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Development of a Web-based Information Exchange Platform for Enhanced Distribution Utility-Consumer Communication in the Nigerian Deregulated Electricity Market

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ABSTRACT

This work developed a web-based platform that can facilitate effective exchange of information between distribution utilities and consumers in the Nigerian deregulated electricity market. The basic components of the platform (Graphical User Interface 'GUI' and database) were analysed and designed using Object Oriented Architecture. Object attributes such as consumers' profiles, consumed energy, bills, payments, forecast tool and helpdesk were employed in the implementation of the components. GUI, usability, portability and load tests were conducted on the platform to examine its performance. The developed GUI and database were functional when operated. The tests conducted revealed that the platform exhibited typical characteristics of web applications and is useful. The developed platform, if adopted by the Nigerian deregulated electricity market would enhance smooth communication between distribution utilities and consumers for improved service delivery and efficiency.

1. INTRODUCTION

Recently the Nigerian vertically integrated and monopolistic electricity market was unbundled and restructured through the Electric Power Sector Reform Act (EPSRA) of 2005 (Boniface, 2014; Makwe *et al.* 2012; Adoghe *et al.*; 2009; Amoda, 2007). The reform was meant to, among others, allow creation of competitive market through private utilities participation in the electricity business operations with the overall goal of improving service delivery and efficiency.

Electricity being an essential commodity for the socio-economic development of any nation has become an integral component of every daily life that its delivery to consumers needs to be enhanced. In the chain of electricity supply, electric power from generation plants through the grid reaches the consumers or end-users from the distribution network. This indicates that distribution utility as an entity in the Nigerian deregulated electricity market occupies a unique position, being the final link to the consumers. Hence, distribution systems along with consumers form one of the key elements of any electricity supply system. However, in a developing nation such as Nigeria, consumers are often faced with series of challenges from the distribution segment of the electricity market. These include issues concerning deplorable state of electricity service delivery, fault rectification in the vicinities of the consumers, inaccurate, irrational and

delay in bill processing, bill payment, ineffective means of communication with the distribution companies to highlight few.

The only way for consumers to address some of these lingering problems in most cases is to visit the servicing distribution utility in person to make a request or lodge complaints officially. Even in some cases, despite several visitations and requests or complaints, the problems may persist. This is not only tedious but a serious time wasting exercise in this civilised era, considering the level of advancements in the field of Information and Communication Technologies globally. Therefore, there is the need for a robust, flexible and versatile information exchange platform that can facilitate smooth communication between distribution utilities and consumers in the deregulated electricity market in Nigeria for effective and improved service delivery.

To develop an efficient information exchange platform that can handle the need of a deregulated system such as business processes between distribution utilities and consumers in the Nigerian deregulated electricity market, the use of innovative technology such as web service is imperative. Web service is one of the important internet services (Shikha and Pratibha, 2016; Chen *et al.*, 2015) and its emergence has led to widespread popularity of web applications (Cerny and Donahoo, 2010) which have revolutionized business domains (Sharma, 2014). Web applications are self-contained, self-describing, modular applications that can be published, located and invoked by other software systems across the web (Shikha and Pratibha, 2016). Most enterprises today have adopted web applications for e-commerce, e-business, content management, advertisements, banking services, different email services like Google, Yahoo and Gmail among others (Das *et al.*, 2015; Cassone *et al.*, 2001, Sharma, 2014). Hence, as a result of open standardization of communication protocols, extensible information representation, pervasive internet technology and advantages of service oriented architecture, research efforts recently in the field of power system engineering are geared towards adoption of web service for secure operations in electricity industry (Lim *et al.*, 2013; Dada, 2012; Tomsovic *et al.*, 2005; Xie *et al*., 2005; Dada, 2002; Qiu *et al*., 2002).

Dada (2014) proposed web service-based architecture for information integration in the Nigerian deregulated electricity market environment. The proposed architecture provides an open, flexible and reliable scheme to automate information and data exchange for efficient business processes of the electricity market system. Dada (2013) presented a conceptual model for developing an information exchange framework for the deregulated electricity market in Nigeria using an object oriented approach. The proposed model called INFOXNET which can be adopted for power system information exchange application is robust, scalable and requires less maintenance. Anbalagan (2013) developed a synchronized and reliable notification system for power distribution network using a secure and scalable web application framework. The system uses web service to automatically update power system operators with outage or restoration information due to data changes with respect to the operational status of the power systems.

Chen *et al.* (2006) proposed web service infrastructure for information integration in power systems. The infrastructure which is robust and expandable has higher cooperation and integration capacity that can overcome the limitations of the traditional point-to-point or gateway solutions to the information integration problems in power systems. Morante *et al.* (2005) developed web services workflow for power system security assessment. The workflow addresses many challenging issues regarding power system security assessment such as interoperability and service integration. Although these research efforts have dealt with various aspects of information exchange application in power system using web service or related technology, however, enhancing the communication gap between distribution utilities and consumers for effective business interactions with these computer technologies is one key area that has not received significant research attention.

Therefore, in this work, a web-based information exchange platform was developed to enhance communication between distribution utilities and consumers in the Nigerian Deregulated Electricity Market.

2. METHODOLOGY

Modelling of the Information Exchange Platform

An object oriented model of the Nigerian deregulated electricity market is shown in Figure 1.

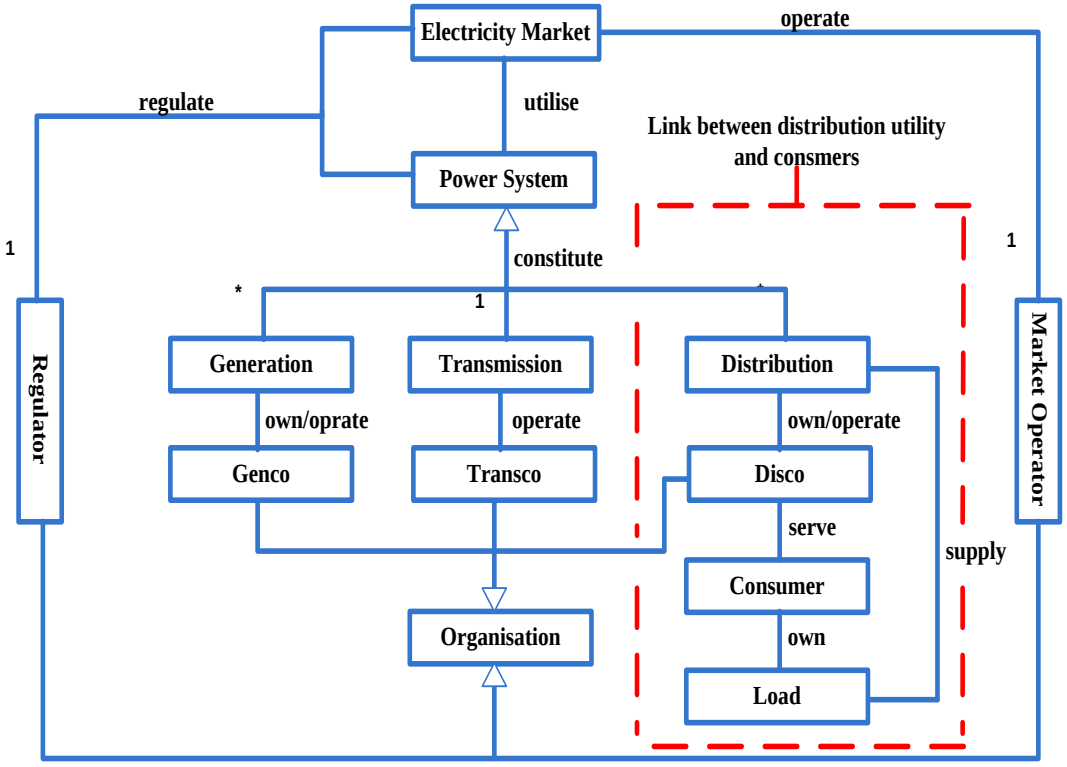

Fig. 1: Object oriented model of deregulated electricity market in Nigeria

Generation companies (Gencos), transmission company (Transco), distribution companies (Discos), market regulator, market operator and consumers are the various entities within the market system. While Gencos, Transco and Discos form the core of power system, consumers complete the chain of power system being the end-users of the electricity produced and are connected to the distribution network. Market regulator and market operator on the other hand complete the electricity market structure by ensuring smooth running of business operations between different organisations. The market regulator implements policies and ensures compliance to the market rules and regulations whereas market operator oversees the market and commercial arrangements between the entities. Since distribution utilities and consumers form important elements of the electricity market system and are inseparable, smooth communication or exchange of information between the two entities is vital to the overall success of the market. The information exchange platform architecture resulting from the electricity market model of Figure 1 is shown in Figure 2.

