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A Novel Blockchain Based Approach to Exchanging Information and Data in Power Systems

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Abstract—**Exchanging information and data using cloud computing in power systems is now becoming a common practice. However, there are still many challenges such as data security, interoperability, and scalability that need to be considered. In this paper, the authors have exploited blockchain technology to enhance data security. A blockchain based approach is developed to exchange information and data in power systems. This approach enables users to exchange information and data without losing ownership or control of the data. The proposed approach provides the solutions to three important problems: scalability, data ownership, and interoperability between different stakeholders within power systems. The case studies evaluate the effectiveness of the proposed novel approach with regard to enhancing information and data exchange. The paper specifically examines enhanced performance concerning scalability, latency, and computation time.**

Keywords— Blockchain, scalability, data exchange, security

I. INTRODUCTION

The large-scale integration of renewables in distribution systems has created bi-directional power flows and has created new challenges for Transmission System Operators (TSOs) and Distribution System Operators (DSOs). As a consequence, there is limited visibility and control of the overall system [1],[2]. Electricity generated from renewable energy sources will inevitably play a big role in meeting energy demand as a result of societal and technological advances. Out of all renewable energy sources, solar and wind energy will play a significant role in the present and future generations. The majority of renewable energy sources are distributed and connected to the distribution network [2]. The integration of these energy resources will help operate the system efficiently. The transition from centralized to highly distributed system management has caused considerable change that has led to increased coordination and communication efforts. Increased coordination and interoperability between system operators and market participants are required at different layers; from connectivity to regulatory policy [3].

Renewable energy sources such as wind solar and energy are inherently intermittent, adding to the difficulties of power systems operation. The future power system's objective is to ensure reliable energy transmission [4]. Significant initiatives in the area of information and data interchange via cloud computing have been documented in recent years [5]. Cloud computing is being used as the major platform for exchanging information and data [6]-[8]. The proposed method could efficiently exchange information and data between TSO and DSO, allowing DSO resources to be used for balancing [9]. An oversupply of intermittent renewable energy sources causes power flow constraints in distribution and transmission networks. These operational constraints will need to be handled in a more coordinated, effective, and cost-effective manner in the future[10]. Infrastructure for information and communication technology (ICT) is very important for better cooperation and coordination between TSOs and DSOs [11].

Blockchain could provide the means for establishing a trade infrastructure within the power system [9]. Users would be able to trade electricity with one another without having to entrust a third party using blockchain. Within the power systems, the use of a blockchain-based trade system provides several advantages [10],[11]. For example, consider the benefits of establishing a real-time market, lower transaction costs due to a streamlined trading structure, and more privacy for smart grid users [12]. In addition to using the blockchain to develop a trade infrastructure, it can be used for transferring information and data within power systems might be developed to address the issue of interoperability.

Blockchain technology can also help to integrate energy generation, transportation, consumption, and storage [13]. In [14] the presented scenarios demonstrate carbon emission rights authentication, cyber-physical system security, virtual power resource trading, and multi-energy system coordination[14]. A central operator may still be required to ensure confidence in direct consumer-to-consumer transaction agreements [15]. Smart contracts execute payments automatically, while the blockchain records data received from smart meters and transactions. A hybrid blockchain for a more energy-efficient internet, decentralized oversight, and reliable and secure data storage is proposed in [16]. A decentralized energy trading system based on blockchain technology is suggested in [17].

Power systems are designed to make local energy production and consumption easier for prosumers and consumers [18]. Transmission losses can be reduced by increasing local energy production and consumption. Electricity should be traded on a peer-to-peer basis between users and consumers. Managing these transactions between smart grid users and consumers in a centralized manner will be very costly and need a complex communication infrastructure. [19]. As a result, a decentralized approach is preferable [20]. Furthermore, as the number of stakeholders grows, managing bulk data in a centralized manner will become more difficult. This will necessitate quick computational capabilities at the central node to process a significant amount of data, increasing its sensitivity to failures.

