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ijirset@gmail.com

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Models and Technology Used in Smart Grid

Mansi G. Kulkarni¹, Sanjana V. Bhavane², Neha F. Rathod³, Prof. Pallavi M. Mankar⁴

UG Student, Department of Electrical Engineering, P. R. Pote (Patil) College of Engineering and Management,
Amravati, Maharashtra, India^{1,2,3}

Assistant Professor, Department of Electrical Engineering, P. R. Pote (Patil) College of Engineering and
Management, Amravati, Maharashtra, India⁴

ABSTRACT: A smart grid is an electricity network enabling a two-way flow of electricity and data with digital communications technology enabling to detect, react and pro-act to changes in usage and multiple issues. Smart grids have self-healing capabilities and enable electricity customers to become active participants. This paper has proposed data Envelopment Evaluation Model for the technical and allocative efficiency evaluation of smart grid. This paper presents condition assessment concept for smart grid equipment which reflects the physical state of the electric grid equipment, which may significantly affect its performance. In this paper we discussed blockchain technologies used in smart grid.

KEYWORDS: Smart Grid, Condition Assessment Model, Data Envelopment Evaluation Model, Block Chain.

I. INTRODUCTION

A Smart Grid is an electricity network that can cost efficiently integrate the behavior and actions of all users connected to it – generators, consumers and those that do both – in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety. A smart grid employs innovative products and services together with intelligent monitoring, control, communication, and self-healing technologies. The smart grid principle is rather based on a hierarchical structure and on the acceptability of intermittent resources such as renewable energies. SG acceptability of the choppy different renewable energy sources and its power outage self-healing capability are the major advantages over traditional power grid. Electric power grid includes three main generation systems with similar assets; systems that are responsible for the production of electricity from fossil fuel, renewable energy sources such as solar and wind, and nuclear power through centralized power plants that may include generators, diesel engines, gas turbines, step-up power transformers, motors, compressors, pumps, switchgear equipment, etc. Smart grid enhancements include various technologies used to improve the stability and reliability of the generation in addition to intelligent controls and generation mix consisting of various renewable energy resources.

Condition assessment in smart grid could be the first step in a more formal asset management system, which allows utilities to reflect the physical state of different electric grid equipment, estimates remaining useful time of the electrical equipment for a more reliable smart grid, and identifies future maintenance requirements. It also provides an analysis of functional and physical deficiencies of electrical equipment for equipment replacement program and for making timely decisions about electrical equipment rehabilitation. In process of its construction, the advanced technology is the key factor for the development of the grid in the intelligent direction. The impact of the assessment technology is significant for the smart grid. From the point of technological progress and technical efficiency, analysis of this effect is the main research idea at home and abroad. In economic management science, the technical efficiency is the ability of maximum output under the fixed input factors of the production unit Data Envelopment Analysis (DEA) has been used to evaluate the technical efficiency and scale efficiency of the power network. Some scholars also use DEA to evaluate the technical efficiency of the hydroelectric power enterprise or transmission and distribution system. The focus of smart grids is to facilitate local production and consumption by prosumers and consumers. By stimulating local energy production and consumption, the transmission losses are reduced. Prosumers and consumers should be able to trade electricity with each other in a peer-to-peer fashion. To manage these transactions between consumers and prosumers participating within the smart grid in a centralized manner would likely to be very costly and would require complex communication infrastructure.

II. METHODOLOGY

Nowadays as smart grid is one of the developing technology in electrical field in this paper we do research study on the new concept which are emerging in smart grid .So the first step is to thorough study of smart grid and its working from various sources like journals, research papers and real time example .In this paper we do research on the technique used to calculate allocative efficiency of smart grid ,the methodological approach used is data Envelopment model.In this paper we study about condition assessment model of smart grid which reflect physical state of equipment used in grid for this we take an example of transformer as it is main equipment in electrical grid .Another important development in smart grid is based on used of blockchain technology ,for the study of used of blockchain technology in smart grid we first research what is blockchain technology and how it works, then we did the research on how it is implemented in smart grid. After collecting all the necessary data,we study and analyses it to prepared this research paper

➤ Working system:

