maintained by a P2P network [9]. It is characterized by a proprietary currency (bitcoin), a consensus mechanism for workload verification, a timestamp of no greater than 1MB (depending on their size per transaction volume), and anonymity. Initially, the block records the bitcoin transaction record and some additional data. A transaction is the transfer of bitcoins from one wallet address (or multiple addresses) to another wallet address (or multiple addresses). Creating a transaction only requires the recipient's wallet. A purse is a public representation of the public key pair and the private key pair for storing and transmitting money. One or more such key pairs are generated for each participant, to make sure that trade in a safe and anonymous manner.The public key is used to verify the message (verification of the digital signature) issued by the holder of the private key and to encrypt the message to make sure only the key holder can decrypt it.

B. Record Storage and Contract Execution

From the financial span to the power industry, the most promising applications of blockchain technology are record storage and contract execution. In the context of Industry 4.0, this application can promote records and data sharing, and promote M2M transactions.

The record added to the blockchain will be stored permanently, each transaction record in the blockchain is bound with trader information, and the complete delivery path of the transaction target can be fully recorded, traced, and can not be destroyed or tampered with, it facilitates the supervision of the transaction. Through blockchain smart contracts that is a series of written software code could be set up [10,11]. In the intelligent contract, the obligations and the conditions of contract execution of each party needs to be specified in the contract. The blockchain system can automatically judge the contract execution condition. When all the decision conditions are satisfied, the blockchain system will distraint the contract terms automatically. On the one hand, it improves the efficiency of contract execution, more importantly, the implementation of the contract is effectively guaranteed without the strong supervision of the third parties.

III. M2M Power Demand Response Management Driven by Blockchain Technology

This section proposes a requirement response management system [12] which is based on micro grid system and Internet of things background, and applies blockchain technology to support M2M information interaction.

A. Smart Grid Example Model

In this paper, take the power flow calculation system of the microgrid with 34 nodes as a example. The topology of the circuit is shown in Figure 2.

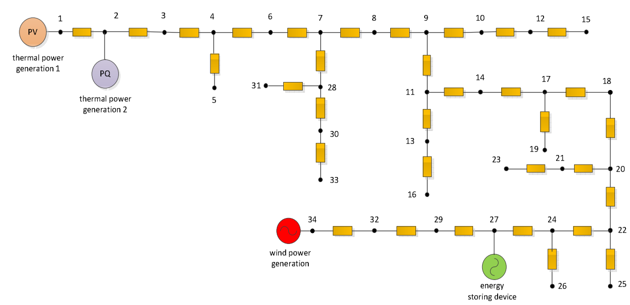

Fig. 2. Power flow calculation system for microgrid operation system of 34 node master-slave control island.

The node 1 adopts constant voltage constant frequency control as the PV node, and as the balance node in the system, and the given voltage amplitude is 1.030pu.The node 2 and 34 use constant power control as the PQ node, injection power of node 2 is 0.1899+j0.0876, photovoltaic cells are added to the nodes 34, the analysis of PV output predicts that the PV cell will generate 0.5183 of the power at the next time, and read the data into the power quality center for power flow calculation. The reference phase angle of the microgrid example system with random power flow is 0 degrees, the steady-state frequency range of the normal operation is [0.994, 1.006]pu, the node voltage amplitude range is [0.9400,1.0600]pu, and the active power limit of the line is 0.53pu. Based on the results of the power flow calculation（shown in Appendix II）, the power of lines 11-14, 14-17, and 24-27 are exceeded, as shown in TABLE I. Adjusting the power of the line to the normal range by adjusting the power output of the generator. The negative value of the sensitivity corresponds to the increase of the active power and the positive value is the decrease of the active power.

