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Using BlockChain technology in Smart Grids

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***Abstract*—Smart grids with information flow based on BlockChain would enable tracking the transfer of energy in a transparent and secure manner. Using BlockChain for energy grids would allow solving problems that plague the traditional system. In this paper we analyse what role BlockChain would play in facilitating the usage of Smart Grids along with its ability to enable a Peer to Peer (P2P) energy transfer platform. Pilot projects using BlockChain for Smart Grids used in conjunction with smart meters have shown significant reduction in cost to the end user. In this paper we further discuss its implementation and key stakeholders involved. This paper does not delve into the security features of BlockChain but rather looks at it as a Black Box and the benefits it provides to the user.**

***Index Terms*—BlockChain, P2P, Smart Grid**

I. Introduction

BlockChain has attracted the attention of major industries such as Banking, Real Estate and HealthCare. It has also gained significant ground in the Energy Sector. However, any large-scale implementation of the same is yet to be established. There have been heavy investments in projects of this field but they still are in their pilot phase. With the advent of BlockChain technology, there have been significant strides made in its implementation. Use of Smart meters in confluence with BlockChain technology can enable an efficient and transparent user experience with reduced costs. The famous Duck Curve problem can be solved using BlockChain enabled P2P energy transfers. Thus, the unmatched potential that BlockChain technology possess in the Energy sector is understated and unexplored. This paper tries to expand on one of the potential implementations of a BlockChain smart contract to help the energy sector.

The current mass production systems are based on the assumption that accessing information regarding the origin, producer, allocator and consumption is expensive and difficult to manage. However, with the advent of decentralized solutions such as BlockChain and the wider array of sensors available to collect data required, this problem seems to be evanescent. The potential use of BlockChain in such an environment will lead the information being accessible to authorised users, to whom the data collected may be more important than those who collected it. This would also ensure that the data collected could not be tampered with as a BlockChain is immutable.

There are also a number of enabling technologies that supplant this implementation.

1) *Microgrids*: Commercial or residential buildings with solar panels and wind generators would enable them to harvest energy and trade it with the party that needs it giving rise to a P2P trading platform. Thus, enabling a lesser dependency on the grid and a tightly knit community.
2) *Vehicle to Grid Networks*: The batteries in the electric vehicles can be used as an energy storage device and utilized by the grid to stabilize itself in cases of energy demand fluctuations or rapid changes. They can work in conjunction with local aggregators that can allow them to sell energy to their neighbours in a P2P manner.

There are certain hurdles that draw scepticism towards P2P energy trading platforms. It is considered insecure for nodes to carry out large-scale decentralised energy trading in a non-trusted and non-transparent environment. Nodes with surplus energy not willing to participate due to privacy concerns. Thus cause an unbalanced supply and demand.

However, these problems can be solved using BlockChain. BlockChain is a decentralised, open and distributed ledger that records transactions in a verifiable and immutable way. This also is the technology behind Bitcoin, a popular cryptocurrency. The very same platform can be used to develop an industry wide energy trading cryptocurrency that is designed to pertain to the needs of the energy sector. BlockChain can cause a microgrid revolution. BlockChain is a technology protocol that enables many use cases where transparency, tracking and certification are necessary. Analysing where the energy came from can have significant impact on the end user. Todays energy market makes this almost impossible to find out the ratios of renewable and non-renewable energy that the end user receives. Energy certification systems used currently make it a difficult and discouraging process.

Presently renewable energy producers track the amount of energy they produce and calculate them manually. This is then put in a spreadsheet which is sent to a certified agency that can take weeks to certify the record. When and if the agency finds it satisfactory, it issues a green certificate which can be sold on the open market as a commodity. Institutes take pride in claiming that their source of energy is renewable. However, current architecture of the grid makes it painfully difficult and convoluted for a company to keep track of it. This makes the process clunky. This entire process can be made simpler and streamlined using BlockChain. Instead of making spreadsheets and sending it to a certified agency, the energy producers and directly record their data on to the BlockChain using electricity meters and make it available to the agency instantaneously. Instead of waiting weeks, the energy company can immediately sell its green energy certificates. This could help start-ups to obtain consistent cash flows. The use of BlockChain will thus not only enable the energy sector to experience a paradigm shift to decentralization, but also result in unprecedented economic benefits for the industry to reap.