Figure 2 is a multi-tenant web-service based information exchange platform architecture. It allows the tenants (Gencos, Transco, Discos, Market Regulator and Market Operator) to share pool of resources such as networks, servers, storage, applications and service often over the Internet. The focus of this work is, however, on the distribution segment of the architecture since it is the link that connects the consumers.

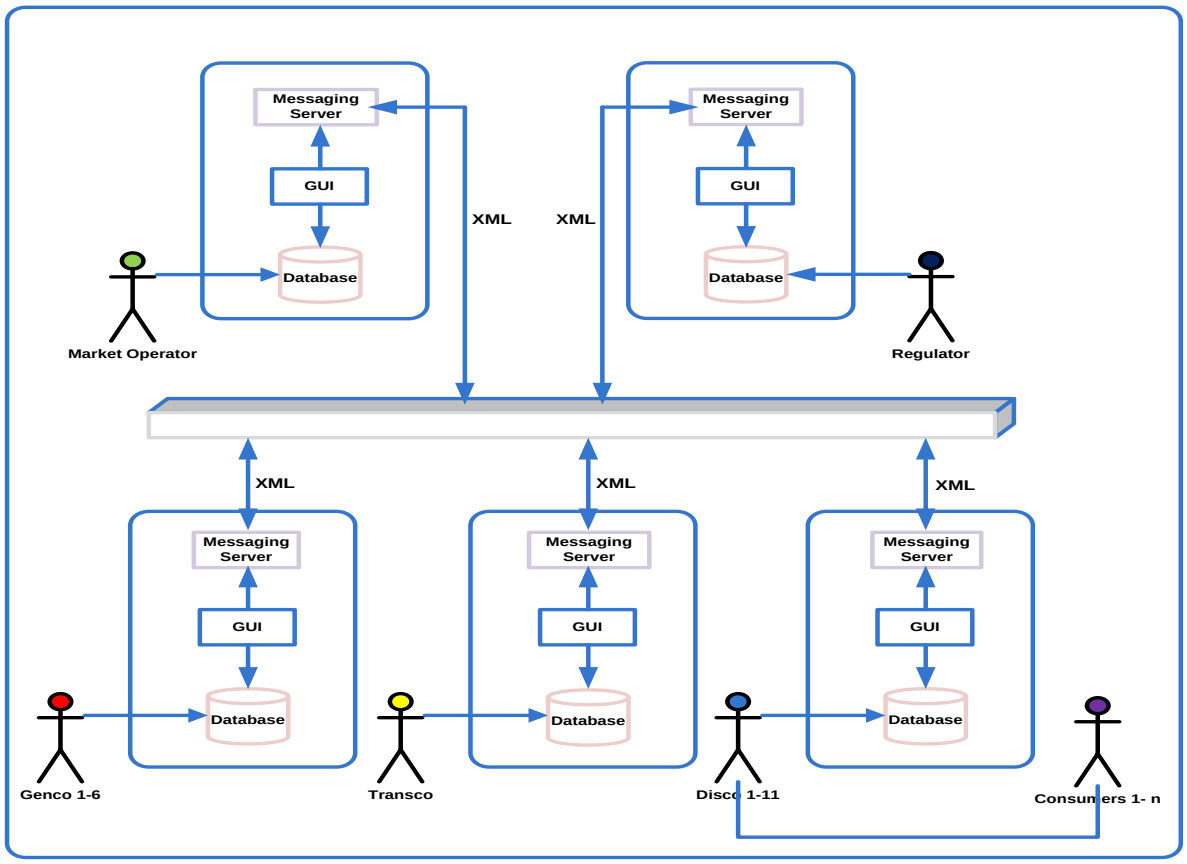

Fig. 2: Information exchange platform architecture of the Nigerian deregulated electricity market (Adebisi *et al.*, 2019)

Design of Disco-Consumer Interface

Disco-Consumer interface is an interface through which the consumers (either prepaid or postpaid meter users) interact with the servicing distribution company to perform different activities such as checking and payment of electricity bill, recharging of prepaid meter cards, request making, comments on service delivery among others. At the consumer end of the interface, consumer sign-up and sign-in interface, bill record interface, bill payment interface and helpdesk are accessible. Disco as the administrator of the Disco-Consumer interface has administrator sign-up and sign-in interface, bill calculation interface, bill payment history interface and helpdesk accessible only to authorised personnel.

Consumer sign-up and sign-in interface

The distribution company creates accounts for consumers (either prepaid or postpaid meter users) on the consumer registration interface available on the Disco dashboard using the procedures presented in the activity diagram shown in Figure 3. Basic information such as surname, first name, other name, phone number, e-mail address, service address, consumer type, meter type, meter number etc. are required for registration. After registration, the Disco provides registration number and pin for consumers to serve as the user's login details (username and password). Figure 4 shows the flow chart for the consumer login and various accessible consumer sub-interfaces.

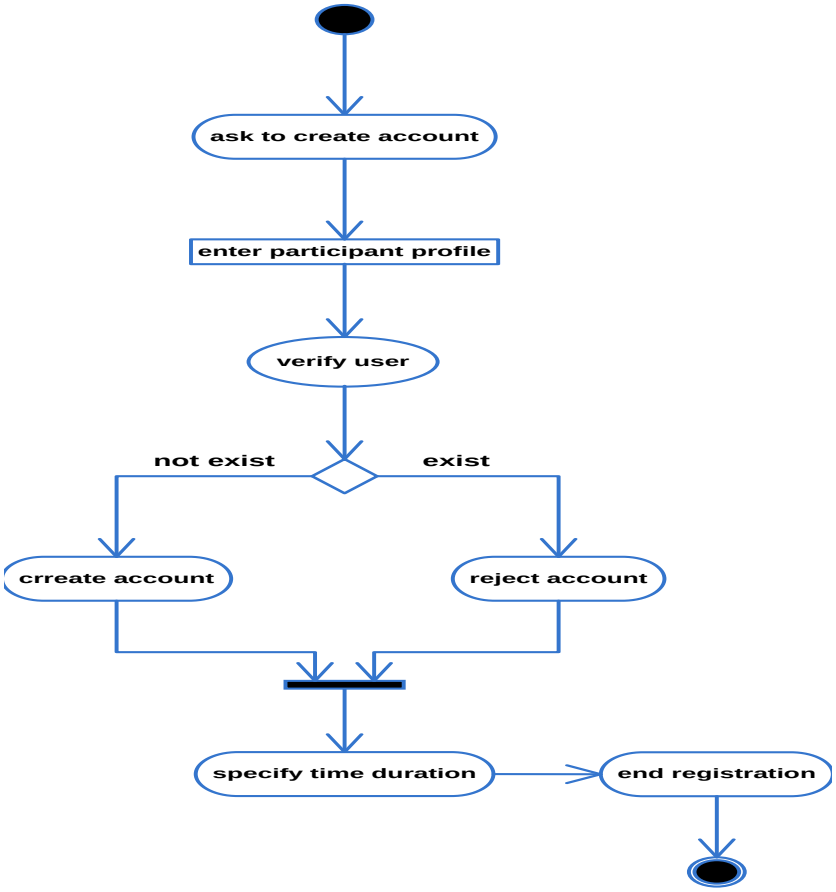

Fig. 3: Activity diagram for registration of consumer

Bill record interface

On this page, consumers (specifically postpaid meter users) can check details of electricity bill for a particular period and make payment. The bill is calculated, processed and sent by the distribution company to the consumers. However, for prepaid meter users, this interface is slightly modified because prepaid cards with which consumers can purchase electrical energy from Disco are involved. Information such as consumer's name, consumer's service address, consumer's type, meter type, meter number, date of last energy purchased, amount paid, kWh of energy purchased, total time for which energy purchased can last, kWh of energy used and left can be checked on the interface by the users.