TABLE I. OUT-OF-LIMIT LINE

Line	Pmean/pu	Whether Out-of-limit	Active Power Deviation
11-14	-0.7643	yes	0.0143
14-17	-0.7657	yes	0.0157
24-27	-0.7712	yes	0.0212

Increase the active power output of generator 2 by 0.026, reduce the active power output of generator 27 and 34 by 0.0026, and the power flow results are shown in Appendix III.

B. Design and Implementation of Power Demand Response Management

Assume that each node have smart terminals, which can obtain the electricity price data of the node in real time (the power flow calculation takes 30 minutes as a cycle, the renewal period of the electricity price is 30 minutes). The generator's revenue in this period is formulated by the electric energy management system according to the formula of power generation income and power flow calculation results.

This application scenario includes a smart grid power quality center, and a generator that actively adjusts the power generation in node 27, and they trade on the blockchain. According to the power flow calculation, the power quality center obtains the optimal compensation active power, as is shown in Appendix I. We can get the transaction information in the data stream that is used to release the transaction information that pecuniary (USD) exchange for the adjustment of electrical energy (kWh) , where the data flow act as the bulletin board. The generator on the node read the transaction information, and analyzes the power usage status as well as the power supply compensation price provided by the power quality center to determine whether the price DR interaction is needed for the power demand of the grid. When the transaction is accepted, the transaction is carried out in the form of atomic exchange (i.e., the two transactions are simultaneous and must succeed or fail together). This scenario is shown in Fig. 3. We assume that the power flow calculation device and the price customization system of the microgrid can join in the blockchain and provide the relevant sensor data and calculation data.

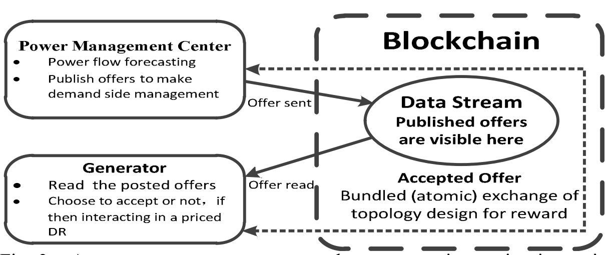

Fig. 3. A power management center and a generator interacting in a priced DR over a blockchain.

This example is implemented by 2 virtual machines running Fedora 24, a blockchain (named BEG) is built with MultiChain [13], and a microgrid model is built with MATLAB. The virtual machine runs Fedora 24, which represents the power management center and generator node on blockchain BEG, and receives data from the power grid model. Fig. 4 is part of the information that the Fedora terminal connects to the BEG.

C. Simulation Results

This section presents the control instructions and running results on the DS blockchain (see Figure 5-Figure 7). Although the process in the example can complete the automated transaction process in Python, it is the most convenient way to obtain the above image by manual operation.


```
{"method":"getinfo","params":[],"id":1,"chain_name":"BEG"}

{
    "version" : "1.0 alpha 25",
    "protocolversion" : 10006,
    "chainname" : "BEG",
    "description" : "Multichain BEG",
    "protocol" : "multichain",
    "port" : 22788
    "setupblocks" : 20,
    "nodeaddress" : BEG@172.16.123.89:22788
    "burnaddress" : "1XXXXXXXvnXXXXXXDAXXXXXX7AXXXXXXxN5pGX",
    "incomingpaused" : false,
    "walletversion" : 60000,
    "balance" : 0.00000000
    "walletdbversion" : 2,
    "reindex" : false,
    "blocks" : 535,
    "timeoffset" : 0,
    "connections" : 0,
    "proxy" : "",
    "difficulty" : 0.00000000,
    "testnet" : false,
    "keypoololdest" : 1568514963,
    "keypoolsize" : 2,
    "paytxfee" : 0.00000000,
    "relayfee" : 0.00000000,
    "errors" : ""
}
```