II. Decentralization of Energy

Millions of power stations face the problem of centralization. The fall of a behemoth power source can result in loss of life during times of calamities. Instead of a homogenous system that can rise and fall all at an instant, a whole bunch of islands can be used that can be independent or depend on each other according to the circumstances. Energy can be provided whenever and wherever needed. Energy can be transacted efficiently using P2P networks. BlockChain here would act like an automated accounting technology. It could capacitate the advent of a shared economy for energy. Similar to how Uber and Airbnb disrupted their respective industries, the energy sector too can benefit through similar implementations using microgrids. Allowing immediate nodes in the microgrid to use the surplus energy produced by prosumer nodes in the grid, will enable lesser dependency on conventional sources and give rise to a tightly knit community. This will also promote renewable energy production methods used by these nodes and the economic benefits they receive will encourage them to keep on doing so. During times of distress, these prosumer nodes in conjunction with the electric vehicle battery packs will allow for the transmission of energy to the areas of higher priority. Health Care institutions and Military installations will benefit off this system, while the BlockChain will ensure that the nodes enabling this transfer are compensated fairly. BlockChain will also bring security to the sector. Nations have faced cyberattacks on their energy grids that have proven devastating.The malicious intents of these hackers can even cause fatal results. However, a decentralized system ensures that all eggs aren't in one basket. It will also enable a cryptographically secure medium for all energy exchanges. Thus, allow the community to support critical infrastructure at times of natural calamity and unfortunate incidents.

III. Smart Grid Architecture

Entities involved right from the production of energy to the consumption will be a part of the architecture. Each party in question will have their own BlockChain node, with its own unique properties. Along with that, they will have a unique address using which they can be identified. This would not only equip the end user to analyse where their energy has come from, but access the party in question and the information about it that he is authorized to. The key stakeholders include Producers, Providers and Consumers.

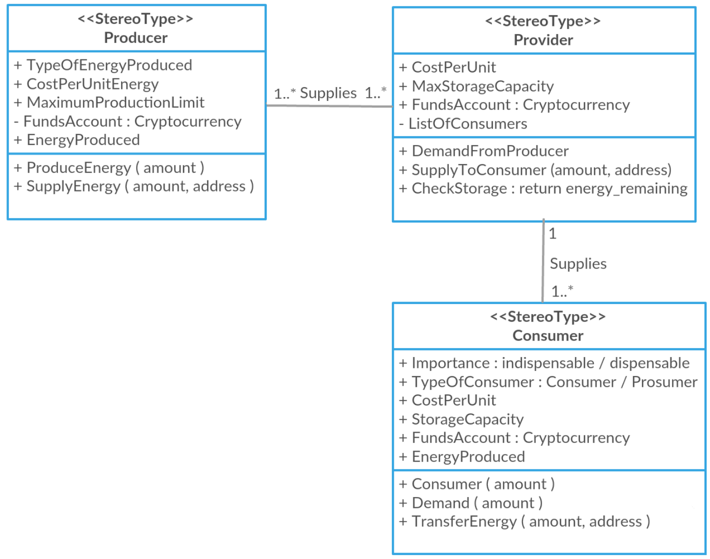

Fig. 1. Architecture Class Diagram.

A. Producer

The producer is considered to be the source of the energy in the Grid. It produces the majority of energy in the grid. It can be renewable or non-renewable. The identification of which empowers the Grid to predict the energy production capacity and satisfy its energy requirement. Knowing the origin of energy not only helps in the regulation, but also reduces costs to the end consumer. Most governments have assistance for renewable energy sources, and charge users less if they use them. Enabling the user to know what percentile of the energy consumed is renewable will allow the user to benefit a lower cost to pay and increase support for renewable sources of energy. This entity has its unique attributes enlisted below:

- Energy source (renewable/ non-renewable)
- A Unique Cost Per Unit of Energy
- A Maximum production capacity
- An account to keep tab on the funds

Besides this, the producer also has the following functions:

- Transfer adequate energy on receiving the required funds.
- Write to the BlockChain every time energy is produced.
- Write to the BlockChain every time energy is transferred.

B. Provider

The provider is the medium through which energy arrives to the consumer from the producer. It is the source of energy through which the consumer derives most of its requirements. It acts like a distributer and has a fixed quota of energy that can be demanded from the producer. The process of making the energy produced available to the consumer in the form that is usable, is done by the provider. The provider also has its own set of attributes:

- A Unique Cost Per Unit of Energy
- A Maximum storage capacity
- An account to keep tab on the funds

- An account to keep tab on the Units of Energy remaining
- A list of consumers that the provider is authorized to send energy to.

The provider also has a set of functions that it must satisfy. They are enlisted below:

- Request energy in exchange for Funds
- Send energy to the consumer, if sufficient funds arrive.
- Enable transfer of Energy between providers if required.

C. Consumer

Today, a consumer in the electric market, doesn't have to be limited to consuming energy only, He can also be a producer using solar panels and other alternative means of producing energy. This qualifies the modern consumer to be entitled as a prosumer. A prosumer is an entity that can consume and produce the required resource. Besides this, the advent of battery packs such as the ones by Tesla, and emerging trends in electric vehicles will enable the consumer to store the energy as well. This enables the consumer to not only provide energy to the grid when in need, but also store it and regulate it. The consumers attribute are :

- The type of Consumer, and importance assigned.
- A maximum storage capacity
- An account to keep a tab on the funds
- An account to keep tab on energy consumed and how much is given back to the grid
- A unique Cost Per Unit of Energy that is charged every time energy is demanded.
- A measure to check how much energy the Consumer can produce.

