APPLICATION OF BLOCKCHAIN SOLUTION FOR RENEWABLE ENERGY DISTRIBUTION

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I. Introduction

Sustainability and digital transformation are increasingly ranking higher on the global agenda. The transition to more renewable energy sources as one of the focus of sustainability means that energy production is more weather-dependent (Bremen 2010). RES produced 33 per cent of UK-generated electricity in 2018; a significant growth since 2000 when renewable energy production was just 2.6 per cent. (DUKES 2019). RES is unpredictable and intermittent. Hence the need for short-term and long-term demand-supply alternatives, innovative energy storing solutions, balanced energy consumption and distribution (Eid et al. 2016).

Global adoption of RES is envisaged to pose different challenges. Data sharing and advanced communication between various fragments of power network are vital, making central management and operation increasingly difficult. Therefore, there is a need for the revamp of local distribution management and control techniques required for advance data exchange in various parts of power network (Ahsan and Bais 2018).

Hence, blockchain, whose intrinsic attribute is the elimination of central control and allowing distributed transaction has emerged as a proposed riposte.

The objective of this paper is to propose a solution to the outlined problem in the energy sector founded on a conceptualised blockchain solution.

The subsequent part of the paper is as follows:

Section II - delivers background and technical outline of blockchain technology; highlight core concepts such as encryption, smart contracts and consensus mechanism.

Section III - gives a brief introduction to RES and outlines the proposed application of blockchain solution to states problem space.

Section IV – discusses the proposed blockchain solution for microgrid, justifying the highlighted approaches.

Section V - concludes this paper and highlight future work.

II. Blockchain Background

Blockchain dates back to a white paper written by Satoshi Nakamoto (Nakamoto 2008). The article launched a peer-to-peer form of electronic currency called Bitcoin. This currency allows direct digital transactions between parties without the need for centralised financial intermediaries. As part of the deployment of Bitcoin, the author invented a database that he dubbed 'a chain of blocks' which was later called a blockchain.

Blockchain provides a decentralised digital transaction database that is managed and updated by nodes (a network of computers) that validate the transactions for approval, before adding to the ledger (Morkunas et al. 2019). Thereby, trading parties share permanent peer-to-peer (P2P) ownership of digitally represented assets without the use of an intermediary or central authority with the automated execution of 'smart contracts' in peer-to-peer networks. Blockchain transactions are cryptographically linked; Thus, manipulations of historical transactions within a single node result in an invalid state which makes the system resilient and secure (Christidis and Devetsikiotis 2016).

Core functionalities of blockchain can be said - to provide authenticated, secure, immutable transactions (database updates), which are constant nodes within a universal network (Glaser 2017).

How blockchain works

Distributed nodes (physical or virtual machine) are connected by a P2P network that has its layer of protocol messages to discover and interacts with other nodes. These nodes can detect each other through their IP address, while users use public keys for referencing. Private keys are used by users to authorise transactions cryptographically. The public-key address represents users. This allows them to log in from any other node. Every node maintains a database of all valid transactions transmitted between network nodes. Transactions are divided into blocks, and each block corresponds to the previous block (Glaser 2017).

Hash Function

The hash functions and public-key cryptography are key components that ensure enhanced security in blockchain technology. A hash function is a mathematical process that operates on any size of data to produce a data of a fixed size called a hash. A hash's value is one dimensional, thereby making it impossible to reconstruct the original input data from the hash output by itself. Blockchain hashes are used as block identifiers as well as transaction and addresses. The hashing algorithm presently used for blockchain is the Secure Hashing Algorithm (SHA)- 256, which generates a nearly unique fixed-size 256-bit hash. Another advantage of hash is that it keeps the database small (Puthal et al. 2018).

Public Key Infrastructure (PKI)

Blockchains use public-key cryptography technique in which the user holds two cryptographic keys; a proprietary (private) secret key and a public key which is could be shared with all network users. The keys are linked such that encrypted information by a part is decrypted by its equivalent only, ensuring authentication and authorisation. For instance, if a sender uses the public key of the receiver to send, the receiver uses their private key to access (Andoni et al. 2019).