Fig. 4. Fedora terminal connected to blockchain BEG and its general information.


```
BEG: issuemorefrom 1WtUTPfU4KvgHwu4sLjeEMReCfWKqZ6D2QAW 1PiVoS5hSMmoFpxyf1Er9TzcJTj2Tx2bs8 'USD' 0.25266763

664ef8c5d2e3f7cbd66b3f60b8a4a90dbe23a9b9ed2c3eb28b9e64197896fbc0

BEG: preparelockunspentfrom 1PiVoS5hSMmoFpxyf1Er9TzcJTj2Tx2bs8 '{"USD":0.25266763}'

{
    "txid" : "cca64c877e78ab62c778782148adcf221c6dde81a498709b0bff1ae75b94d216",
    "vout" : 0
}

BEG: createrawexchange cca64c877e78ab62c778782148adcf221c6dde81a498709b0bff1ae75b94d216 0 '{"KWh":2.3}'

51c1ef59c13a4e6a9adf1e7ba95dd57a90916d7511f2068e35b6c4788f63db31ca1e093cd25a490d2999345159c5241ec7c86c9efd00283d
5d3c2bf0361f8288


BEG:  publish 'elec-market-open' 'decreasing_load_2.3_kWh' 51c1ef59c13a4e6a9adf1e7ba95dd57a90916d7511f2068e35b6c
4788f63db31ca1e093cd25a490d2999345159c5241ec7c86c9efd00283d5d3c2bf0361f8288

b8e8ca45daf289d186ce985790d35db078d648a5a7c6fbbe27377f42bcdea6ff
```


Fig. 5. Preparing and publishing a offer from power management center.


```
BEG: liststreampublisheritems elec-market-open 1PiVoS5hSMmoFpxyf1Er9TzcJTj2Tx2bs8 false 1
[
    {
        "publishers" : [
            "1PiVoS5hSMmoFpxyf1Er9TzcJTj2Tx2bs8"
        ],
        "key" : "decreasing load power 2.3 kWh" ,
        "data" :  "51c1ef59c13a4e6a9adf1e7ba95dd57a90916d7511f2068e35b6c4788f63db31ca1e093cd25a490d2999345159c5241
        ec7c86c9efd00283d5d3c2bf0361f8288",
        "confirmations" : 1,
        "blocktime" : 14851392022,
        "txid" : "b8e8ca45daf289d186ce985790d35db078d648a5a7c6fbbe27377f42bcdea6ff"
    }
]

BEG: decoderawexchange  51c1ef59c13a4e6a9adf1e7ba95dd57a90916d7511f2068e35b6c4788f63db31ca1e093cd25a490d2999345159
c5241ec7c86c9efd00283d5d3c2bf0361f8288

{
    "offer" : {
        "amount" : 0.00000000,
        "assets" : [
            {
                "name" : "USD",
                "assetref" : "74-266-1006",
                "qty" : 0.25266763
            }
    }
},
    "ask" : {
        "amount" : 0.00000000,
        "assets" : [
            {
                "name" : "kWh",
                "assetref" : "75-265-11743",
                "qty" : 2.30000000
            }
        ]
    },
    "requiredfee" : 0.00000000,
    "candisable" : false,
    "cancomplete" : true,
    "complete" : false
}
```


Fig. 6. Finding and decoding a offer from power management center.

Fig. 7. Adding a matching transaction to the offer, broadcasting the accepted purchase offer to the chain and confirming that the offer has been validated within the blockchain.

Typical trading processes are as follows:

- The power management system node prepares and publishes a agreement that money is exchanged for a certain amount of power adjustment, as shown in Figure 5. The preparation is to lock in the preset amount of money in the wallet of the power management system and encode the details of the agreement.
- The relevant generator finds the protocol and decodes its contents (Figure 6).
- According to the amount of allowance provided by the power management system,decide whether to accept the agreement.
- Get ready for a deal, the relevant lines shall be ready for modulation to match the agreement provided by the power management system, and attach the adjustment details. Then, the transaction information is encoded and uploaded to the blockchain.
- After the network communication and microgrid verification, it is recorded in a specific area of the blockchain. And wait for the consensus time of the round, thus triggering a consensus deal with the contract.
- Finally, verify the validity of the transaction in the blockchain (Figure 7).