Bill payment interface

This is a page where postpaid meter users after checking the bill of electricity consumed over a period can pay. The prepaid meter users can also recharge their accounts through this interface. For bill payment or recharge, consumers need to specify information such as the third party bank where payment is to be debited, payment card (ATM card) details such as the card number and CVV, amount to pay or recharge among others. After completion of the process, the consumer will receive a message acknowledging the payment of bill or recharge from Disco when such a Disco has received payment or recharge notification from the involved third party bank.

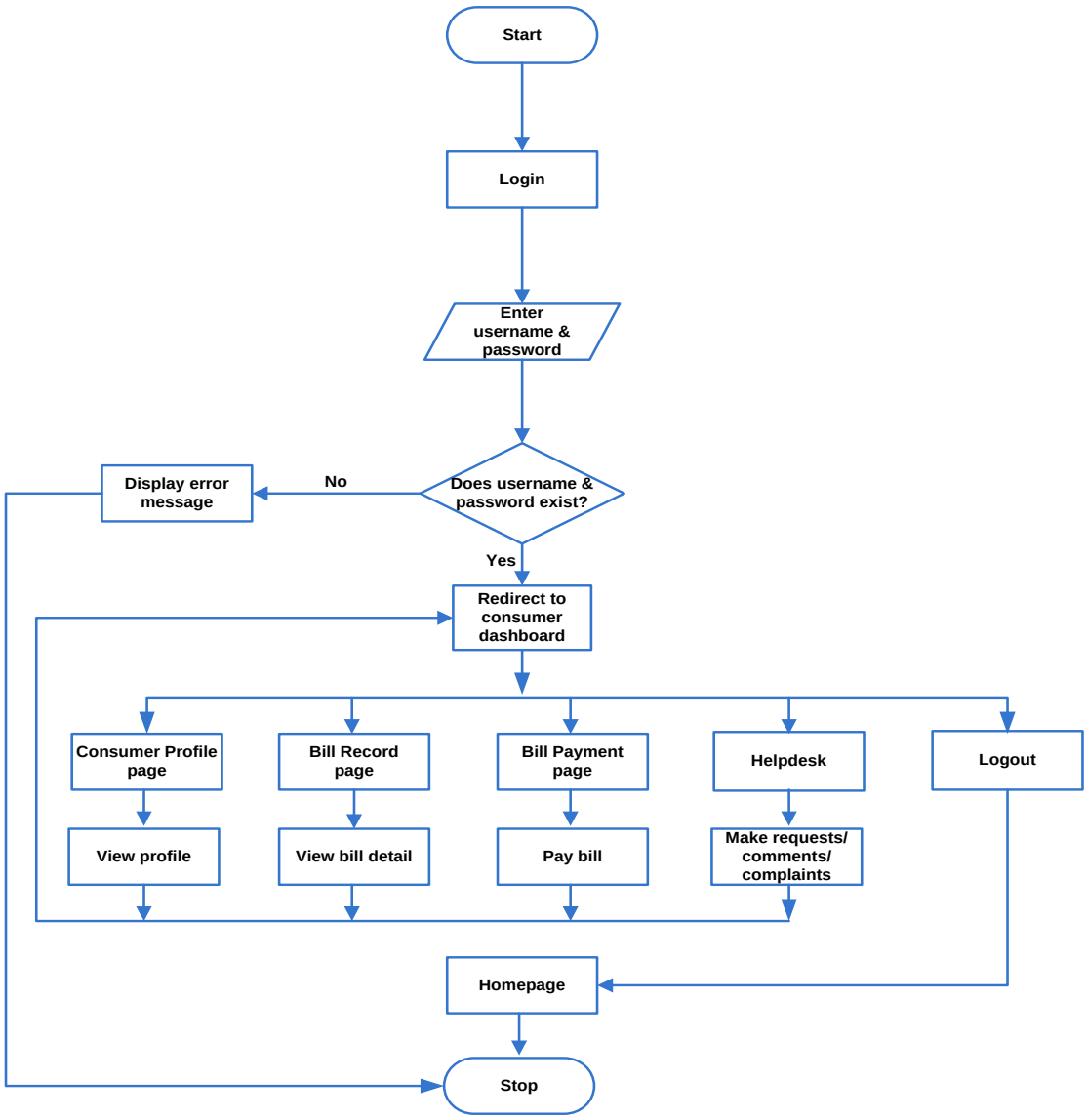

Fig. 4: A flow chart for consumer login and various accessible sub-interfaces

Helpdesk

Helpdesk also called support is an interface where consumers can communicate with Disco. The communication, in form of message, can be a comment on the quality of service rendered by the Disco, request for fault rectification in the consumer service area, request by consumer regarding bill settlement with Disco or other important information that can improve the service delivery from the Disco. The interface contains sub-interfaces where the consumers can make requests, view sent and received messages.

Administrator sign-up and login interface

A consumer needs an administrator. Distribution Company is the administrator of the Disco-Consumer interface. The administrator processes any information that relates to the consumers. For any assigned personnel from Disco to sign up, the user is required to create an account by filling the necessary object fields. With the created account, the user can login into the information exchange platform to perform

different activities in relations to the consumers. Figure 5 is a flowchart for the administrator sign-up and login and various functions that can be performed.