Smart Contracts

Smart contracts are self-executing scripts that live on the blockchain, allowing multi-step process automation. Smart contract is activated when a transaction is presented to it, which it then automatically implement the specified parameters or action on each node in the network. (Tushar et al. 2020).

Today, established publicly available instances of blockchain technology includes Bitcoin and Ethereum.

Types of blockchain

- Private: Private or closed blockchain allows only preapproved users to access and transact. Identities of all users are known before the transaction.
- Public: In a public or open blockchain, anyone can participate and transact with each other without knowing the identity of each party before the transaction. Also, all transactions are available for anyone to view.
- Consortium: This is a variant of private blockchain which runs under the leadership of a group whereby shared records of transactions are accessible to preapproved participants.
- Hybrid: Hybrid blockchain has the combined elements of both private and public blockchain.

Consensus Mechanism

The methodology used to achieve consensus in blockchain networks primarily defines crucial performance features which include scalability, speed of transactions, resource consumption, i.e. electricity. A block can be created or proposed by a node on the system and encrypts transactions followed by the approval of the network participants-a process known as reaching a consensus. After a block has been accepted, it becomes part of the blockchain (Andoni et al. 2019).

The following discusses types of consensus algorithm.

Proof of Work (PoW)

PoW is the original consensus algorithm in a blockchain network, i.e., bitcoin, whereby miners compete to solve a mathematical puzzle for a transaction to be validated, adding a new block to the chain, and the successful miner is rewarded. The 'work' requires a large amount of processing power to complete. Accurate work and speed of blockchain system depend on it. Also, the PoW limits denial-of-service attack and other service abuses such as spam on internet resources in a network (Puthal et al. 2018).

Proof of Stake (PoS)

While PoW rewards its miner for solving complex mathematical puzzles, PoS substitutes computational work with an arbitrary selection process whereby chances of mining successfully are proportional to validators' assets. That is, the possibility of producing a block is solely dependent on what participating nodes have invested in the network, e.g. the ownership of coins. PoS is deemed to hypothetically lead to faster blockchains with reduced electricity consumption (Andoni et al. 2019).

Proof of Authority (PoAu)

In the PoAu system, network members place their trust in an authorised node(s) for block generation, which means that a block is approved if a greater number of the authorised nodes sign the block. For instance, a participant with a special key may generate all of the blocks. PoAu can basically a revamped PoS algorithm in which the 'stake' of the miners is their identity (Andoni et al. 2019).

Other consensus algorithms include Poof of Elapsed Time (PoET) (Jdebunt 2017), Proof of Activity (PoAc) (Castor 2017), Proof of Capacity (PoC) (Pylon. 2018) etc.

Advantages of blockchain

- Privacy (Anonymity): Users public key hash value functions as the ID indicator. The hash value has no association with the user's real identity, safeguarding the user's personal privacy.
- Tamper-proof: Whenever a record/transaction is created in the blockchain, a new timestamp will be registered simultaneously; any alteration of the data generated before that timestamp is not permitted.
- Immutable: With consensus algorithm used to determine the record of new transactions, adversaries need to control more than half the network nodes (which is nearly impossible), or possess a greater computational capacity, to manipulate data in data recording processes (also proven impossible till date).
- Disaster Recovery: the replication of data on all nodes in a blockchain network ensures that arbitrary attack on one or more nodes in the network will not cause damage to the whole system.
- Insusceptible to malicious attacks: It solves the problem of single-point failure present in a centralised system
- Transparency: All nodes in the network has access to authentication of a historic record of the device transactions, providing a high level of transparency.

Despite the unique features of blockchain technology, it's essential to note that the technology still has its share of limitations. Few of the technological challenges include scalability, transaction latency, distribution of computing resources, consensus building.

Other limitations of blockchain include;

- Lack of knowledge/awareness about the technology
- Lack of specialised skill
- High energy consumption: The process of the mining as a means of validation of transaction consumes lots of power.
- Integration complexity with other monolithic applications

III. Renewable Energy Sources

RESs are resources that can be repeatedly used to generate energy, e.g. wind, solar, biomass and geothermal energy (Rathore and Panwar 2007). The efficient use of RES minimises environmental effects, creates minimal secondary waste, thereby, offering an excellent opportunity to reduce greenhouse gas emissions and mitigate global warming (Panwar et al. 2011).