For many applications within power systems, blockchain and big data technologies were merged. The applications of

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blockchain in big data systems are decentralized private data management, IoT connectivity, digital property resolution, and government agencies. A blockchain-based access control architecture is presented in [22] to strengthen the security of Big Data platforms. However, while using blockchain technology to perform access control operations, the framework developed additional severe flaws. A blockchain access control ecosystem is proposed in [23] that offers a better approach to handling access control of massive data sets while also preventing data breaches. Hyperledger Fabric with smart contracts is integrated with Hadoop for storing data off the chain.

The remaining sections of the paper are organized as follows: Section II introduces the blockchain technology from a wide perspective with some recent real-life applications, a novel platform based on blockchain technology for TSOs and DSOs information and data exchange is presented in section III, and the Implementation and results are presented in section IV. Section V discusses the current limitations and future work. Finally, conclusions are presented in section VI.

II. BLOCKCHAIN AND HADOOP

A. *Blockchain Technology*

A blockchain is a decentralized database that stores an encrypted ledger. The name comes from the fundamental structure. A block on the blockchain represents a collection of all transactions. Transactions that have recently occurred and have been validated. A block is a unit of measurement. A hash code that cannot be altered is used to identify it or can be easily modified. The most common blockchain platforms are Bitcoin and Ethereum. When transactions are put into the blockchain, they are combined and permanently stored as a single block. These blocks are chronologically and linearly linked together to form a blockchain. A hash of the block header uniquely identifies each block within the blockchain. The method for creating blocks and incorporating them into the blockchain system is to track the complete chain of effective network activity starting with the original block [24]. The structure of a blockchain is presented in Fig. 1.

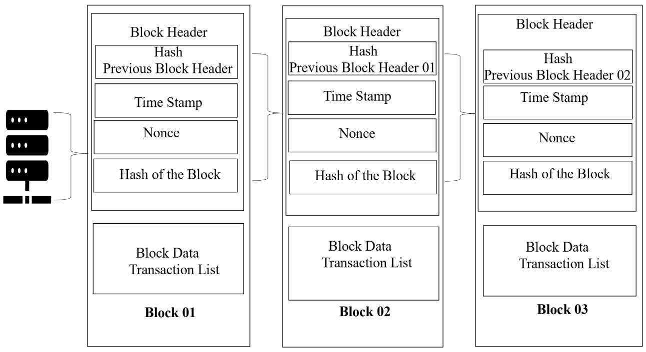

Fig 1. Blockchain Blocks illustration

Public and private blockchains are the two forms of blockchain [25]. In a public blockchain, the members are anonymous. To join the network, the verification process is not restricted. Examples of public blockchains are Bitcoin and Ethereum [24]. The permission to join a private blockchain is limited and depends on the blockchain manager. The blockchain consortium is used for the verification process and it can choose which nodes will take part in the verification process. Due to the decentralized nature of blockchains, any node in the network can check the validity of a transaction. These nodes compile and append a block of transactions to the existing chain. It's feasible, though, that numerous nodes will simultaneously create new blocks to contribute to the blockchain. To solve this issue, the nodes must agree on which of them will append a new block. This agreement is called a consensus agreement.

B. *Hyperledger Fabric (HLF)*

Hyperledger Fabric is a private blockchain that requires user identification and is appropriate for enterprise applications. Hyperledger Fabric, unlike Bitcoin and Ethereum, does not have a cryptocurrency, and access to the network is limited to network members exclusively. Anyone can join the network. In Hyperledger Fabric, the PBFT [26] technique validates transactions and constructs blocks. A Fabric network is made up of several entities such as peer nodes, ordering service nodes, and customers from various companies. A Membership Service Provider (MSP) [26], often affiliated with an organization, provides each of these with a network identification. All entities in the network have access to and may verify the identities of all organizations. When an external application has to interface with the ledger, it can use Hyperledger Fabric which is written in chain code [26]. The global state, rather than the transaction log, is where the chain code interacts the most. The chain code can be written in the computer languages Go or Node.js.