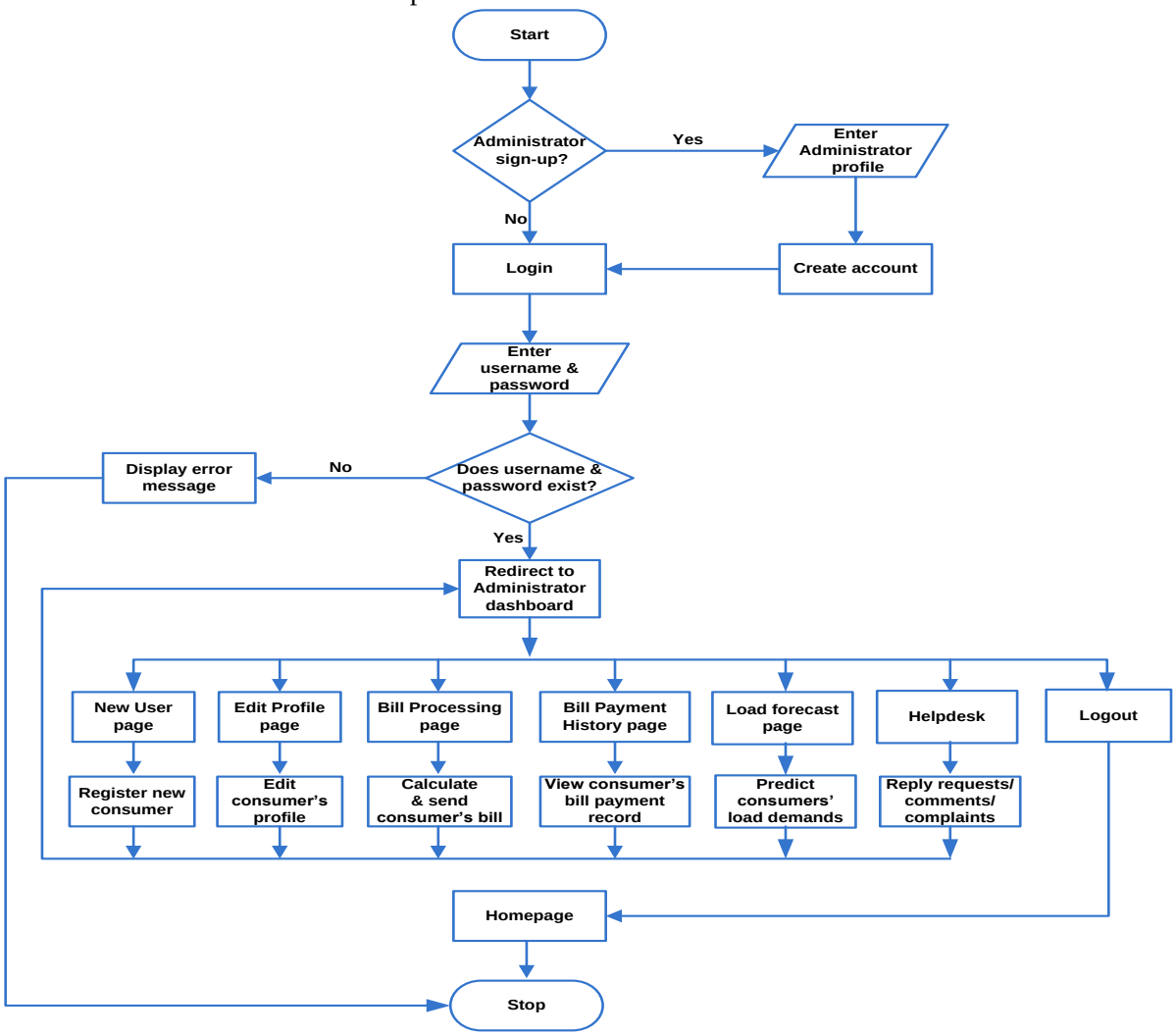

Fig. 5: A flowchart for the administrator sign-up and login and various accessible sub-interfaces

Bill calculation interface

This is a page where the consumers' bills are processed. To calculate the bill of energy consumed or energy purchased on recharge for a consumer, some parameters are required. The required parameters for postpaid meter users include present meter reading (P_s in kWh), previous meter reading (P_v in kWh), consumption (C_o in kWh), rate (R in ₦/kWh), current charge (C_c in ₦), Value Added Tax (VAT in ₦) and arrears (A in ₦) if available. Figure 6 is a flowchart for processes involved in bill calculation for consumers using postpaid meter.

However, for consumers using prepaid meter, the processed highlighted by the flowchart in Figure 6 was modified as presented in Figure 7 to determine the energy purchased (E_p in kWh) on recharge, time equivalent of energy purchased (T_{Ep} in h) on recharge, total energy available for use (E_T in kWh) and total time equivalent available for energy usage (T_{ET} in h). A_m, d_l, E_b, T_{Eb} are respectively amount in ₦ to be paid for energy recharge, consumer's demand level in kW, energy balance in kWh from previous recharge and time equivalent of E_b in h.

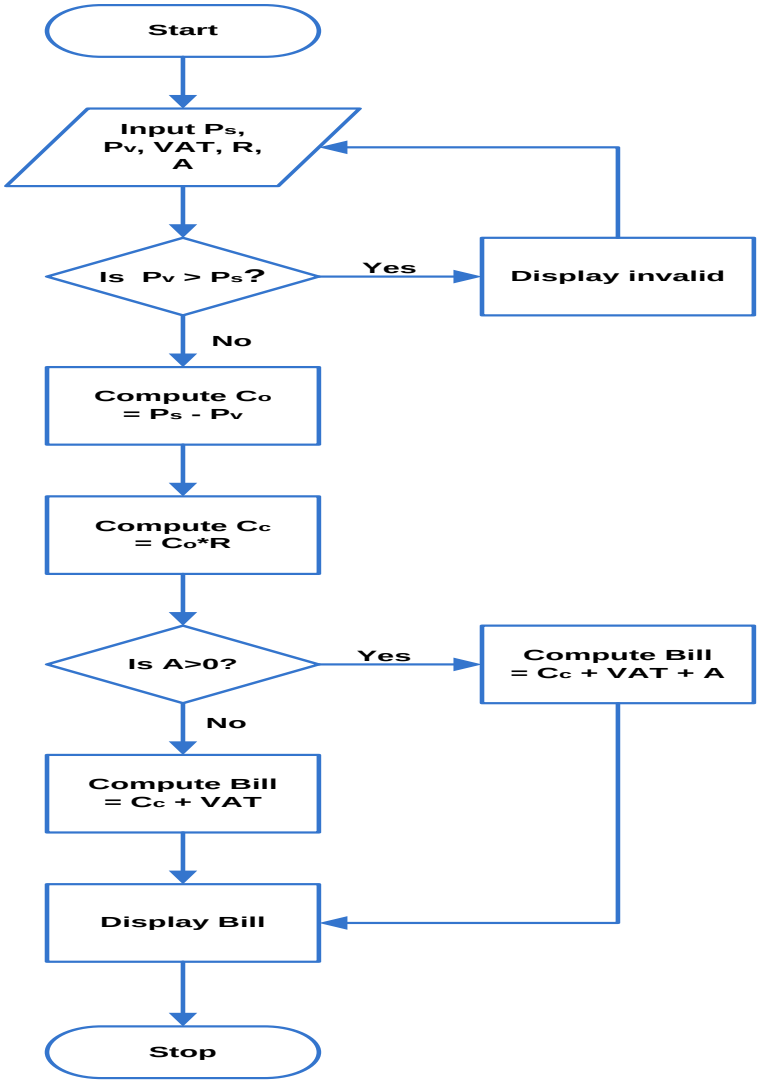

Fig. 6: Flowchart for computing bill for postpaid meter users

Database System

For the purpose of this work, a relational database server was used for the logical data organisation while Structured Query Language (SQL) which was used for data access and manipulation in the database was implemented using Microsoft SQL (MSSQL) server. The data handled by the distribution company in relation to the consumers in the database system are categorized as user administration data, meter data, bill settlement data and messaging service data.

User administration data

The user administration data basically are used for the control of who accesses the information exchange platform. The three tables available for data storage in this segment include:

i. Users: user id, password, registration information.
ii. Groups: group id and name. The group can be residential, commercial or industrial consumers.
iii. User Group: mapping of users to groups.