According to (Goldemberg et al. 2000) RES supply, 14 per cent of the total world energy demand and the share is envisaged to increase exponentially between 30-80 per cent in 2100 (Fridleifsson 2001). The global renewable energy scenario by 2040 in Figure 2 below is presented to be at 47.7 per cent (Kralova and Sjoblom 2010). However, the heterogeneous energy generation gives rise to high volatility, causes fluctuating availability, rising instability, making energy delivery more complex. Hence, deliveries and costs are often subject to high levels of uncertainty.

The production of RES in a decentralised manner has been researched as one of the possibilities for meeting small-scale energy needs in a safe, efficient and environmentally friendly way (Reddy and Subramanian 1979). Implementation of blockchain-based energy market solution is thus, proposed to increase transparency, reduce energy waste and allow consumers to maximise home use and monitor consumption.

	2001	2010	2020	2030	2040
Total consumption (million tons oil equivalent)	10,038	10,549	11,425	12,352	13,310
Biomass	1080	1313	1791	2483	3271
Large hydro	22.7	266	309	341	358
Geothermal	43.2	86	186	333	493
Small hydro	9.5	19	49	106	189
Wind	4.7	44	266	542	688
Solar thermal	4.1	15	66	244	480
Photovoltaic	0.1	2	24	221	784
Solar thermal electricity	0.1	0.4	3	16	68
Marine (tidal/wave/ocean)	0.05	0.1	0.4	3	20
Total RES	1,365.5	1,745.5	2,964.4	4289	6351
Renewable energy source contribution (%)	13.6	16.6	23.6	34.7	47.7

Figure 1: Global renewable energy scenerio by 2040 (Kralova and Sjoblom 2010)

Microgrid energy market

Microgrid energy markets enable energy providers to distribute energy in a geographical location. Microgrid facilitates efficient, sustainable and local energy generation and consumption. Based on the current distribution state, there is a need for advanced, stable and smart information systems, which are critical to their effective operation (Jimeno et al. 2011). This is where a decentralised distribution system lends itself to the industry.

The deployment of blockchain-based microgrid energy systems is one that has not been fully exploited by scholars, with particular emphasis on electricity distribution, monitoring and financial payments.

Why decentralised microgrid?

- To distribute energy efficiently without the need for an intermediary
- To securely record and store transactions
- To safely store ownership record, i.e., energy certification
- To provide end-to-end transparency for all parties
- To avoid a single point of failure

Proposed Implementation

A hybrid blockchain is proposed for the implementation of this solution using proof-of-stake as the consensus mechanism. The combination of both public and private blockchain attribute is needed to grant permission to the various users/stakeholders on the network based on their roles and contribution to the system. For instance, a consumer's permission will distinctively be different from that of the producer or energy regulating body. The categories of stakeholders highlighted are the producers, who send their generated energy to the microgrid, the consumers who make use of the energy, the regulating body that monitors the distribution and pricing of energy sale and the government who oversees licensing.