To achieve a modernized smart grid, a wide range of technologies should be developed and must be implemented. These technologies generally grouped into following key technology areas as discussed below:

- **Intelligent Appliances:** Intelligent appliances have capable of deciding when to consume energy based on customer pre-set preferences. This can lead to going away along toward reducing peak loads which have an impact on electricity generation costs. For example, smart sensors, like temperature sensor which is used in thermal stations to control the boiler temperature based on predefined temperature levels.
- **Smart Power Meters:** The smart meters provide two-way communication between power providers and the end user consumers to automate billing data collections, detect device failures and dispatch repair crews to the exact location much faster.
- **Smart Substations:** substations are included monitoring and control non-critical and critical operational data such as power status, power factor performance, breaker, security, transformer status, etc. substations are used to transform voltage at several times in many locations, that providing safe and reliable delivery of energy. Smart substations are also necessary for splitting the path of electricity flow into many directions. Substations require large and very expensive equipment to operate, including transformers, switches, capacitor banks, circuit breakers, a network protected relays and several others.
- **Integrated communications:** The key to a smart grid technology is integrated communications. It must be as fast as enough to real-time needs of the system. Depending upon the need, many different technologies are used in smart grid communication like Programmable Logic Controller (PLC), wireless, cellular, SCADA (Supervisory Control and Data Acquisition), and Blakey Considerations for Integrated Communication.
- **Phasor Measurement Units (PMU):** This is used to measure the electrical waves on an electricity grid using a common time source for synchronization. The time synchronizer allows synchronized real-time measurements of multiple remote measurement points on the grid.
- **Super Conducting Cables:** These are used to provide long distance power transmission, and automated monitoring and analysis tools capable of detecting faults itself or even predicting cable and failures based on real-time data weather, and the outage history.

III. CONDITION ASSESSMENT CONCEPT FOR SMART GRID EQUIPMENTS:

Condition assessment reflects the physical state of the electric grid equipment, which may significantly affect its performance. The performance of the grid equipment is the ability to provide the required level of service to customers. Generally, this can be measured by identifying system reliability, availability, capacity, and equipment criticality. Condition assessment provides information about equipment technical details, collected data analysis, maintenance history, repair, and replacement. All of this is considered as essential information for extending the remaining useful life of electrical grid equipment and more importantly for the timely intervention steps to bring beneficial levels of service. Condition assessment system of smart grid contains equipment assessment along with their current condition, the useful lifetime of that equipment, permanent monitoring of the grid component, planning,



designing, operation, and maintenance programs. Implementing condition assessment to the smart grid one achieves several potential benefits, that are driving newfound interest

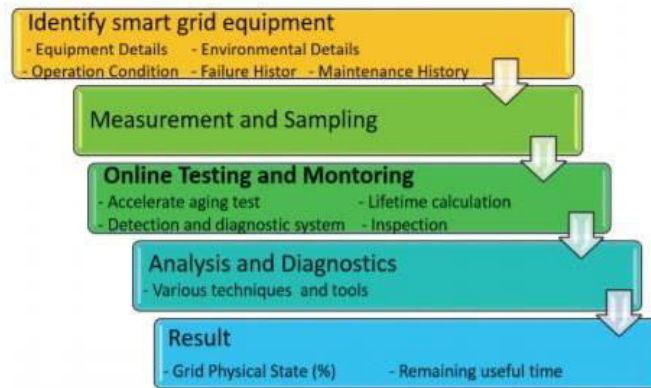


Fig No. 1 Thepower grid condition assessment stage

➤ **SmartGrid ConditionAssessmentArchitecture**

The architecture of a condition assessment specifies the arrangement of the smart grid components and analyzes the performance of each part. The proposed condition assessment architecture is composed of two modules. The first module gathers maintenance strategies of the grid components. The second one is a detection and diagnosis module, which aims to detect the occurrence of drifts from the known and unknown failure modes for determining the current state of the process.