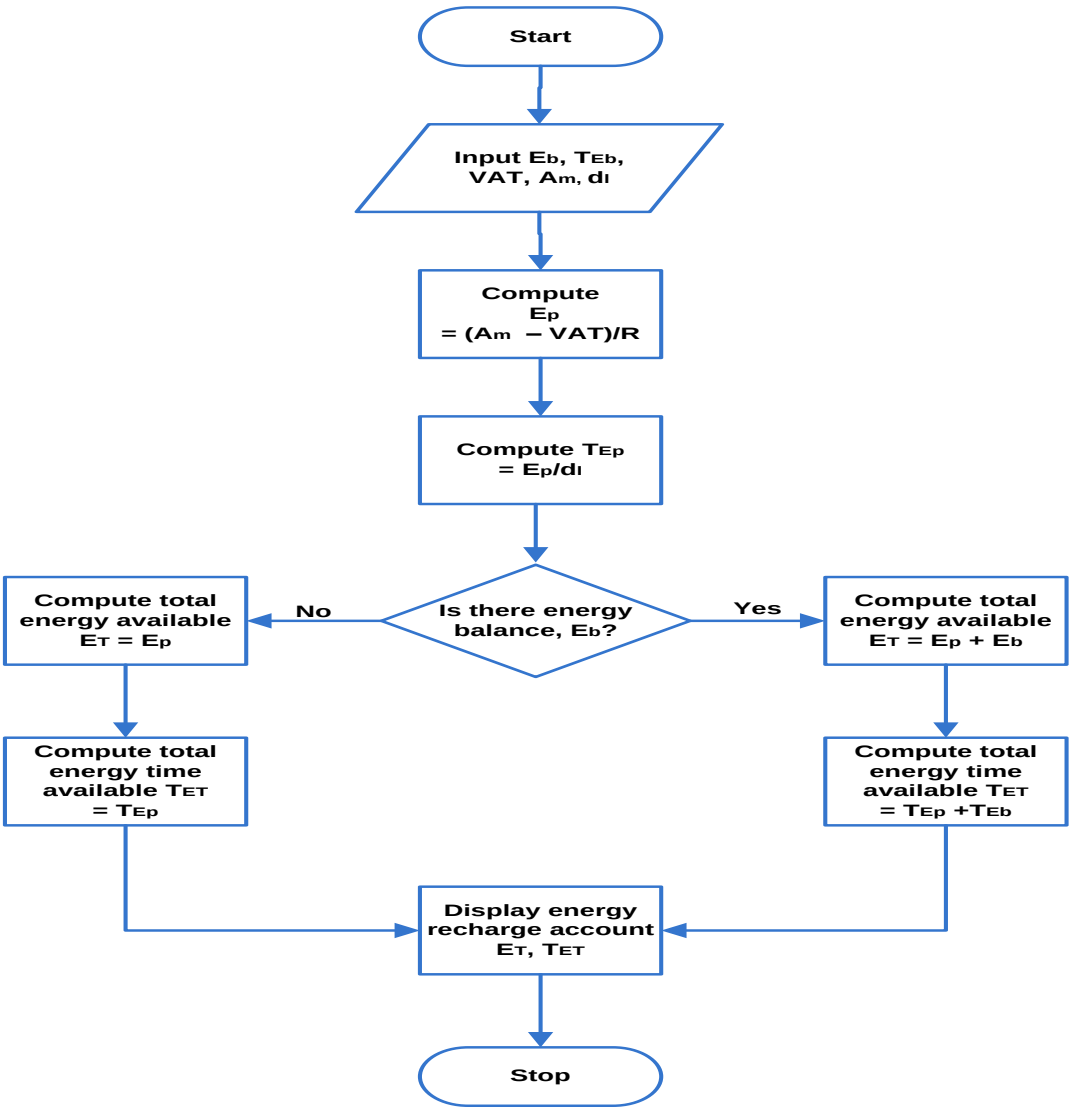

Fig. 7: A flowchart for energy recharge by prepaid meter users.

Meter data

The meter data deal with all the information regarding the consumer meter(s). The tables available for data storage in this segment are:

i. Meters: meter id, user id and meter information.
ii. Meter Reading: mapping of reading from meter to the user and the reading will be in terms of the kWh of energy consumed (for postpaid meter users).
iii. Energy purchase: mapping of the amount of energy to purchase with the user's meter (prepaid meter users).

Messaging services data

The messaging services data involve all interactions between users and Disco in the form of session where requests and responses can be made. Hence, a session can be a mere communication (request and response) or business transaction. The tables in this section are:

i. Communication Session: session id, user id, message exchange and session duration. Here, the user can be residential, commercial or industrial consumers.

ii. Business Transaction Session: transaction id, user id, transaction type, number of transactions, transaction periods, dispatch periods etc.

Bill settlement data

The bill settlement data deal with the billing aspect of the electricity business transaction between Disco and consumers. The main tables in this section are:

i. User: user id, name and user information.
ii. Group: group id and name. The group here can be residential, commercial or industrial consumers.
iii. User Group: mapping of users to group.
iv. User Bill: bill id, user id, energy supplied, energy consumed, dates of energy supply, duration of energy supplied, amount billed.

The business logic that connected the database subsystem with the GUI subsystem was implemented using C# programming language along with other web programming frameworks such as HyperText Mark-up Language (HTML), Cascading Style Sheets (CSS), JavaScript and ASP.NET.

Testing of the Information Exchange Platform

Having developed the web-based information exchange platform, the system was hosted and tested to assess its performance. GUI, usability, portability and load tests were conducted on the platform. GUI test was used to validate the performance of the GUI (menus, buttons, dialog boxes, icons etc.) on the platform whereas the usability test was used to examine the ease of use of the platform by different users. Portability test was performed to determine whether the platform supports cross platform. Load test on the other hand was conducted to assess the performance (specifically response time in seconds and throughput in requests per second) of the platform under varying workload. The GUI, usability and portability tests were carried out with 40 randomly selected users each with a laptop (mini or big), a mobile phone (Android or iPhone) and internet facility.

The users after being provided with the website address of where platform was hosted and the login detail (username and password), were requested to separately access the platform from their laptops and mobile phones to examine the platform's accessibility, ease of use and GUI functionality with each criteria ranked as high or low. The users' perspectives were analysed using simple percentage. The load test was performed with a simulator (visual studio online testing tool) and the user loads vary between 10 to 50 concurrent users. The platform's response time and throughput were determined during the simulation. While response time is the time between the request and first response that is received by the user, throughput is the amount of work that can be performed by a system or component in a given period of time (Kattepur and Nambiar, 2015).

3. RESULTS AND DISCUSSION

The Developed Information Exchange Platform

Some of the basic interfaces of the developed web-based platform to facilitate exchange of information for smooth communication between distribution utilities and consumers in the Nigerian deregulated electricity market are presented in Figures 8 to 11.

Figure 8 is a login page into the information exchange platform where personnel from Disco end or consumers can access the platform. While Figure 9 shows a page where the Disco can register consumers by filling the necessary object fields, Figure 10 is a page where the distribution utility can project the load demand of consumers. Figure 11 is an interface where the consumers check all the recent payment or recharges.

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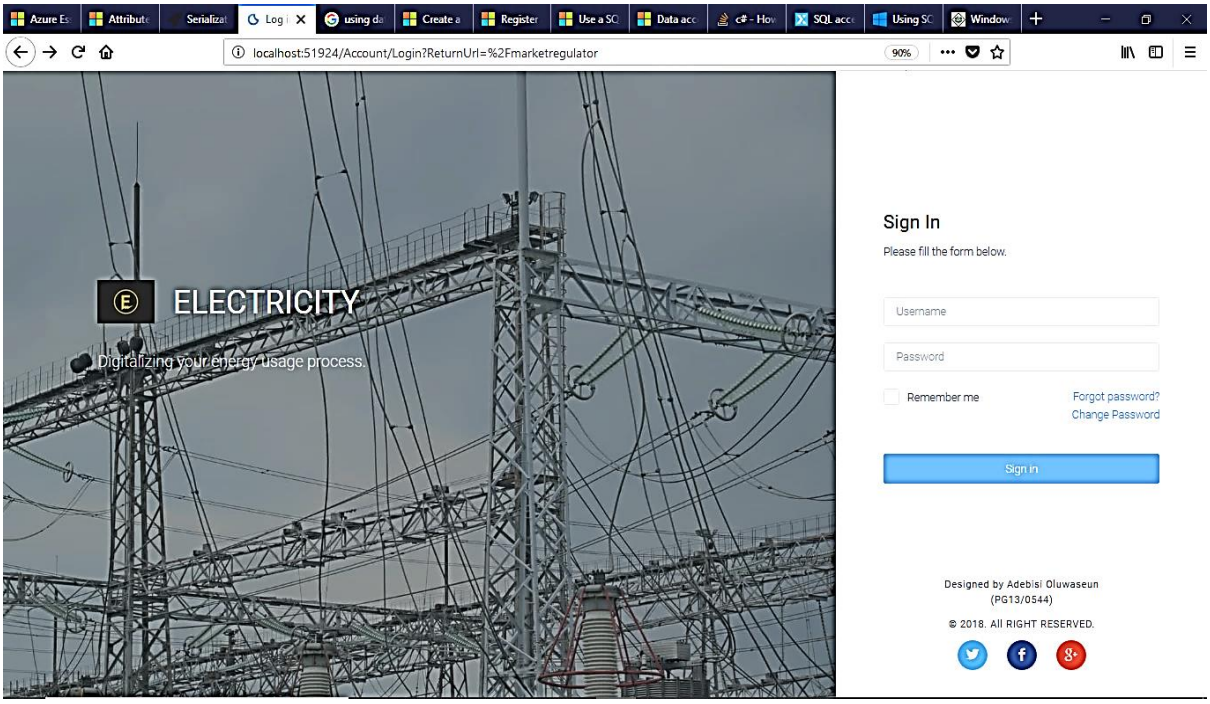