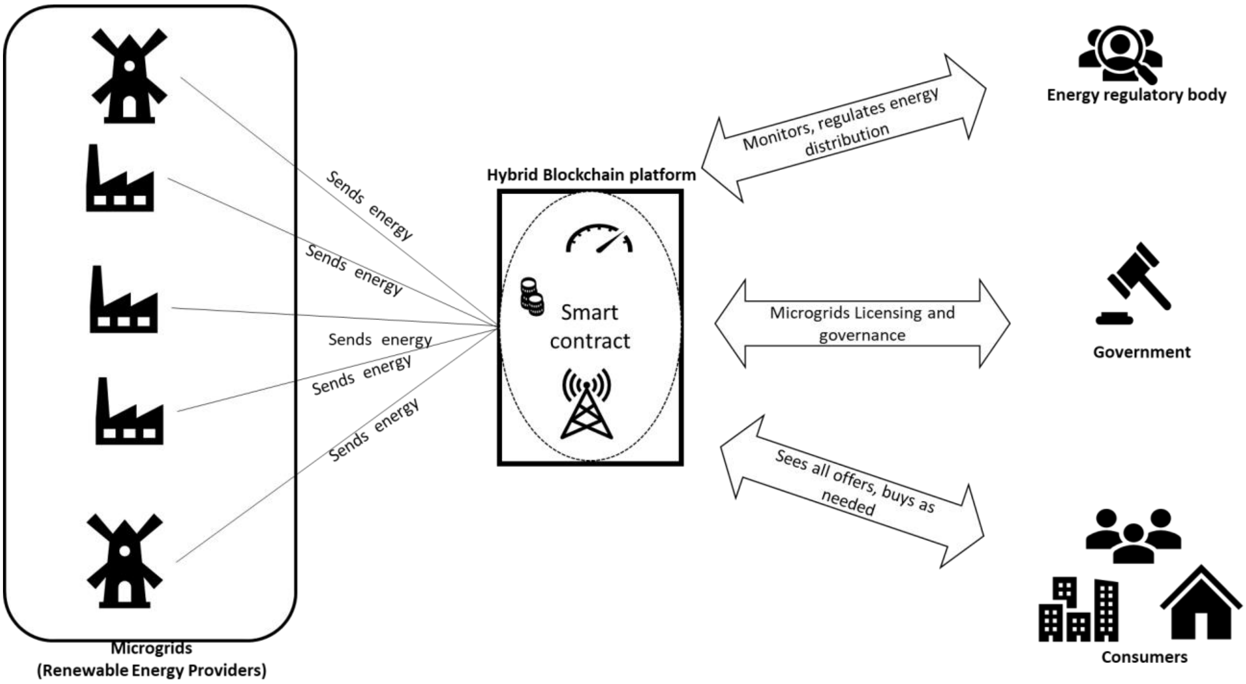

Figure 2: Proposed RES distribution rich picture

Sample User Stories for Each Actor

1. As an energy producer, I want to be able to supply my energy directly via a decentralised distribution platform to the consumers, so that I don't need an intermediary.

   Acceptance Criteria: - Energy is successfully supplied to consumers directly via a decentralised platform.

2. As an energy consumer, I want to be able to buy my energy directly from the producer in a transparent manner so that there is no additional hidden or intermediary cost.

   Acceptance Criteria: - Energy is successfully bought from producers via a decentralised platform

3. As a Government agency, I want to ensure that energy producers conform with governmental guidelines so that consumers only purchase energy from a licensed producer

Acceptance Criteria: - Only licensed producers can supply to consumers on the blockchain platform

4. As an energy regulatory body, I want to be able to monitor and regulate energy distribution and ensure pricing fairness.

   Acceptance Criteria: - Energy and pricing are independently monitored on the blockchain platform.

IV. Discussion

Microgrids offer more comprehensive tracking of usage and distribution of electricity as well as other vital data that could help drive awareness and speed up the maturity of the RES sector. The use of hybrid blockchain creates a balance between publicly available records and privately managed data. The different levels of permission that will be implemented thereby guarantee the availability of necessary data to each group based on their roles, to make informed decisions. This combination of public and private blockchain attributes also negates the security and privacy problems surrounding customer data in a centralised system.

Proof-of-stake is proposed as the consensus mechanism as opposed to proof-of-work mainly because of the energy consumption disparity, i.e., PoS does not require significant energy consumption to validate or create new blocks as opposed to PoW. Hence, energy efficiency makes it a greener option. Also, PoS prevents the theoretical possibility of 51 per cent attack because attackers will have to put all their assets on the line to attempt such an attack. Furthermore, PoS is preferred to Proof-of-authority to avoid designating power to validate transactions to a particular actor(s) in the blockchain network. The PoS mechanism is envisaged to promote trust amongst participants of the network because as earlier mentioned, all stakes (which can be defined in various ways) is put on the line for transaction validation.

V. Conclusion and Further works

To recap, we discussed the definition and history of blockchain technology, including trends and shortfalls in the current energy ecosystem, highlighted major stakeholders and processes.

To simplify the paper and the proposed decentralised solution in the RES sector, we added sample user stories of the key actors, stating an advantage of the platform for each group.

Further works will delve deeper into the roles of each of the actor as mentioned earlier, the permissions, hybrid setups, consensus mechanism, smart contract applications and the overall architecture of the platform.

We will also be discussing other technical aspects concerning further benefits and a prototype in subsequent papers.

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