IV. CONCLUSION

In the smart grid environment, a large number of energy production consumer’s access will spawn a new business model, P2P bilateral trading of energy come into being. This paper presents a method to manage the demand and transaction of grid by blockchain, decentralized power market framework is used, blockchain technology and smart contract are used to realize the independent maintenance and management of transaction information as well as the automatic transfer of funds in the whole network node.

In combination with the application of each blockchain, a centralized energy trading and supply system will be realized in the future. Electrical energy generated in a distributed generation device will transmitted to the end user via a smaller network. Smart meter will measure the amount of energy production and consumption, and in the case of ensuring the overall power quality of the grid, the data collected by the intelligent meter can be used for demand side management to ensure the quality of the grid power. While the payment of electricity trade and encrypted money will be controlled by the smart contract and executed through the blockchain.

On the question of selecting record node in blockchain, this paper only uses MultiChain to build a private blockchain to simulate. The number of record nodes in the blockchain has a greater impact on the efficiency of storage and communication, there will be more in-depth study of this area in the future, and thinking about the establishment of a more reasonable blockchain structure.

Blockchain technology has the potential to carry out industrial revolution by promoting industrial transformation and operation. In addition, there is an important potential for many undeveloped research areas(such as latency, throughput, size and bandwidth, fork, side chain, multi-chain and usability from the developer's perspective) and applications (smart contracts, licensing, , Intelligent property) to further innovate.

REFERENCES

[1] PENG Xiaosheng, DENG Diyuan, CHENG Shijie, WEN Jinyu, LI Zhaohui, NIU Lin. Key Technologies of Electric Power Big Data and Its Application Prospects in Smart Grid[J]. Proceedings of the CSEE. 2015, 35(3):503-511.

[2] CAO Junwei, WAN Yuxin, TU Guoyu, ZHANG Shuqing, XIA, Aixuan, LIU Xiaofei, CHEN Zhen, LU Chao. Information System Architecture for Smart Grids[J]. CHINESE JOURNAL OF COMPUTERS. 2013, 36(1):143-167.

[3] ZHANG Xiaoping, LI Jianing, FU Hao. Global Energy Interconnection Dialogue Industry 4.0[J]. Power System Technology. 2016, 40(6):1607-1611.

[4] Kraft M, Mosbach S. The future of computational modelling in reaction engineering. Philos Trans Roy Soc Lond A: Math Phys Eng Sci 2010; 368:3633–44.

[5] Condos J, Sorrell WH, Donegan SL. Blockchain technology: opportunities and risks. Technical report, State of Vermont, USA; 2016.

[6] Rogaway P, Shrimpton T. Cryptographic hash-function basics: definitions, implications, and separations for preimage resistance, second-preimage resistance, and collision resistance. Berlin, Heidelberg: Springer; 2004.

[7] Lewis A. A gentle introduction to blockchain technology; 2015.

[8] Buterin V. Consensus mechanisms used in blockchain; 2014.

[9] Antonopoulos A M. Mastering Bitcoin: Unlocking Digital Crypto-Currencies[M]. O'Reilly Media, Inc. 2014.

[10] Watanabe H, Fujimura S, Nakadaira A, et al. Blockchain contract: A complete consensus using blockchain[C]// Consumer Electronics. IEEE, 2016:577-578.

[11] Cardeira H. Smart contracts and their applications to the construction industry. In: New perspectives in construction law conference.

[12] TIAN Shiming, WANG Beibel, ZHANG Jing. Key Technologies for Demand Response in Smart Grid[J]. Proceedings of the CSEE. 2014, 34(22):3576-3589.

[13] Greenspan G. MultiChain private blockchain. Technical report, MultiChain; 2015.