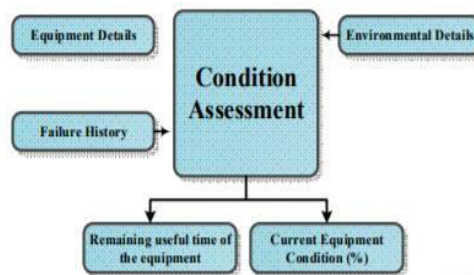


Fig No. 2 Condition assessment architecture

➤ **ConditionAssessmentModel**

The smart grid includes many electric equipment on generation, transmission, distribution, and consumers sides. Transformer is an essential equipment in all electrical grids. It is the heart of electric utility and smart grid system. In this work, a case study is discussed on a large power transformer condition assessment for the smart grid. Several condition assessments of electric grid machine are based on current signature analysis, vibration analysis, dissolved gas analysis, furan analysis, degree of polymerization, temperature analysis, and field analysis. The condition assessment model focuses on the fundamental frequency component to evaluate the condition of electric machine online. The core vibration amplitude is proportional to the squared value of terminal voltage and the square value of current, respectively.

$$\alpha_{core} \propto U^2 \dots (1)$$



$$F(t) \propto I^2, \alpha \text{winding} \propto I^2 \dots \dots \dots (2)$$

The winding vibration variation could be given by,

$$\Delta w = \sqrt{\alpha^2 + \alpha^2 - 2\alpha_1\alpha_2 \cos\beta} \dots \dots \dots (3)$$

Where α_1, α_2 are the total vibrations Magnitudes under different loads and β is the phase angle between the total vibrations. As the core vibration is extremely small, short time interval between two samples of the total vibration changes is little, and consequently the angle β is small. The winding vibration variation may be written as

$$\Delta w = |\alpha_2 - \alpha_1| \dots \dots \dots (4)$$

The winding vibration variations are calculated for each sensor. $\Delta \omega_{ij}$ is the result of J^{th} sensor obtained from the I^{th} and the

$(I + 1)^{\text{th}}$ core vibration samples of power transformer in the grid. The winding vibration variations from all sensors are proportional to the currents squared variation. (5)

$$\Delta \omega_{ij} \propto (I_{i+1}^2 - I_i^2).$$

The selection of the feature extraction method that permits an effective characterization of the sensors plays a crucial role for condition assessment in terms of reliability and accuracy. In principal component analysis (PCA) is used to analyze the vibration variations from different sensors in the core of the transformer to build the matrix and determine sampling rates of these sensors

$$W = \begin{pmatrix} \Delta w_{11} & \dots & \Delta w_{1m} \\ \vdots & \ddots & \vdots \\ \Delta w_{n1} & \dots & \Delta w_{nm} \end{pmatrix} \dots \dots \dots (6)$$

The first step of condition assessment model is to obtain the covariance matrix. The normalized vibration variation matrix X in the PCA model could be given by,

$$X = \begin{bmatrix} x_1^T \\ \vdots \\ x_n^T \end{bmatrix} \in R^{n \times m}, \quad x_i = \begin{bmatrix} x_{i1} \\ \vdots \\ x_{im} \end{bmatrix} \dots \dots \dots (7)$$

The covariance matrix is decomposed as,

$$C_{xx} = \frac{1}{m-1} X^T X = U \Lambda U^T \dots \dots (8)$$

Where the columns of U are the eigenvectors, and they are also known as PCs. $\Lambda = \text{diag} \{ \lambda_1 \lambda_2 \dots \lambda_m \}$ contains eigenvalues in descending order of magnitude $\lambda_1 \geq \lambda_2 \geq \dots \geq \lambda_m$. Only one main principal component exists after PCA transformation. Main principal contribution (MPC) is used as parameter and given by,

$$MPC = \lambda_1 / \sum_{i=1}^m \lambda_i \dots \dots (9)$$

The degree of the winding vibration variation from different sensors provides the monitoring unit with the deviation level. The MPC value moves closer to 0, which means that the condition of the transformer had been affected. If it is close to 1, it means that the winding vibrations from different sensors follow the same rule. According to this, the available information is beneficial to make a report to help in diagnosing, classifying and assessment of the transformer performance characteristics and physical state. The steps are normally linked together in order to collect the data and process it using real-time signal processing for having real data update in the main control center and for providing updated maintenance patch notes.