C. *Smart Contracts*

Smart contracts are one of the most significant components of a blockchain. Nick Szabo [29] first proposed the smart contract concept. On the blockchain, smart contracts can be any type of decentralized computer program that runs without the assistance of a third party. A blockchain transaction can only take place if the smart contract parameters are met. Anyone can utilize the public blockchain to develop smart contracts that need a lot of processing power because it is anonymous. The Proof of Work (PoW) consensus process involves all users in the network [30], there can be considerable delays to the network if the smart contract takes a long time to execute or has an infinite loop. A Denial-of-Service (DoS) attack like this might be fatal for the entire network. As a result, it's critical to reduce the complexity of smart contract computations. To link smart contract execution complexity to financial restrictions, Ethereum created the idea of 'gas' [31]. To deploy a smart contract to the network, a substantial amount of gas is required. The network execution of a smart contract requires the user's available gas. It stops processing when the user account's available gas runs out. Operational complexity is reduced in this way, avoiding the network from experiencing unrealistic or extra delays.

D. *Big Data System*

Big data is described as a set of data that are too big to be comprehended, collected, handled, and processed efficiently using traditional methods[27]. Big data has four major characteristics: volume, diversity, velocity, and authenticity [27]. These attributes show the size of generated and stored data, as well as the type and nature of data, data generation and processing speed, data quality, and data value [27]. A method or strategy for analysing huge amounts of data is known as big data analytics. Some of the most popular frameworks for big data analytics include Hadoop [28], Spark3, MongoDB4, Strom5, Cassandra6, Neo4j7, and others. Hadoop is a prominent open-source framework that may be used both on-premises and in the cloud.

E. Hadoop

Hadoop is a distributed computer cluster framework for managing large data collections. Hadoop is an open-source platform based on the MapReduce programming technique. The Hadoop Distributed File System (HDFS) [32] and distributed processing called MapReduce are the two layers of Hadoop. HDFS is a commodity-hardware-based distributed file system. It shares many characteristics with other distributed file systems. Despite this, it is unique among distributed file systems in that it is designed to work on low-cost hardware and is highly fault-tolerant. HDFS is a file system designed for applications that demand quick access to big data collections. HDFS has master and slave nodes as its architecture. Several data nodes, usually one for each node in the cluster, handle storage attached to the nodes on which they run. HDFS is meant to store very large files consistently across multiple servers in a large cluster. Each file is organized as a series of blocks, each of which is the same size except for the final. A file's blocks are replicated for fault tolerance. Per file, the block size and replication factor can be changed. A file's number of replicas can be specified by an application. When a file is created, the replication factor can be defined and then altered later. At any one time, write-once HDFS files only have one writer. The HDFS architecture is presented in Fig. 2. [32].

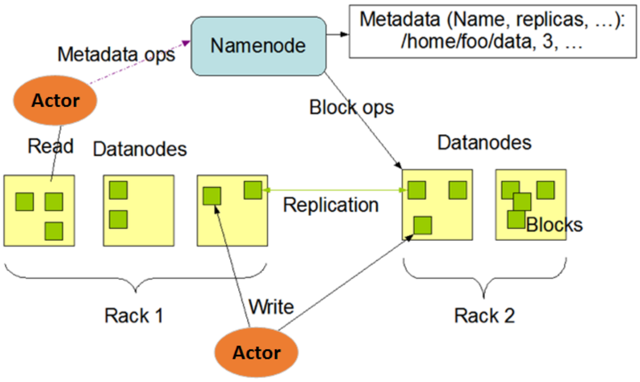

Fig 2. HDFS Architecture

The MapReduce distributed processing system has two functions/tasks: map and reduce. Data is transformed into granular structures using the map function. A tuple comprising key/value pairs is returned by the map function. Reduce combines and groups tuples into a single set with a single key value. The file system saves both input and output functions. The MapReduce framework [33] includes a single job tracker and task trackers. The master, or job tracker, will keep track of available resources, assign resources, and assign work to the slaves, or task trackers. Slave task trackers compute the tasks assigned by the Job Tracker and report back to the master on their progress.