Besides these attributes, the Consumer or prosumer will have certain functions to perform. They are:

- Consume the energy in storage
- Transfer energy to a neighbour when in need there by reducing strain on the grid enabling a truly P2P environment.
- Supply energy back to the grid when net production exceeds net consumption.
- Demand for energy on transfer of funds.

IV. Entity Interaction

The flow of energy is unidirectional from the Producer to the Provider. On production of the energy and on subsequent requests for it by the provider, the producer sends the energy to the provider if it had the necessary funds or cryptocurrency with it. If the funds are absent, only energy commensurate to the available funds is sent. If the energy that is demanded is less than what has been produced, then the remaining portion is produced while ensuring that the maximum production limit of the producer is not crossed.

Algorithm 1 ProducerToProvider

Require: $EnergyProduced \geq 0$
Ensure: $ProviderFunds \geq EnergyDemanded * CPU$
  $ED \leftarrow EnergyDemanded$
  $EP \leftarrow EnergyProduceed$
  if $ED > EP$ **then**
    $ProduceEnergy(ED - EP)$
    $TransferEnergy(ED, ProviderAddress)$
  else
    $TransferEnergy(ED, ProviderAddress)$
  end if

The flow of energy from the Provider to the Consumer may or may not be unidirectional. The provider will have a list of consumers that buy energy from it. The provider on receiving and storing energy from the Producer forwards it to the Consumers when they require it. The energy transfers are dependent of the availability of funds with the consumer. If the consumer does not have the adequate amount of funds for the energy requested, commensurate energy is transferred. A provider can demand for energy from the producer if it runs out of reserves, but will be charged a higher fee or cost per unit. Prosumer units in the consumers and the Electric Vehicle Battery packs can be used to stabilise the grid. This relationship and bidirectional flow of energy will also enable the reduced dependency on the producer and non-renewable sources of energy.

Algorithm 2 ProviderToConsumer

Require: $ProviderStorage \geq 0$
Ensure: $ConsumerFunds \geq EnergyDemanded * CPU$
  $ED \leftarrow EnergyDemanded$
  $ES \leftarrow EnergyInStorage$
  if $ED > ES$ **then**
    $DemandFromProducer(ED - ES)$
    $TransferEnergy(ED, ConsumerAddress)$
  else
    $TransferEnergy(ED, ConsumerAddress)$
  end if

The interaction between Consumers depends on the type of consumer and its priority level. If the consumer is also a prosumer then it can supply and meet the energy requirements of its neighbouring node. When the storage capacity of the prosumer node is satiated, the energy then produced can be used to supply the neighbours. This prevents wastage of energy, and reduces dependency on outer factors thus enabling a dampened reliance on providers. In events of natural calamities, these very prosumers could be the source for critical equipment and supply the necessary resources to the higher priority nodes.

Algorithm 3 ConsumerToConsumer

Require: $EnergyProduced \geq ConsumerStorage$
Ensure: $PeerFunds \geq EnergyDemanded * CPU$
  $EP \leftarrow EnergyProduced$
  $ER \leftarrow EnergyRequired$
  $ED \leftarrow EnergyDemanded$
  $SurplusEnergy \leftarrow EP - ER$
  $ES \leftarrow EnergyInStorage$
  if $requester == Consumer$ **then**
    $TransferEnergy(SurplusEnergy, ConsumerAddress)$
  end if
  if $situation == Emergency$ **then**
    $PeerAddress \leftarrow Consumer[indespensible]$
    $TransferEnergy(EP, PeerAddress)$
  end if

V. FUND TRANSFERS

There are various implementations of blockchains which include private and public blockchains. These blockchains consist of a series of their own interfaces and implementations to enable financial interactions amongst entities. The smart grid architecture can implement a paradigm where crypto-currencies can be used for commensurate transfer of funds on receiving the adequate energy. These funds can be tokens generated that are digital assets built on top of the blockchain. These tokens can represent a physical object like gold or to a native currency to pay a transaction fee. Tokens may also be used to represent financial instruments. These tokens can be heavily regulated, that is to say that their supply can be constant or can be governed by a sophisticated monetary policy. Using blockchain in our Smart Grid architecture will permit us to use these elegant tools for financial transactions.

VI. CONCLUSION

In this paper we addressed the potential of BlockChain being used in the Energy Sector. We looked into the potential uses and the areas in the energy industry that BlockChain could disrupt. We delved into the users of this system the benefits of using BlockChain compared to the traditional centralized system that is currently being used. We discussed about the relationships that different entities in the system architecture would have with each other. We discussed about the benefits of a P2P energy trading platform and the related areas that to gain from this implementation. We also went over the various forms of energy storage and supply problems that BlockChain can address and briefly explored usage of electric vehicle batteries for stabilizing the grid. Overall, we confer that the use of BlockChain in the energy sector with the combination of Internet of Things ,integration of microgrids and the advent of innovative energy storage solutions point us in the direction of a feasible, reliable and a decentralised system with higher security and privacy compared to the traditional centralized system.

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