Fig. 8: Sign-in interface of the information exchange system

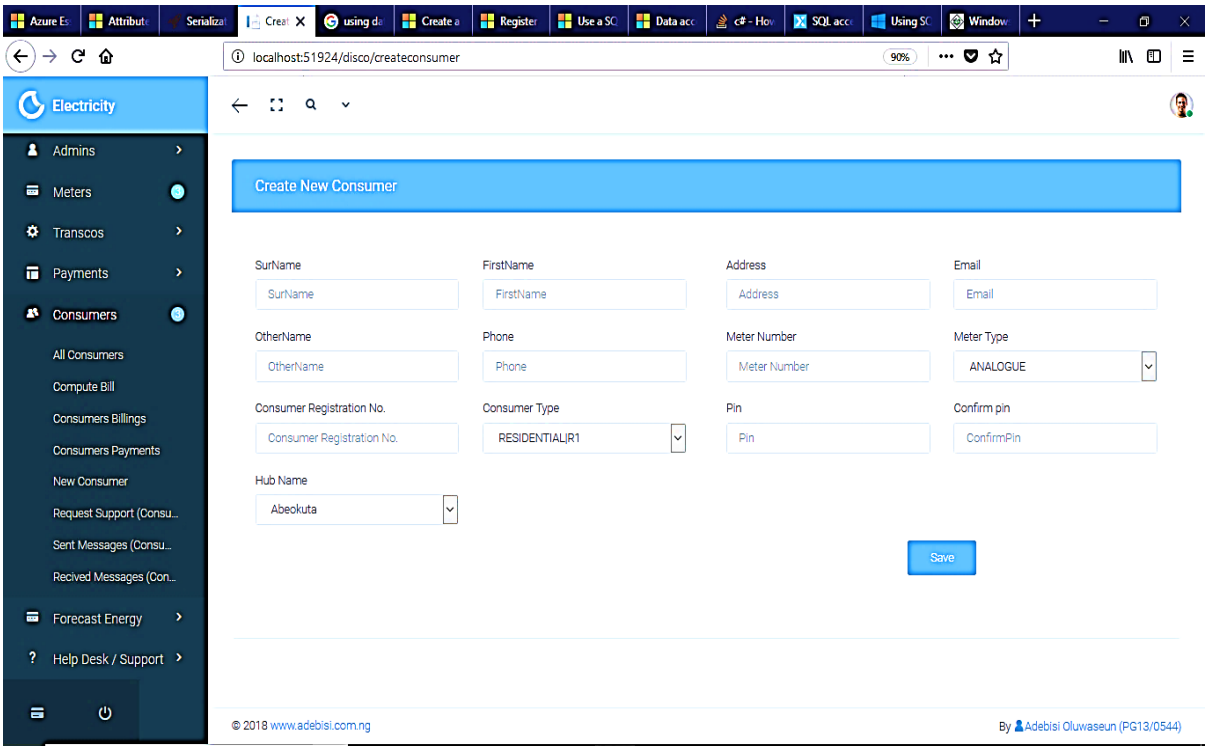

Fig. 9: Consumer's registration page on Disco Interface

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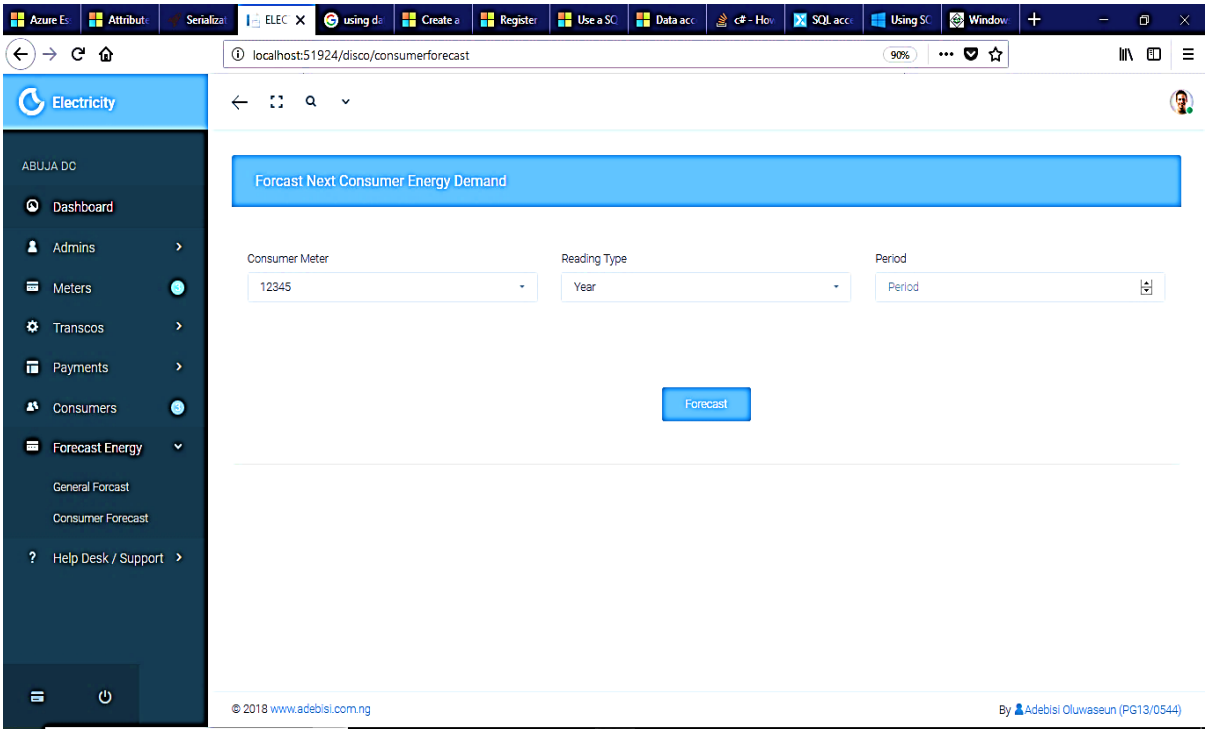

Fig. 10: Consumers' load forecast page on Disco interface

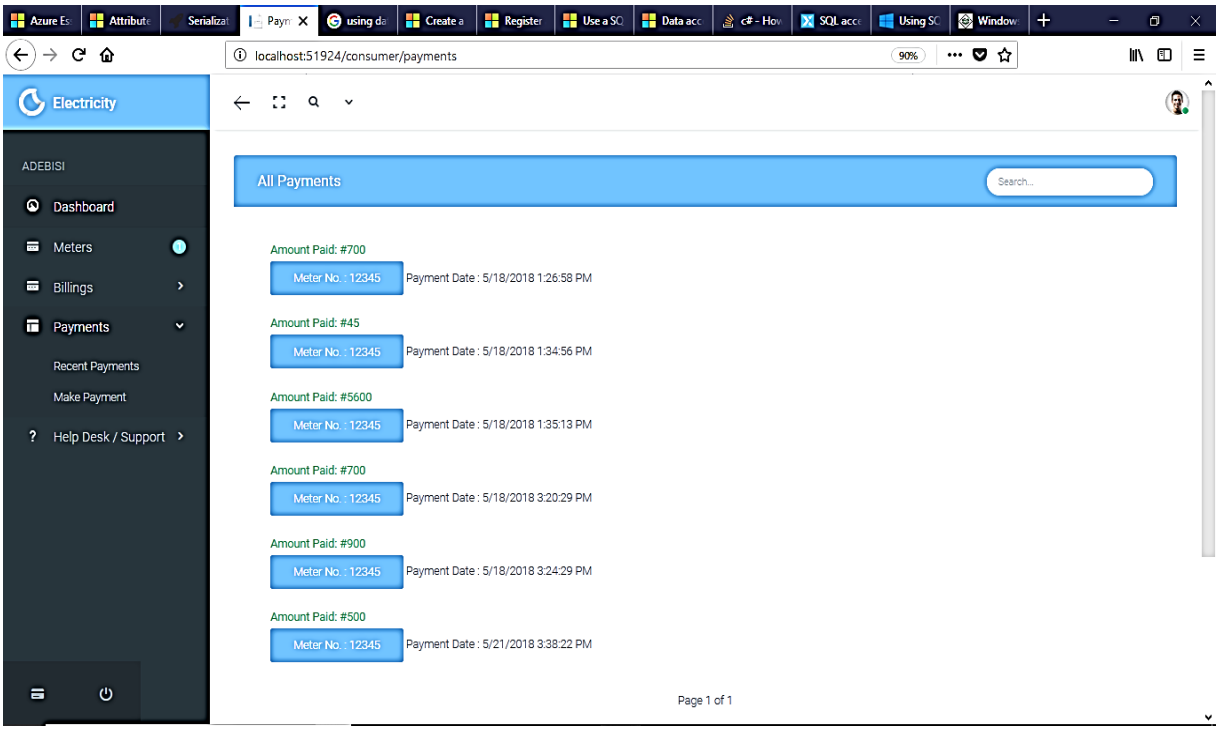

Fig. 11: Payment page showing recent payments or recharges by a consumer

GUI, Accessibility and Portability Tests Results

The perspectives of users on the platform's accessibility, GUI functionality and ease of use when accessed through mobile phones and laptops are presented in Figures 12 and 13 respectively.