- *Benefits of Condition Assessment Analysis*

Cost-benefit analysis of condition assessment of electric equipment in smart grid directly compares benefits and costs. Calculation of the cost of electric equipment in smart grid includes operations, installation, maintenance and repair costs. The condition assessment benefits of electric equipment are made based on the following definition

$$\text{Risk} = \text{Probability of occurrence of an event X} \text{Consequently of this event}$$

$$\text{Benefit} = \text{Risk without assessment} - \text{Risk with assessment}$$

The costs of condition assessment system often appear to be high because equipment is massive, not accessible, and difficult to examine. But, the most recognized benefit of condition assessment is the major savings that can be achieved



on repair costs and on increasing electrical power maneuvering capability. In addition, the cost benefits of condition assessment are high compared with the expenses that could result in sudden equipment failure or in unscheduled outages.

IV. DATA ENVELOPMENT EVALUATION MODEL

Data envelopment evaluation model is performed to evaluate the efficiency. This model considers the development of smart grid in time continuity through its improvement. That is, the construction effect of smart grid at the end of the last time should be the initial condition of the next time, so the model of management efficiency assessment is dynamic. At the same time, it takes into account the relationships between different attributes, that is; the benefit of building an attribute can be construction investment of another attribute. The objective function of the data envelopment evaluation model is as follow

$$\min \frac{\sum_{t=1}^T W^t \left(\sum_{k=1}^K \omega^k \left(1 - (1/m_k) \sum_{i=1}^{m_k} (s_{iok}^{t-}/x_{iok}^t) \right) \right)}{\sum_{t=1}^T W^t \left(\sum_{k=1}^K \omega^k \left(1 + (1/r_k) \sum_{i=1}^{r_k} (s_{rok}^{t+}/y_{rok}^t) \right) \right)} \dots(1)$$

The constraints are shown below:

$$\text{s.t.} \begin{cases} \sum_{j=1}^n \lambda_{jk}^t x_{ijk}^t + s_{ik}^{t-} = x_{iok}^t, & o = 1, \dots, n; k = 1, \dots, K; i = 1, \dots, m; t = 1, \dots, T \\ \sum_{j=1}^n \lambda_{jk}^t y_{rjk}^t - s_{rk}^{t-} = y_{rok}^t, & o = 1, \dots, n; k = 1, \dots, K; r = 1, \dots, s; t = 1, \dots, T \\ \sum_{j=1}^n \lambda_{jk}^t z_{jk_i}^{t,t+1} = \sum_{j=1}^n \lambda_{jk}^{t+1} z_{jk_i}^{t,t+1} \\ \sum_{j=1}^n \lambda_{jk}^t z_{j(k,h)_i}^t = \sum_{j=1}^n \lambda_{jh}^{t+1} z_{j(k,h)_i}^t \\ \sum_{j=1}^n \lambda_j^k = 1, & k = 1, \dots, K \\ \lambda_{jk}^t \geq 0, s_i^{k-} \geq 0, s_r^{k+} \geq 0, & i = 1, \dots, m; r = 1, \dots, s; k = 1, \dots, K. \end{cases}$$

....(2)

In this formula, $z_{j(k,h)_i}^t$ is correlation value of decision element j from the attribute k to attribute h in t time slot t^{t+1} ; λ_{jk}^t is influence value of decision element j in attribute k from year t to t+1 years.

Through the optimization of the model, the parameters are set as follows:

$$\sum_{j=1}^n \lambda_{jk}^t z_{j(k,h)_i}^t = z_{o(k,h)_i}^t$$

..... (3) $\sum_{j=1}^n \lambda_{jh}^t z_{j(k,h)_i}^t = z_{o(k,h)_i}^t$

From this, the efficiency of each decision element can be calculated as follows:

$$\theta_o^t = \frac{\sum_{k=1}^K \omega^k \left(1 - (1/m_k) \sum_{i=1}^{m_k} (s_{iok}^{t-}/x_{iok}^t) \right)}{\sum_{k=1}^K \omega^k \left(1 + (1/r_k) \sum_{i=1}^{r_k} (s_{rok}^{t+}/y_{rok}^t) \right)} \dots(4)$$

Among them, the attribute efficiency values of decision-making unit DMU are as follows:

$$\theta_{ok} = \frac{\sum_{t=1}^T W^t (1 - (1/m_k) \sum_{i=1}^{m_k} (s_{iok}^{t-}/x_{iok}^t))}{\sum_{t=1}^T W^t (1 + (1/r_k) \sum_{i=1}^{r_k} (s_{rok}^{t+}/y_{rok}^t))}$$

This is the equation to calculate attribute efficiency by data assessment model. This method considered dynamics of smart grid development and development dynamics as influence parameters.

