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Scalability and Reliability Analysis of a Novel Cloud Platform for TSO-DSO Information and Data Exchange

Mubashar Amjad, Gareth Taylor, Chun Sing Lai, Zhengwen Huang, Maozhen Li

Department of Electronic and Electrical Engineering
Brunel University London, UK

mubashar.amjad@brunel.ac.uk, gareth.taylor@brunel.ac.uk, chunsing.lai@brunel.ac.uk, zhengwen.huang@brunel.ac.uk, maozhen.li@brunel.ac.uk

Abstract—**Reliability and performance measurement of the cloud computing platform is significant for future information and data exchange in power systems. This paper presents a novel approach for creating virtual machine clusters based on a service-oriented approach. Cloud computing techniques can be utilized to achieve greater interoperability between Transmission System Operators (TSO) and Distribution System Operators (DSO). One of the key elements of cloud computing systems is virtualization, which allows several virtual machines to be built on a single server. This research leverages cloud computing as the major platform for information and data exchange between TSO and DSO. In this work, we have performed a series of tests on the data exchange platform to test its scalability and reliability. The main objective of the proposed virtual machine clustering is to achieve high scalability and reliability.**

Index Terms— **Data Exchange, Cloudera, Distribution System Operators (DSO), Transmission System Operators (TSO), Cloud Computing Platform, Renewable Energy Sources (RES).**

I. INTRODUCTION

The large-scale increase in the integration of renewables at distribution networks has changed conventional power flows and has created new challenges for Transmission System Operators (TSOs) and Distribution System Operators (DSOs), as a consequence of limited visibility and control of the overall system [1]-[3]. In terms of congestion management, voltage control, and frequency, the overall system balance and directly related market and operating procedures are critical to ensure supply security. Balancing Service Providers (BSP) are liable for providing balancing services at the transmission level. These services are directly provided to users by BSP [4], [3]. There is a growing need for the TSOs and DSOs to improve the current observability levels on each other’s systems. The actions taken by one operator can significantly affect other system operators and is a growing concern. The replacement of traditional generation methods with renewable energy sources at transmission and distribution has reduced the overall system control over generation [5].

The distribution network is transitioning from a passive system operation mode to a more active system operation mode, allowing TSOs to profit from resources installed within the DSOs system's boundaries [6]. Therefore, the collaboration between TSOs and DSOs in terms of information and data exchange must also be strengthened to ensure the effective and efficient use of flexibility-based services throughout the system [5]. Information and data exchange between TSOs and DSOs is common practice, however, there is a need to significantly improve the levels of information and data exchange to increase overall system interoperability.

New methods have been created to strengthen the coordination between TSOs and DSOs. These approaches necessitate scalability and standardization of the information and data exchange mechanism between TSOs and DSOs [7], [8]. The amount of data that needs to be exchanged has increased as the number of flexible resources within the scope of DSO operations has grown. This is useful for strengthening coordination, and cooperation between TSOs and DSOs to operate more flexibly when managing demand and generation [9]. This improvement will help to operate the overall system more efficiently and enable the participation of new actors in the power system

The information and data exchange via the cloud computing platform is seen as a crucial future study field for smart grids. It is also worth noting that the proposed method uses a cloud computing platform method to achieve the necessary information and data exchange between TSOs and DSOs [10]. It demonstrates the benefits of using the cloud platform that enables the exchange of information and data for TSOs and DSOs. In power systems cloud computing technology, a lot of work has been done with multiple breakthroughs by peers in this field [11],[10]. Some of the complications have been simplified with this technology and similarly, it works well with power systems transient simulation that includes the calibration, and accuracy [12].

The utilization of a cloud-based distributed infrastructure to support large amounts of data storage and processing is common. HDFS is one of the most widely used file systems. Similarly, most cloud providers offer non-uniformed memory architecture nodes that can be leveraged to optimize virtual machine allocation [13]. Few efforts have recently been made to address the issues of data placement on heterogeneous storage infrastructure [14], virtual machine allocation on various servers [15], and intelligent resource allocation on the cloud [16], [17]. Virtualization technology enables cloud providers to solve energy inefficiencies by allowing several VM instances to be created on a single physical server, allowing for better resource use [18]. In current virtualization-based datacenters, virtual machine (VM) placement has become a critical topic that has recently gotten a lot of attention. However, most existing solutions focus on the placement of individual VMs and neglect the application's structural information due to the related complexity.