III. PROPOSED ARCHITECTURE FOR DATA EXCHANGE BASED ON BLOCKCHAIN AND HADOOP

This paper proposes a novel architecture for exchanging information and data for entities in power systems by combing Hyperledger Fabric (HLF) blockchain with Apache Hadoop. This ensures the privacy and security of the data as third-party computing is performed in the data owner's environment. Power system entities such as TSOs and DSOs will benefit from this platform. Blockchain and smart contracts provide full transparency about who, when, and for what purpose data is accessed, as well as the ability to specify different purposes for exchanging data.

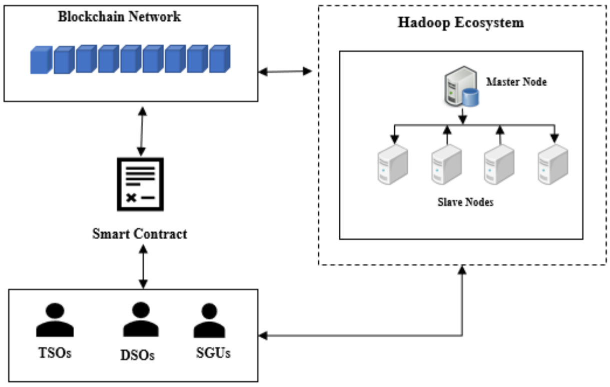

Fig 3. The architecture of the blockchain based approach for data exchange

The proposed architecture is shown in Fig. 3. It consists of three components, data storage, blockchain, and computation. Data suppliers and Data consumers are the main users of the blockchain consortium. Data is provided by the user and that data is transferred to Big Data resources for processing via blockchain. Data consumers which are authorized by the system will only be able to use the provided data set to run their code. The smart contract that assesses the code given by the data consumer is deployed by data providers. The smart contract restricts computational complexity by monitoring harmful functions in the consumer code. HDFS is used as a storage layer, where the data is stored and is also included in the architecture.

Due to the limited storage of the shared ledger of the HLF blockchain. The HLF's performance worsens as the blockchain platform's shared ledger grows in size. The proposed system traces data provenance using a shared ledger. To address the difficulties highlighted before, the data is placed in the Hadoop environment. Data has been preserved in off-chain storage in this manner. Data checksums are used to verify and confirm the integrity of data. By comparing the recorded information in the shared ledger with the stored data in the Hadoop system, the HLF blockchain can validate stored data. The HLF network designed a chain code to make these actions easy in each peer node. The data checksum and provenance data are sent using the built-in client library. Operators for file storage are no longer necessary. For secure and validated data, the distributed Hadoop ecosystem provides a pluggable storage alternative. The user can speed up the data processing by storing data in Hadoop instead of storing it on the blockchain. This data can then be transferred information to the blockchain for verification. The ledge is then used to acquire the location and address of the data. The data is then retrieved from the Hadoop storage. The workflow for the proposed architecture is shown below in Fig. 4.