V. BLOCKCHAIN APPLICATIONS IN SMART GRID

Many researchers and industry leaders believe that the rise of the blockchain technology will theoretically adopt advanced development and smooth the shift towards the smart grid. Decentralized technologies have always been a basis for many smart grid technologies. The integration of renewable energy sources, energy storage devices, and electric vehicles into the electrical grid has begun a broad research area on new control schemes to address these issues. The different and desirable advantages of blockchain technology created considerable interest in exploring and adopting this technology in smart grids. Blockchains applications in the smart grid could be divided through the different parts of the smart grid as follows:

- **Power generation:** Blockchain technology gives the dispatching agencies a full knowledge about the overall operation status of a power grid in a real-time perspective. This enables them to develop dispatching plans that would maximize profits.
- **Power Transmission and Distribution:** Blockchain systems enables the automation and control centres to have decentralized systems that overcome the main challenges seen in the traditional centralized systems.
- **Power Consumptions:** Similar to the generation and transmission sides, blockchain could be beneficial in this side by managing the energy trading between the prosumers and the different energy storage systems as well as the electric vehicles. The following are the main categories where the blockchain applications are extensively studied and utilized in smart grid.

V. I New Frameworks of Blockchain in Smart Grids

The utilization of the blockchain in smart grids could offer various advantages to our current and future electrical power system. Most of the advantages to the electrical power system which are specifically linked to the characteristics and the working principles of the blockchain arise from the established decentralized trading infrastructure. The major advantages linked to characteristics and the working principles of the blockchain with respect to the electrical power system are the decentralization of trust, increased security, increased resilience, increased transparency, increased scalability, less bureaucracy, and increased computational capacity. From these advantages, several new frameworks of blockchain in smart grids could be adopted as illustrated next.

V.I.I Blockchain as a Cyber Layer

Blockchain could be easily integrated into the different parts of the smart grid by creating a cyber layer that is designed for the blockchain applications. Illustrates how the blockchain technology could be a new cyber layer that supports the operation and the development of smart grids. It shows that every application in the smart grid could have its own specified blockchains such as energy trading and cyberphysical security blockchains. Energy trading blockchain shall be connected to the different energy traders in the grid such the power plants, consumers and prosumers. Electric vehicles blockchain facilitate the charging operations between the different stations and the prosumers. Microgrid blockchain handles the operations and the control of the microgrid with the various distributed generations in it. Finally, cyber-physical security blockchain shall be responsible for handling security and data protection issues in the smart grid. The integration of these different blockchains shall strengthen and smoothen the operation of the smart grid.