This paper investigates the scalability and reliability of the novel cloud computing platform from a service-oriented

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approach for virtual machine allocation for information and data exchange between TSOs and DSOs. A novel use case strategy is used that supports cloud computing as the primary platform for exchanging information and data between TSOs and DSOs using clusters of virtual machines [10]. Case studies suggest that the proposed method successfully transmits the exchange of information and data between the TSOs and the DSOs to achieve a balance with the DSO's resources.

The remaining sections of the paper are organized as follows: Section II presents the novel cloud platform design for TSOs and DSOs information and data exchange. Section III presents the demonstration and analysis of the cloud computing platform in terms of scalability and reliability. The conclusions and further research are presented in section IV.

II. A Novel Cloud Computing Platform

Fig. 1 shows the design of a novel cloud platform for TSOs and DSOs information and data exchange. Cloud computing is the on-demand availability of computer system resources, especially data storage and computing power, without direct active management by the user. Specifically, different types of actors, such as TSO, DSO, and other market participants. A web portal serves as a front end in the platform design. Defined services can be accessed by these actors through a web portal. A cluster of virtual machines is created on the physical computers that serve as a back end to support the web portal [19].

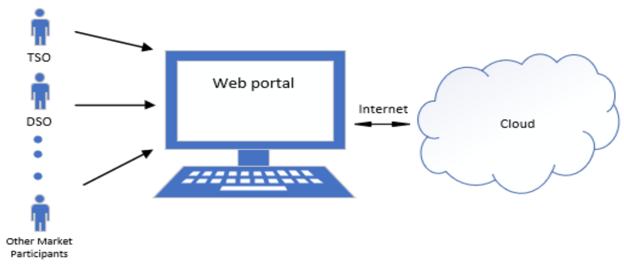

Fig 1. A novel System Design of the data exchange cloud platform

A. *TSO DSO Information and Data Exchange platform Artichuture*

A service-oriented approach is designed to provide service demand to different VMs and resource allocation. For convenient management and to increase systems efficiency, it is necessary to deploy different services to different VMs for secure operation. An example of the deployment of services, i.e., Service 1 and Service 2 on the data exchange platform is presented in Fig. 2. In terms of the service development, Service 1 could be deployed on VM 1 and VM 2, as it only involves one method and needs relatively fewer system resources. By contrast, Service 2 could be deployed on VM 2, VM 3, and VM 4, as it involves more methods and needs more system resources. Since the services are deployed on many virtual machines, they can still be accessed reliably, even if any virtual machine goes down. Similarly, more services can be deployed on the platform.

All of the architecture is structured in terms of a service-oriented approach, where all of the various activities are carried out. The user can control each virtual node directly via the associated web service. We were able to attain greater flexibility and better resource allocation as a result of this. The service-oriented approach we used to create the cluster of virtual machines will ensure a high level of modularity and interoperability.