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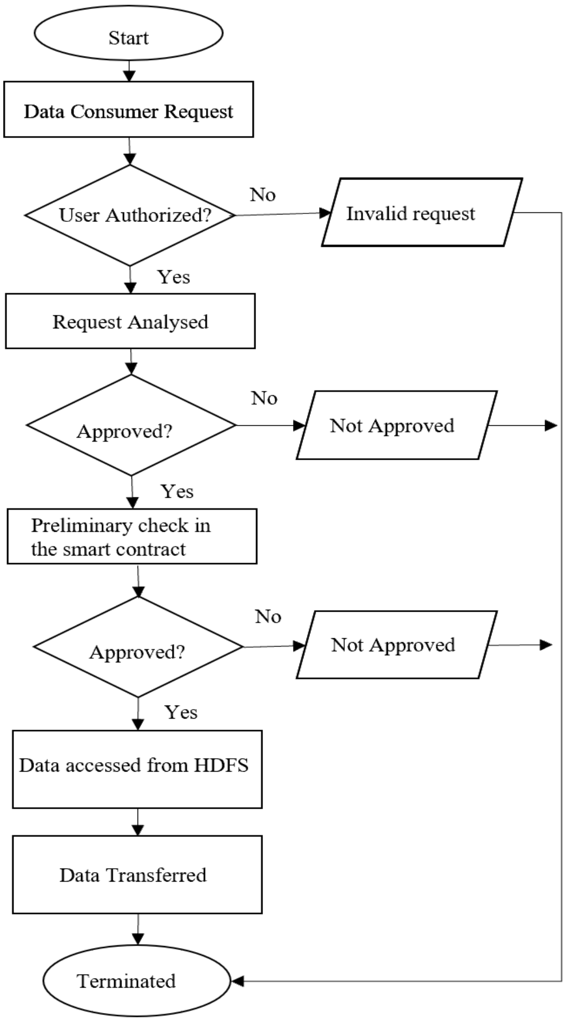

Fig 4. Work Flow of the Proposed Architecture

The workflow explains the process of Information and data exchange. A user requested certain data from the data provider. That request is checked to see if the user is authorized for that request. If the request is approved the preliminary checks are performed by the smart contract. When the checks are approved the data is transferred to the user. The novel aspect of the newly proposed framework is that the entities within power systems can manage control and manage information and data exchange.

IV. IMPLEMENTATION AND RESULTS

The use case presented in this paper is comprised of a single scenario that outlines a specific data exchange mechanism between TSO and DSO. There are four tasks between the DSO and the TSO for data exchange on the platform during the entire procedure. The first task is performed by DSO which requests load information from the TSO by sending network-ID/load information in terms of data flow. The second task is performed by TSO, which will then send load information back to the DSO if the request is approved, and the DSO will retain load information for future use. The third task is performed by TSO, if TSO rejects the request from the DSO it will be asked to alter and resend the relevant data. However, if the TSO aspects the request, it will ask the DSO to modify and resend the corresponding data to complete the fourth task [8]. Fig. 5 presents the platform mechanism of all four actions for the use case under study.

Fig 5. Platform mechanism of Use Case

The Hadoop ecosystem is used for data storage in this paper. There are three nodes in use: one master node and two slave nodes. The execution of user code is not taken into account in this work. The following is the experimental setup: Three nodes are used for the experimental implementation of the above-mentioned use case:

TABLE I. EXPERIMENTAL SETUP

Number of Nodes	*Memory*	*CPU*	*Operating system*	*Programming language*
One Master Node	32 GB	2.40 GHz*4 processor	Ubuntu 22.02	Python 3.7
Two Slave nodes	16 GB	2.40 GHz*2 processor	Ubuntu 22.02	Python 3.7

The performance analysis of the proposed approach is evaluated by keeping all data in the blockchain and storing data using an on/off-chain approach are shown in Fig. 6 and Fig. 7. When a large amount of data needs to be stored, distributed data storage outperforms non-distributed data storage in terms of reading and writing data. Because data is saved individually, the volume of data on the blockchain network can be decreased, and the distributed database is maintained locally, so it is not restricted by storage capacity and can be enhanced. As a result, the separate storage scheme minimizes the quantity of data on the blockchain network, This offers several advantages, including improved system scalability and capacity use. The basic concept behind blockchain is to store data in a decentralized manner to maintain data security [34]. The proposed approach combines the blockchain with the traditional data storage system. This proposed approach integrates blockchain and Hadoop, making it somewhat less secure than keeping data on a blockchain network but still safer than traditional data storage.