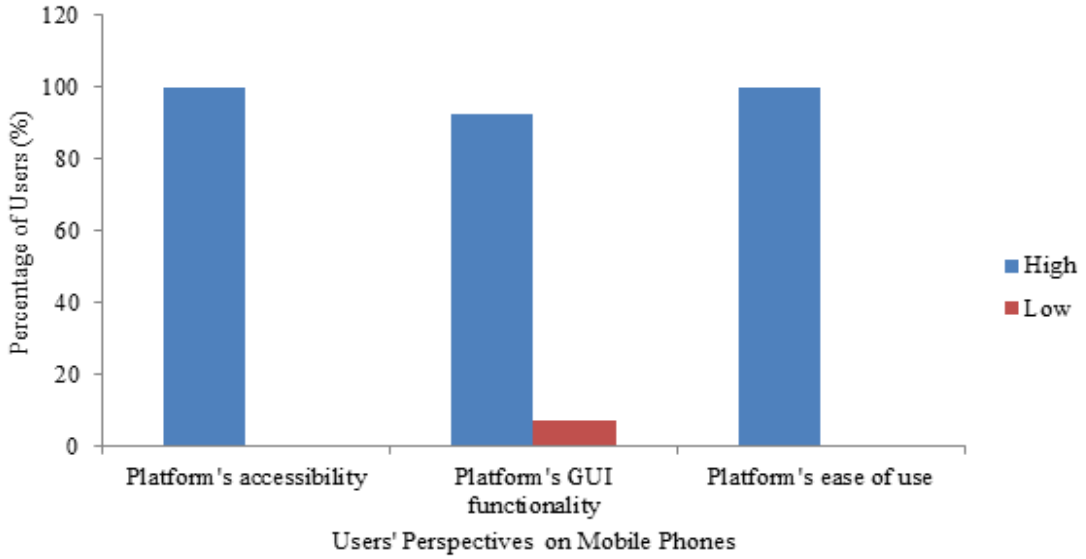

Fig. 12: The users' perspectives on platform's accessibility, GUI functionality and ease of use on mobile phones

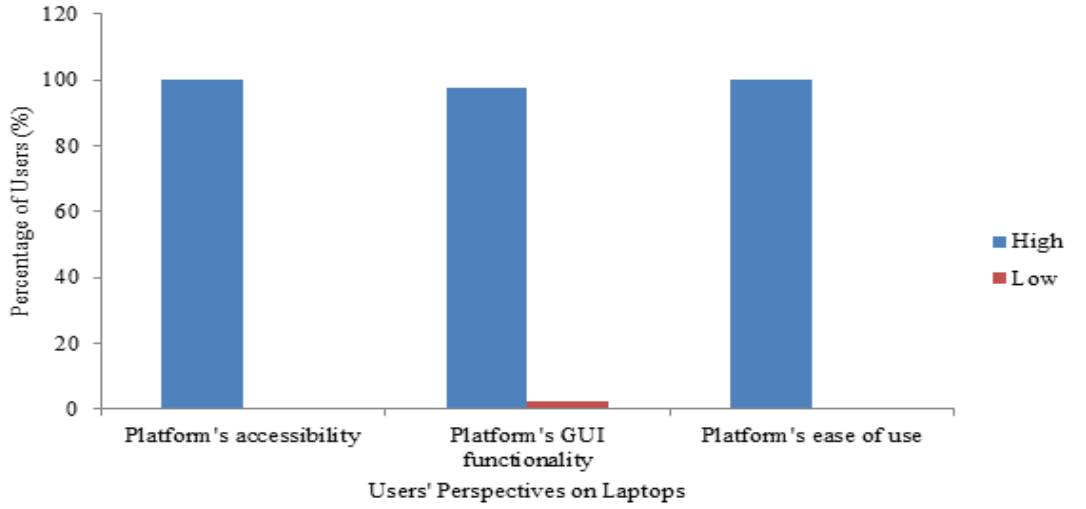

Fig. 13: The users' perspectives on platform's accessibility, GUI functionality and ease of use on Laptops

From Figures 12 and 13, all the users randomly selected for the tests perceived that the accessibility, GUI functionality and ease of use of the platform were high when accessed through mobile phones and laptops. However, the users differ on the platform's GUI functionality. While 92.5 and 97.5 % of the users respectively perceived that the platform's GUI functionality on mobile phones and laptops was high, 7.5 and 2.5 % of the users respectively claimed the platform's GUI functionality on mobile phones and laptops was low. These in essence were insignificant compared to the percentage of users who perceived the GUI

functionality of the platform was high. Therefore, the platform as observed from these tests has a good accessibility, GUI functionality and is easy to use.

Load Test Results

The results of load test conducted on the platform are presented in Figures 14 and 15.