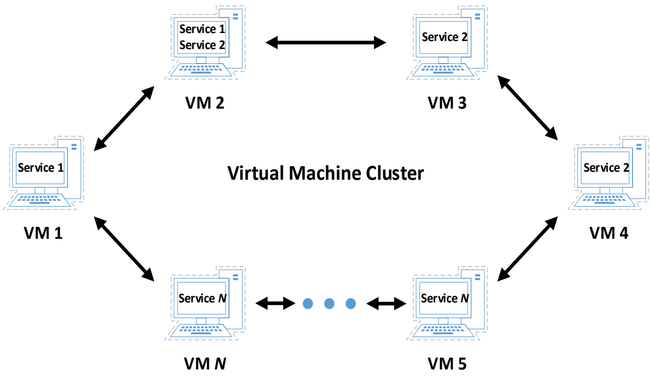

Fig 2. Service deployment on the data exchange platform

Cloudera is a scalable and highly adaptable platform that makes it simple for businesses to manage their data demands as they grow. Cloudera has pre-installed Apache Hadoop, which allows users to analyze and manage their data safely and securely [20]. The software architecture of the data exchange platform is built based on the system design. The web portal is supported by a virtual machine cluster, which comprises virtual machines created on physical systems. A Hadoop Distributed File System (HDFS) is created on top of the virtual machine cluster for data sharing between different actors within the services. The data flow between data sources and systems is automated with Apache NiFi. NiFi works in conjunction with the Cloudera data platform to provide a data pipeline for data sharing. The files are sent to the data-sharing platform from the source server. These files are uploaded to the HDFS file system once the source file is received on the platform.

Table 1 presents the detailed experimental setup for the demonstration. Simulated and real data of the CIM (Common Information Model)/XML (extensible Markup Language) format is used in the demonstration. Python as a programming language is used for coding the information and data exchange procedure between different actors.

Table I. Experimental setup for demonstration

Platform Software	Cloudera
File System	HDFS
Programming Language	Python
Number of VMs	3-120
VM Disk Size	64 GB
VM Memory	8 GB
Number of VM Processors	2
Data Format	CIM/XML
ETL Tool	Apache Nifi

B. *Bussines Use Case Description (BUC)*

BUC 1 includes two scenarios and each scenario defines a specific data exchange process between different actors. In this paper, only Scenario 1 which is Distributed Renewable Energy Sources (DRES) under incentive is implemented for BUC 1. The service which is the service operational planning activities coordination between TSO and DSO up to 72 hours ahead is extracted from BUC 1 in this particular scenario. It

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defines information flow between TSOs and DSOs to facilitate network operations programming. With up to 15-minute sample periods. The DSO can forecast load and distributed generation disaggregated by technology type and location. If communicated with the TSO and correctly aggregated, this information will allow for more efficient and stable functioning of the bulk power system. [21], [22].

BUC 2 includes five scenarios and each scenario defines a specific data exchange process between different actors. In this paper, only Scenario 2 which is development plans are implemented for BUC 2. The service which is the coordination of long-term network development plans between TSO and DSO on the TSO/DSO interface is extracted from BUC 1 in this particular scenario. It defines information exchange between TSOs and DSOs necessary for the preparation of long-term power network investment, expansion, and reinforcement plans to provide long-term network stability and robustness. The DSO and the TSO exchange their plans for future relevant changes to the current simplified network models. These could include adding new interfacing substations or HV power lines as well as removing existing substations or HV power lines. Network plans could also include reinforcement plans of either the DSO or TSO network and foreseen connection of significant grid users either in the DSO network or in the TSO network. This information is normally exchanged when a relevant change to the TSO/DSO interface is made to the plan. Considering the plans of the TSO and the DSO for the respective networks, both the TSO and DSO can identify synergies to optimize the investments and identify the best moment to execute the plans [21], [22].

BUC 3 includes two scenarios and each scenario defines a specific data exchange process between different actors. In this paper, only Scenario 1 which is real-time information exchange is implemented for BUC 3. The service which is the exchange of real-time information between TSO and DSO concerning their networks and other connected resources is extracted from BUC 3 in this particular scenario. It focuses on guaranteeing that the necessary real-time information exchange between TSOs and DSOs is put in place, aiming to enable better supervision and control of transmission and distribution networks. Furthermore, it will develop the necessary procedures to enable frequent upgrades of the TSO and DSO's observability zones. This will ensure appropriate visibility of each other's networks, independent of network topology changes over time [21], [22].

BUC 4 includes only one scenario and it defines a specific data exchange process between different actors. In this paper, Scenario 1 which is fault occurrence, detection, and information exchange is implemented for BUC 4. Service location of faults at distribution network lines, connected to the interface with the transmission network is extracted from BUC 4 in this particular scenario. Its specific goals include improving the location of faults on distribution lines near the transmission network's interface and optimizing DSO operations. It concentrates on DSO-owned and operated distribution lines that are directly connected to TSO-owned and operated transmission bays. The DSO can increase the location accuracy of faults on its distribution lines by having access to information collected on the TSO side in transmission bays connecting distribution lines. This necessitates the sharing of new data in real-time between both system operators [21], [22].