The response time of writing the data with and without blockchain is presented in Fig. 6. To measure the response time we have generated fixed file sizes ranging from 500 to 2500 MB. The black bar in Fig. 6 represented the time when the file is available in HDFS. The shaded part of the bar in black represents the overhead time when blockchain is used to write the file while validating the transaction. It can be seen that using blockchain brings an overhead to the performance while writing the data. When the file size is increased, the blockchain overhead proportionally decreases, this is mainly because HDFS is taking more time for writing the file. The blue bar in Fig. 6 represented the read time for the file. The shaded part in red of the bar represents the overhead time when blockchain is used to read the file while validating the transaction against the hashed value stored on Hyperledger. It can be seen that the blockchain overhead in reading the file is very less compared to writing the file using blockchain. The blockchain overhead proportionally decreased while increasing the file size.

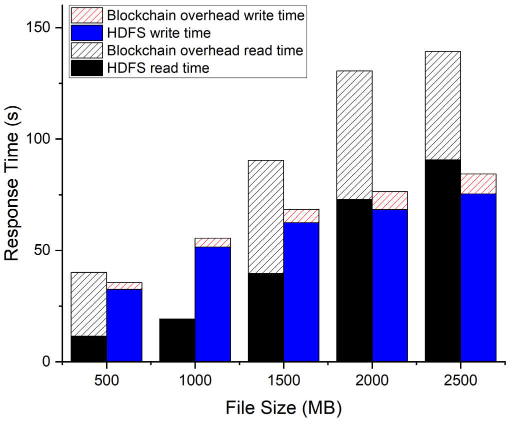

Fig 6. Write/Read time with and without Blockchain

Fig. 7 represents the Read/Write rate of the data with and without blockchain. The black bar in Fig. 7 represented the rate at which the file is written in HDFS. The shaded part of the bar represents the overhead when blockchain is used to write the file into HDFS. The blue bar represents the read rate of reading the data in HDFS. The shaded part in red shows the blockchain overhead rate of reading the file from HDFS using blockchain. It can be seen that the rate of reading the file increases as compared to writing the file using blockchain. This is mainly because the time taken to write the file is more as compared to reading the file. Equation 1 [35] specifies how the *Read/Write rate* is calculated with regards to a sum of *N* tasks where the *i* index identifies individual tasks :

$$Read/Write\ rate\ (N) = \sum_{i=1}^{N} \frac{File\ size\ (i)}{time(i)} \tag{1}$$

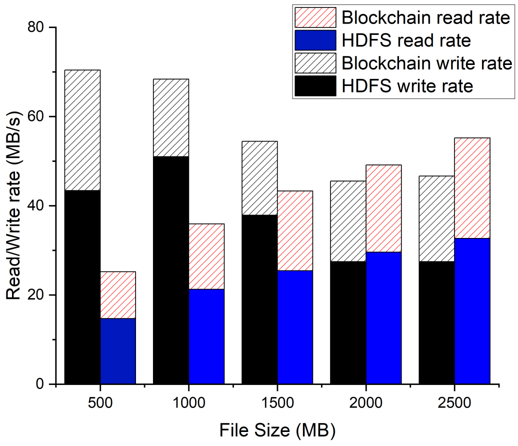

Fig 7. Read/write rate with and without Blockchain

The size of a file block is important because the length of the hashed message affects the performance of secure hash algorithms [36]. The block size of the blockchain has an impact on the throughput and latency. To evaluate the optimum block size we ran an experiment by varying the size of the block from 8 to 2048 KB. Fig. 8 shows the transaction latency with the different sizes of the block. It can be seen that with increasing the size of the block the latency increases. To obtain the latency below 10 seconds, we use the block size of 512 MB.