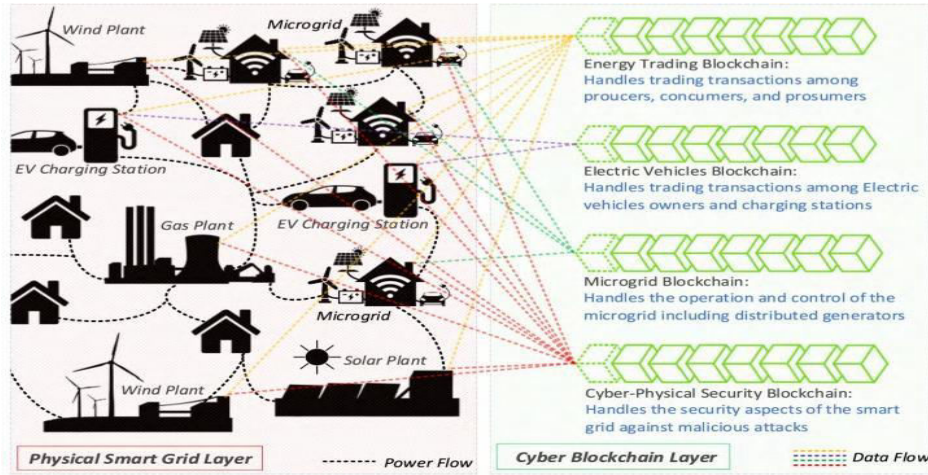


Fig No. 3 Cyber Blockchain Layer

V.I.II Agent/Aggregator Based Microgrid Architecture

Through the adoption of an enhanced level of the blockchain, a decentralized computing platform is created in addition to the trading infrastructure. When all the peers who participate within the network devote a share of their computational capacity, the total available computational capacity is increased within the electrical power system. This is a critical aspect when it comes to the operation and control of the microgrids. Illustrates a futuristic roadmap for the blockchain applications in microgrid operations. It illustrates that different components in the microgrids could have their own blockchains, such as smart metering aggregator, wind energy aggregator, and energy storage aggregator. These different chains shall provide the microgrids with a more flexible, reliable, and secure operation and control structure. Further, it increases the trust between the owners of these microgrids and the utilities as well. Moreover, the Blockchain increases the scalability of the electrical power system; hence if an extra customer would be connected to the microgrid there would be a negligible increase in complexity.

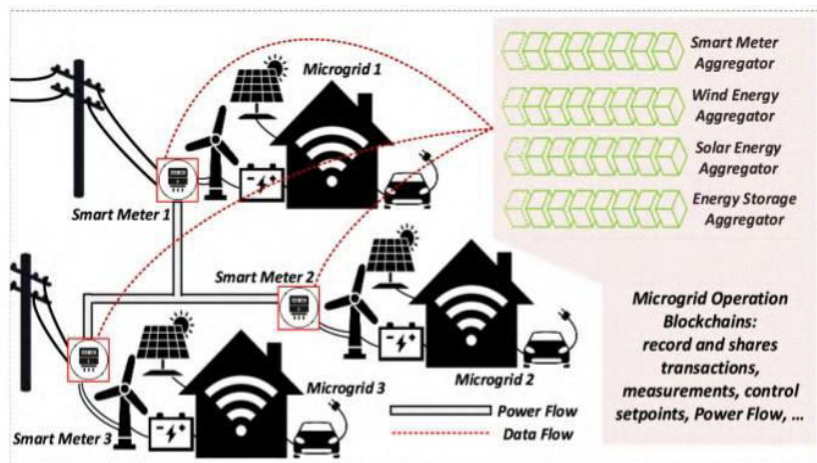


Fig No. 4 Futuristic Roadmap for The Blockchain Applications in Microgrid Operations

V.I.III Smart Grid Protection and Security

Blockchain offers increased security for the electrical power system. The applied cryptographic securitization combined with the consensus mechanism provides immutability of the data which has been incorporated in the Blockchain. Once an energy transaction/data has been included in the blockchain, it would be tough to alter this transaction for illegitimate purposes or to delete the transaction resulting in a very secure and robust system. The Blockchain also provides increased resiliency for the electrical power system. Since every peer in the network contains a copy of the ledger, there is an absence of a single point of failure compared to centralized data architectures which decrease the vulnerability for malicious attacks and therefore the electrical power system is more resilient. Besides, it increases the resilience of the electrical power system because the computational capacity is fragmented rather than concentrated in one giant computer. Illustrates how different blockchains could be utilized in different smart grid layers for the sake of protecting the data. In this figure, every layer of the smart grid is handled by different blockchain aggregator. These blockchains shall have the protection means of the smart grid by providing a reliable and secure data storing platform. Furthermore, because there is no direct link between the identity within the Blockchain environment and the identity of the specific consumer/producer. Therefore, it will decrease the vulnerability against malicious attacks which increases the resilience of the electrical power system.