III. Performance Measurement

In this section, the benefits of the data exchange cloud platform designed are analyzed in detail from two different aspects, which are scalability and reliability respectively.

A. Scalability

Experiment with services extracted from BUC to evaluate scalability first. In this experiment, it is assumed that several TSOs interact with multiple DSOs to exchange data in services extracted from BUC.

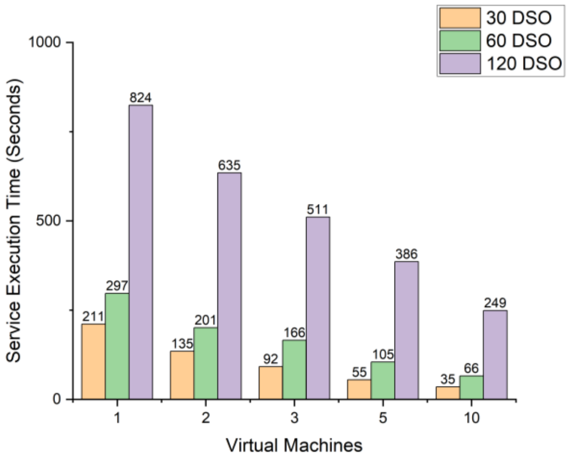

Fig 3. Service execution time for BUC 1 involving 1 TSO and increasing numbers of DSOs

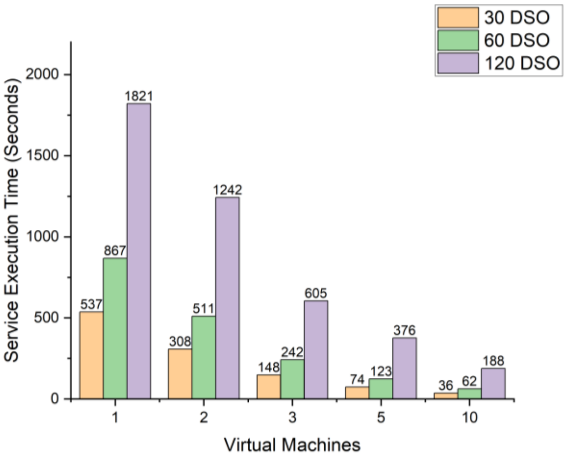

Fig 4. Service execution time for BUC 1 involving 2 TSOs and increasing numbers of DSOs

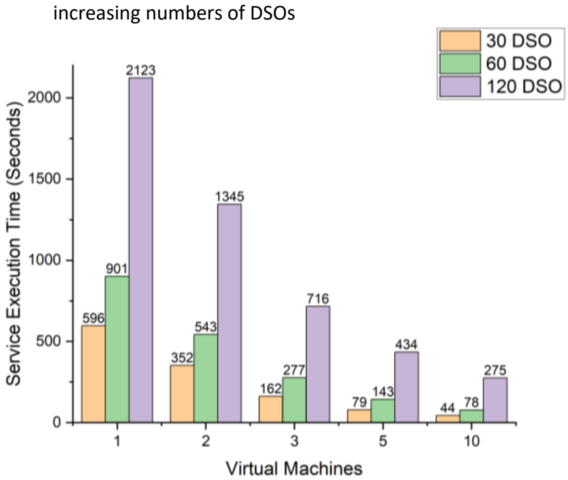

Fig 5. Service execution time for BUC 1 involving 3 TSOs and increasing numbers of DSOs

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Fig. 3 shows that as the number of DSOs increases from 30 to 120, the service execution time increases almost linearly. This is mainly because more actions and data to be exchanged are required, and more DSOs participate in the service. In addition, regardless of the number of DSOs, the service execution time decreases almost linearly, and the number of virtual machines increases from 1 to 10 because the actions of the service are distributed on each virtual machine with the same specifications and configuration. Similarly, in Fig. 4 and Fig. 5, although 2 or 3 TSOs are participating in the data exchange process, the same conclusion can be drawn because the same number of actions are distributed on the virtual machine cluster. With this system, we have achieved linear performance scaling, even as we add more resources, proving that the system is highly scalable.