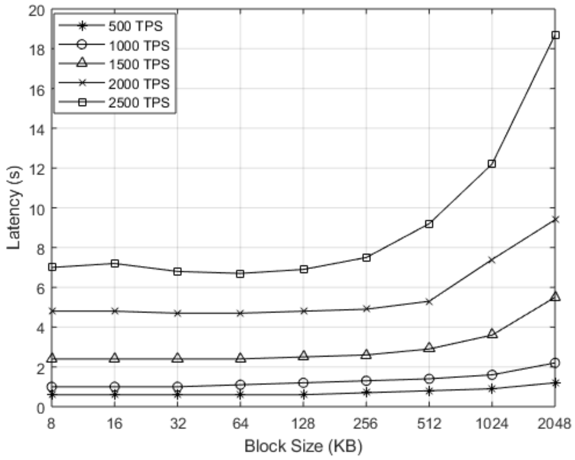

Fig 8. Impact of Block size on latency

Throughput is the number of Transactions Per Second (*TPS) [36]* that is recorded in a given time. Throughput is an important indicator to measure the performance of the system. Equation 2 [35] specifies how the *TSP* is calculated with regards to a sum of *N* tasks where the *i* index identifies individual tasks:

$$TPS(N) = \frac{\sum_{i=1}^{N} File\ size\ (i)}{\sum_{i=1}^{N} time\ (i)} \tag{2}$$

By varying the number of nodes with the file size of 1500 MB, the *TPS* of HDFS and blockchain is presented in Fig. 9. The replication factor of 3 is used for HDFS. As we increase the number of nodes the *TPS* of both HDFS and blockchain increases. Higher throughput is achieved by increasing the number of nodes. Therefore, if the number of nodes is increased the system scales linearly. Our evaluation shows that blockchain is an effective framework that can be used for data exchange between entities of the power systems. In the 2 nodes case, the ratio between HDFS Blockchain is significantly smaller than the other two is caused due to random variations in network latencies due to intermittent network connections.

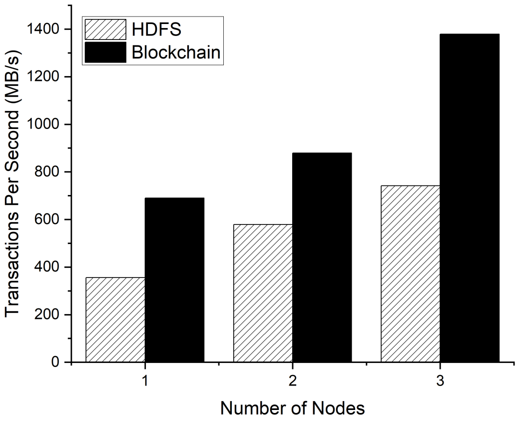

Fig 9. Performance evaluation of the proposed approach

V. LIMITATIONS AND FUTURE RESEARCH

Despite that the blockchain has several benefits, there are some challenges and limitations that need to be addressed. Scalability, speed, and the high energy costs associated with blockchain are all common challenges. Although the blockchain is generally accepted as a technology to enhance data security, still the security of blockchain remains unproven. The energy consumption for the execution of the consensus algorithm should be examined. The proposed approach in this paper provides scalability and data management. However, it currently has some limitations in terms of the maximum number of nodes that can be used with HLF. More experimental demonstrations are required for specific use cases and scenarios to evaluate the scalability, reliability, security, and data management. Different applications and scenarios to offer a more complete proof of concept and to ensure fitness for purpose in terms of integrating other components besides HDFS. The performance of the platform with an increasing number of virtual processing units will also be investigated.

VI. CONCLUSION

A novel approach for information and data exchange between TSOs, DSOs, and other potential stakeholders of the power systems is presented in this study. The proposed approach integrates blockchain and big data technologies like HDFS. The majority of existing information and data exchange platforms are centralized, resulting in a single point of failure vulnerabilities, malicious attacks, and altered data. Blockchain provides a decentralized solution to the problems with current systems. A decentralized consensus system used by blockchain can ensure trustworthy transactions of data. This new proposed platform can increase TSO-DSO interoperability, allowing the overall system to run more efficiently in terms of security of supply and congestion management. The experiments performed suggested that the proposed platform scales linearly by increasing the number of nodes. Our evaluation of a private blockchain for data exchange between different entities of power systems suggests can be used with acceptable overhead. Furthermore, experimental results show that the suggested platform can be used to share data and information in a power system.

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