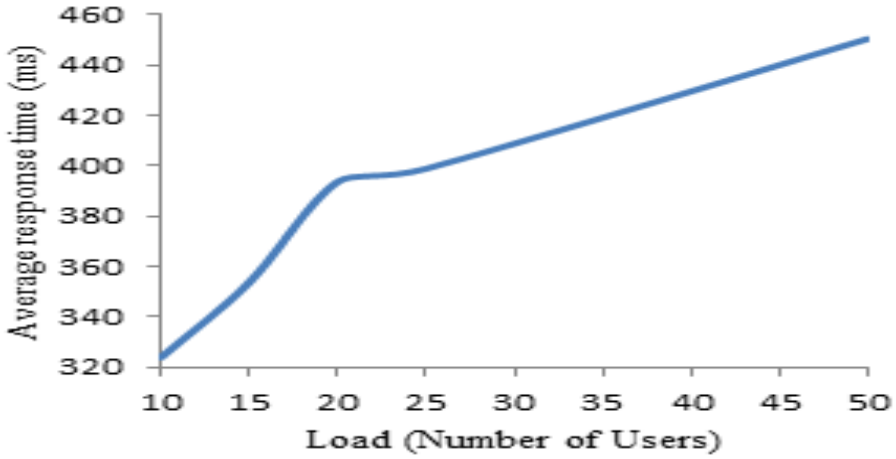

Fig. 14: Plot of average response time versus variation in workload

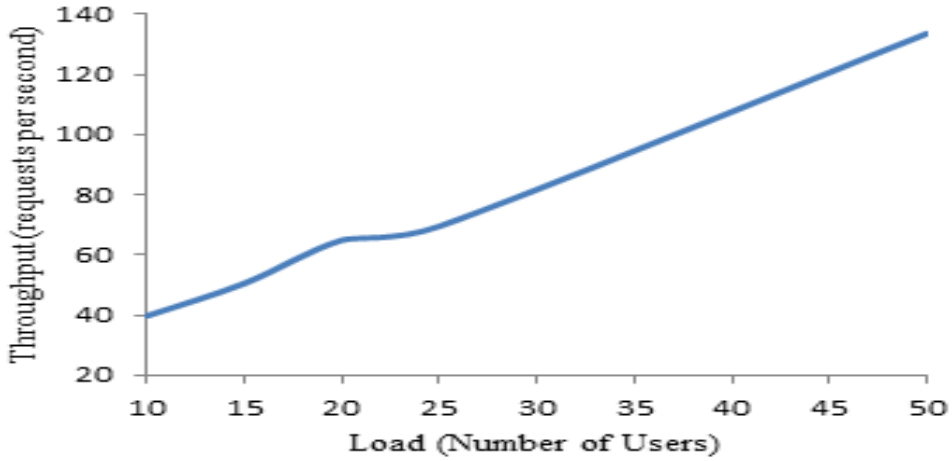

Fig. 15: Plot of throughput versus variation in workload

From Figures 14 and 15 respectively, it was revealed that the response time and throughout of the platform respectively increased as the workload increased, therefore, varying almost linearly as the user populations. While the observed response time conforms to the work of Chen *et al.* (2015), Andreolini *et al.* (2005) and Shin *et al.* (2000), the throughput observed during the load test on the platform agrees with the work of Jayasinghe *et al.* (2014) and Wang *et al.* (2012). Chen *et al.* (2015), Andreolini *et al.* (2005) and Shin *et al.* (2000) in their respective investigations found out that response time of web applications was a function of the workload, increasing progressively as user loads increase. Similarly, Jayasinghe *et al.* (2014) and Wang *et al.* (2012) in their respective findings discovered that throughput of web applications increases progressively as user loads increase, with saturation setting in at some specific user load point. However, in our simulation, no saturation was observed. Therefore, as observed from the load test, the developed web-based information exchange platform exhibits basic characteristics of web applications.

4. CONCLUSION

Effective information sharing in any deregulated electricity market environment is a critical requirement to the successful business operation between the entities. In this work, a web-based information exchange platform that enhance smooth communication between distribution utilities and consumers in the Nigerian deregulated electricity market for improved service delivery and efficiency was developed. Insights on the expected performance of platform were provided. The tests conducted on the platform revealed that it exhibited typical characteristics of web applications and is useful. The platform provides stress-free means of performing some routine tasks such as bill calculations, bill payments, recording of meter readings among others which would have been tedious exercises by manual processes for effective business transactions between distribution utilities and consumers in a deregulated market environment. More importantly, the developed information exchange platform provides a means of eliminating the use of paper-based transactions in electricity business operations since all transactions are web-based.

References

Adebisi, O. I. and Adejumobi, I. A. (2019). Development of a Web Service Based Information Exchange Platform for the Nigerian Deregulated Electricity Market. In Proceedings of 2019 IEEE PES/IAS Power Africa Conference, Abuja, Nigeria, Pp 176-181.

Adoghe, A. U., Odigwe, I. A. and Igbinovia, S. O. (2009). Power Sector Reforms – Effects on Electric Power Supply Reliability and Stability in Nigeria. International Journal of Electrical and Power Engineering, 3(1): 36-42.

Amoda O. (2007). Deregulation in Nigeria: Historical Overview, Motivation, Status and Recommendations (Online). www.nigeriavillagesquare.com (Accessed 20 February, 2014)

Andreolini, M., Colajanni, M. and Lancellotti, R. (2005). Impact of Technology Trends on the Performance of Current and Future Web-based Systems. International Journal of Web Services Practices, 1(1-2): 121-132.

Boniface, O. A. (2014). Challenges of Deregulation of Electric Power Sector in a Third World Economy. International Organisation and Scientific Research Journal of Electrical and Electronics Engineering, 9(3) Ver. 3: 19-22.

Cassone, G., Elia, G., Gotta, D., Mola, F. and Pinnola, A. (2001). Web Performance Testing and Measurement: A Complete Approach (Online). https://www.cmcrossroads.com/sites/default/files/article/file/2012/XDD3579filelistfilename1_0.pdf (10 October, 2017)

Cerny, T. and Donaboo, M.J. (2010). Performance Optimization for Enterprise Web Applications through Remote Client Simulation (Online). https://cs.baylor.edu/~donahoo/papers/CD10a.pdf(10 October, 2017).

Chen, C. P., Lin, G. J., Lin, Y. H., Song, H. P. and Bai, Y. W. (2015). Performance Measurement and Queueing Model of Web Servers with a Variation of Webpage Sizes. IEEE 2015 International Symposium on Next Generation Electronics, Tarpei, Taiwan, Pp 1-4.

Chen, Q., Ghenniwa, H. and Shen, W. (2006). Web-Services Infrastructure for Information Intergration in Power System. In Proceedings of 2006 IEEE PES General Meeting, Montreal, Que., Canada, Pp 1-8.

Dada, J. O. (2014). Web-Services- Based Architecture for Information Integration in Nigeria Deregulated Electricity Market Environment. International Journal of Computer Applications, 87 (13): 1-8.

Dada, J. O. (2013). Conceptual Modelling of Information Exchange Network for Nigeria Deregulated Electricity Market Using Object-Oriented Approach. International Journal of Engineering and Technology, 3 (4): 449-463.

Dada, J. O. (2012). Information Exchange Framework for Deregulated Electricity Market in Nigeria. International Journal of Engineering and Technology, 2(6): 1052-1061.

Dada, J. O. (2002). Information Exchange Network for the Liberalised Electricity Market with Objected-Oriented and Internet-Based Tecnologies. Fortschr.-Ber. VDI Reihe 21 Nr. 323. Düsseldorf: VDI Verlag.

Das, M. S., Govardhan, A. and Lakshmi, D. V. (2015). QoS of Web Services Architecture. In Proceedings of 2015 International Conference on Engineering and MIS, Istanbul, Turkey, Pp 1-8.

Jayasinghe, D., Malkowski, S., Li, J., Wang, Q., Wang, Z. and Pu, C. (2014). Variations in Performance and Scalability: An Experimental Study in IaaS Clouds Using Multi-Tier Workloads. IEEE Transactions on Service Computing, 7(2): 293-306.

Kattepur, A. and Nambiar, M. (2015). Performance Modelling of Multi-Tiered Web Applications with Varying Service Demands. In Proceedings of 2015 IEEE International Parallel and Distributed Processing Symposium Workshop, Hyderbad, India, Pp 415-424.

Lim, S., Lee, H - S., Yun, S - Y. and Hwang, P. (2013). Power System Integration Technique Based on Service Oriented Architecture. 22nd International Conference on Electricity Distribution, Stockholm, Sweden.

Makwe, J. N., Akinwale, Y. O., Atoyebi, M. K. (2012). An Economic Assessment of the Reform of Nigerian Electricity Market. Journal of Energy and Power, Scientific and Academic Publishing, 2(3): 24-32.

Morante, Q., Ranald, N. and Zimeo, E. (2005). Web Services Workflow for Power System Security Assessment. In Proceedings of 2005 IEEE International Conference e-Technology, e-Commerce, e-Service, Pp 374-380.

Qiu, B., Liu, Y. and Phadke, A. G. (2002). Communication Infrastructure Design for Strategic Power Infrastructure Defense (SPID) System. IEEE Power Engineering Society Winter Meeting, 1: 672-677.

Shikha, D. and Pratibha, S. (2016). Performance Testing: Improvised Web Testing Tool. International Journal of Computer Science and Mobile Computing, 5(9): 171-178.

Shin, D. J., Koh, K. and Won, Y. (2000). Measurement and Analysis of Web Server Response Time. Proceeding of the 6th Asia Pacific Conference on Communications, Seoul, Korea.

Tomsovic, K., Bakken, D. E., Venkatasubramanian, V. and Bose, A. (2005). Designing the Next Generation of Real-Time Control, Communication, and Computations for Large Power Systems. Proceeding of The IEEE, 93(5): 965-979.

Wang, Q., Kanemasa, Y., Li, J., Jayasinghe, D., Kawaba, M. and Pu, C. (2012). Response Time Reliability in Cloud Environments: An Empirical Study of n-Tier Applications at High Response Utilization. In Proceedings of 2012 IEEE Symposium on Reliable Distributed Systems, Irvine, CA, USA, Pp 378-383.

Xie, Z., Manimaran, G., Vittal, V., Phadke, A. G. and Centeno, V. (2005). An Information Architecture for Future Power Systems and Reliability Analysis. IEEE Transaction on Power System, 17(3): 857-863.