Similarly, experiments were performed on services extracted from BUC 1, BUC 3, and BUC 4 to evaluate scalability. In this experiment, assume that 3 TSOs interact with 60 DSOs to exchange data in services extracted from BUC 1, BUC 3, and BUC 4. Fig. 7 shows the service execution time of three BUCs deployed on different numbers of virtual machines.

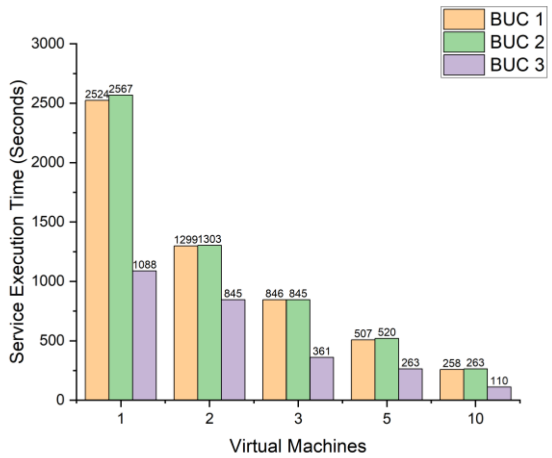

Fig 6. Service execution time for increasing virtual machines in the three cases

In Fig 6, regardless of BUC 1, BUC 3, or BUC 4, as the number of virtual machines increases from 1 to 10, the service execution time decreases drastically. This is mainly because all actions and data DSOs required for data exchange between TSOs are distributed on more virtual machines so that more computing and storage resources can be used to speed up the data exchange process. It can also be inferred from this that as the number of virtual machines continues to increase, the service execution time will further decrease, and the marginal benefit is relatively small. However, after the number of virtual machines reaches a certain level, the service execution time will fluctuate around a certain level. A certain value is due to the management workload of the virtual machine cluster.

Finally, the services extracted from the four BUCs are deployed on different numbers of virtual machines to evaluate scalability. In this experiment, it is assumed that the services extracted from each BUC involve 2 TSOs and 30 DSOs. In addition, all services are executed simultaneously on the virtual machine cluster. The following service deployments were explored:

Case 1: BUC 1, BUC 2, BUC 3, and BUC 4 are deployed only on VM 1
Case 2: BUC 1 and BUC 2 are deployed on VM 1, and BUC 3 and BUC 4 are deployed on VM 2
Case 3: BUC 1, BUC 2, BUC 3, and BUC 4 are deployed on VM 1, VM 2, VM 3, and VM 4 respectively.

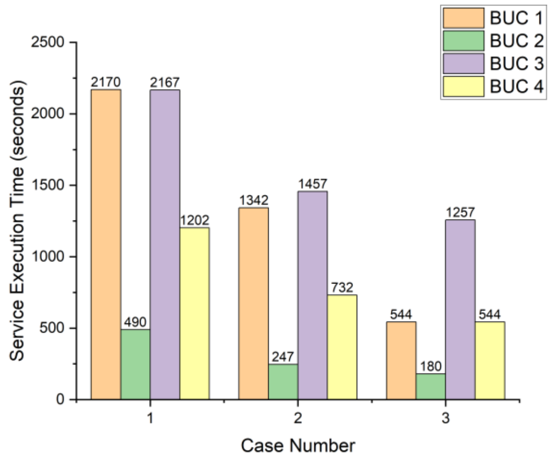

Fig 7. Data storage of different actors of BUC in the local file system before data exchange through the cloud platform

In Fig. 7, you can notice that in Case 3, the total service execution time (green) is the shortest because each service is executed on a virtual machine with sufficient computing and storage resources. In contrast, Case 1 has the longest total service execution time because all services are executed only on a virtual machine that shares computing and storage resources.