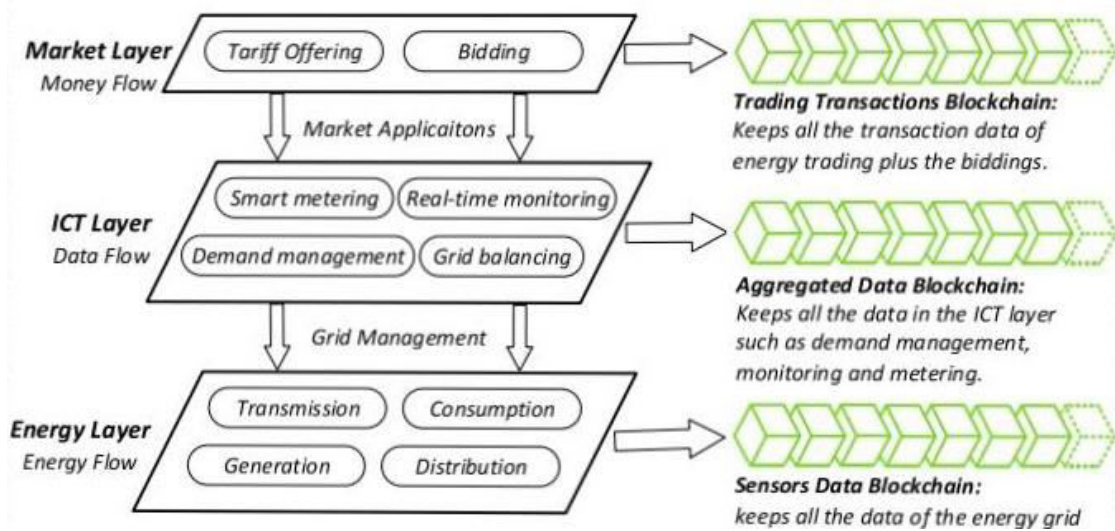


Fig No. 5 Different Blockchains In Different Smart Grid

I. Advantages

- The integration of blockchain into the smart grid allows the community to maintain transactions in the system in a consensus manner.
- The blockchain provides immutability to the smart contracts and transaction data, by restricting a record to be changed or erased. Therefore, a smart contract between a generator and a consumer will always be executed, providing certainty that a producer will always deliver the electricity when a consumer has paid.
- Another key advantage offered by tele management systems is that bills are more accurate. They always reflect the real consumption of each month instead of estimates, reducing the cost of the old system of manual energy meter readings. In addition to being able to access information about the installation remotely, problems become easier to diagnose and solutions can therefore be implemented faster, improving customer service.
- The presented idea of condition assessment is crucial for more reliable smart grid. It increases the reliability, safety, and lifetime of the grid equipment and components.



- Data Envelopment Analysis has proven to be an excellent tool in decision support system for measuring efficiency and productivity of a set of decision-making units (DMUs) where multiple inputs convert into multiple outputs

II. Disadvantages

- Challenge which the Blockchain faces is issues regarding the scalability of the Blockchain. The main limitation regarding the scalability of the current design of the Blockchain is the limited transaction throughput.
- Blockchain application in the energy sector is still a budding technology and is prone to attacks from the energy conglomerates who might exploit it for financial advantages.
- Error risk: this risk is always present if the human factor is engaged even though the blockchain is a highly secured technology
- The biggest concern is Security in a smart grid system. Grid system uses some smart meters, which are automated and provides communication between power provider and customer. Here some type of the smart meters can be easily hacked and they may control the power supply of a single building or an entire neighborhood.

VI. CONCLUSION

In this paper, there was presented different aspects related to electrical smart grid i.e Condition assessment model, data envelopment model and blockchain technology used in smart grid. The presented system of condition assessment is essential for a robust and reliable smart grid. The presented idea is crucial for more reliable smart grid. This system does not require any change in the smart grid infrastructure. Smart grid condition assessment vision is expected to be a critical part of the future smart grid management systems. Data envelopment model presented to find allocative efficiency by using mathematical model. Smart grid is a booming technology in the energy sector and it essentially needs a reliable and secure framework for operations, the integration of blockchain into the smart grid allows the community to maintain transactions in the system in a consensus manner. This paper surveyed the recent applications and utilization of the blockchain in the smart grid sector from research. However, to successfully implement the blockchain within the smart grid, significant challenges must be countered in the coming years.

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