In summary, to evaluate the scalability of the data exchange cloud platform designed, three different experiments were conducted. Experimental results show that the designed platform has a high degree of scalability and flexibility. In other words, as more virtual machines are included in the cluster, the platform is designed to support more services, exchange more data, and involve more participants at a higher execution speed.

B. Reliability

Three different deployments of services extracted from BUC 1, BUC 2, BUC 3, and BUC 4 were explored to evaluate reliability, as shown in the Figures below. The virtual machine cluster in Fig. 8(a) is the most reliable of all three deployments. This is mainly because the services extracted from each BUC are deployed and executed on at least two different virtual machines. Therefore, even if any virtual machine in the cluster is destroyed, the service can still be reliably supported. However, the other two clusters in Fig. 8 (b) and Fig. 8 (c) cannot support all services when one virtual machine in the cluster is threatened. In particular, the virtual machine cluster in Fig. 8 (c) cannot support any services. If a virtual machine is compromised, all services are deployed on the virtual machine because the cluster consists of only one virtual machine. Therefore, it can be inferred that the data exchange cloud platform designed will be more reliable, flexible, and robust.

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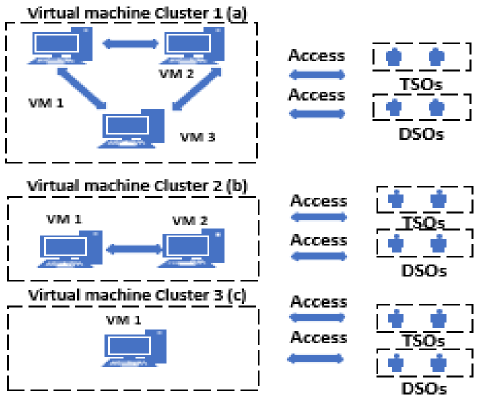

Fig 8. Virtual Machine Clusters for reliability analysis

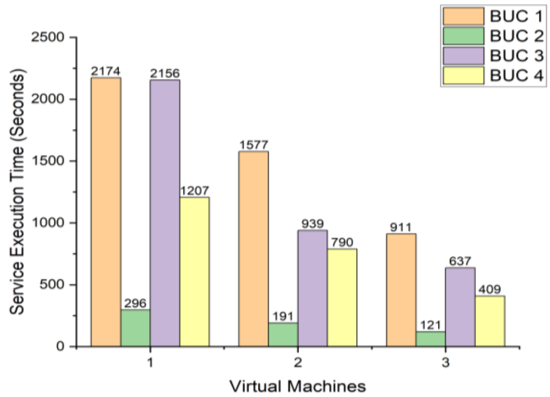

Fig 9. Service execution time for four BUCs on the three virtual machine clusters

Fig. 9 describes the service execution time of the corresponding BUC deployment on the three virtual machine clusters, involving 2 TSOs and 30 DSOs during the data exchange period. you can notice that the total service execution time is the shortest when we have there are three virtual machines in our cluster as compared to cluster 2 and cluster 3.

IV. Conclusion and Future Research

In this paper, the advantages of applying cloud computing techniques to information and data exchange platform design are elaborated on two key aspects: scalability and reliability. The proposed cloud platform is capable of handling more users allowing them to exchange information data at a very high speed and volume. The information and data exchange platform has been tested with a range of use cases. The results gathered from these tests confirm that the designed platform is widely applicable for exchanging information and data between TSOs and DSOs in the future. This cloud platform will help facilitate greater interoperability between the different market participants of the system.

From the series of experiments conducted it is evident that the data exchange platform is scalable and reliable for exchanging data between the actors of the power system. Moreover, it enables the actors to access the services through a web portal, and different actors can access different services based on their roles or needs. More demonstrations will be conducted for various situations and scenarios in order to give a more complete proof of concept and check fitness for purpose in terms of priority information, data requirements, and interfaces. The trade-off between the number of virtual machines and corresponding execution times required for a given data package will be further investigated.

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