RPowerLABS: A Free Web-based Virtual Laboratory for Electric Power System Studies in Nigeria

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Abstract—**This paper describes a modern free web-based virtual laboratory for the simulation of electric power systems with a focus on education and research in Nigeria. The RPowerLABS project offers diverse simulation laboratories that have been deployed using latest cloud computing technologies and are deployable within an institution's internal network. Most of its simulation labs are already preloaded with several IEEE power systems and the Nigeria power systems alongside line diagrams to provide industrial cases that mimic real-life scenarios for better learning outcomes for electrical engineering students. The project is based on the R language and is pioneering the deployment of online virtual labs with synchronous communication and learning management capabilities in Africa. The time domain simulation of the Nigeria power system using RPowerLABS is presented, while the potentials of using RPowerLABS for both distance learning and classroom-based instruction is discussed alongside its industrial potential.**

Keywords—RPowerLABS; power system simulation; R language; virtual labs; Nigeria Power System

I. Introduction

The breakthrough of the Internet technology within this millennium, has promoted advances in many other spheres of technology. Recent progresses in the commercial availability of cloud computing technologies have empowered the development of software applications for mission critical analysis and simulation. So many software organizations have been focusing lately on transitioning their standalone products to Internet-based systems. Neplan AG is one such power system analysis software company that has declared this development [8].

While there have been several free desktop packages that are used for power system analysis, it is fewer when compared to Internet-based power system analysis tools. One reason for this is that, the development platforms of many power system analysis software packages have somewhat restricted the deployment of these applications over the World Wide Web – these restrictions could be cost-based or technology-based.

It is my observation that there is a growing use of open source languages (such as R and Python) for advanced scientific computing tasks within the tertiary (internationally) due to reasons that concern flexibility, reproducibility and economy. This is true seeing that most of these open source languages are available across a wide range of operating systems and easily accessible over various cloud computing infrastructures since they are free. Most programs that are developed on them are free and open source which encourages reproducibility. For the field of electrical engineering, it has already been established that an open source approach could be a valid alternative to commercial software for power system education [2].

The Internet technology boom has also significantly influenced distance education in various fields. In Nigeria and Africa generally, distance learning (based on the Internet) in the domain of electrical power system engineering, is still under development with the availability practical lab sessions usually a major concern. In countries like the US and UK, lab sessions are catered for through residential workshops held at the university premises severally with the students mandated to attend as part of the requirements of the program.

Distance education and e-learning provide a particular potential for developing countries that are faced with a unique set of challenges in the area of higher-education. While the demand for engineers in developing countries is high, the higher-education institutions are faced with financial and infrastructural difficulties [9]. Computer-supported instruction (both as distance education as well as implemented into traditional curricula) presents potential for improving higher education in developing countries with comparably low investment [10].

This paper discusses the current developments of RPowerLABS and its application to electric power system education and research in Nigerian tertiary institutions as well as the industry. The RPowerLABS project is an on-going project with a current set of deliverables that are free for academic use online and offline. The application of RPowerLABS to the time domain analysis of the Nigeria 330kV power system is also investigated and its potential for the power industry is discussed in the following sections.

II. Overview

The RPowerLABS project is a free, web-based virtual power system laboratory project for simulation and analysis with several potentials for both classroom-based learning and distance learning using Internet and open source technologies. The software project began as a case study of using R, an emerging scientific computing tool for the purpose of power system engineering simulations [4].

A. *The RPowerLABS Software*

The RPowerLABS software is fully built using the R programming language. The project started as a desktop application and has since scaled into a full-featured web-based application. It is built using the reactive programming model that underlies the *shiny* framework. *Shiny* is a framework for building web applications in R [15]. Thus, the user is not required to go into the data input file to change parameters when he desires to try out several operating scenarios. The reactive model makes it possible to interact with the application from the web page directly.

As at the time of writing this article, the RPowerLABS software contains simulation labs for *power flow analysis, contingency analysis, fault studies, time domain of SMIB system, multi-machine transient stability analysis, coherent generators and dynamic equivalents, synchronous machine transients, automatic generation control* and *transmission line analysis*. A module for *economic dispatch and optimal power flow* is already available, but not publicly free; however, experiments are on-going to incorporate better algorithms for ill-conditioned systems. Modules for *unit commitment, electric machinery*, etc are expected in the near future [14].

The software comes preloaded with several test power systems (e.g. IEEE power systems and the Nigeria power system) for quicker and easier utilization, and evaluation. Most simulation labs also come with preloaded lab manuals and exercises that would provide background information to lab participants and test their abilities. There is a provision for the software to be integrated with a learning management system such as Moodle for creating lab quizzes and synchronous communication between lab participants (especially in a distance learning mode).

The software is flexible and is fully customizable. A set of related simulations could be aggregated on one interface based on a user's demand. However, custom features are not currently free services. RPowerLABS is aimed at providing developing nations with diverse labs that would give each student a chance at using an industry-like application for free (or for a stipend when extra services are requested).

B. *The R Programming Language [3]*

R is a free language and software environment for statistical computing and graphics developed at the University of Auckland, New Zealand. The R Project is an international collaboration of researchers in the field of statistical computing and the formal project structure is provided by the R Foundation based in Vienna. The R software continues to be released under a free license with applications ranging from statistical computing and big data analytics, to life science, computational physics, econometrics, clinical trials, chemistry, financial engineering, machine learning, high performance computing, optimization, natural language processing, etc. RPowerLABS appears to be the first reported application of R to the domain of electric power system engineering.

C. *Electrical Power Simulation and Analysis in Nigeria*

Electrical power system experiments are usually based on computer simulations because of the nature of the power system. It is therefore prime for current tertiary students in Nigeria to be acquainted with such simulations which would aid them in their personal studies, terminal research projects and industrial practice [3].

In the Nigerian power industry, the development of indigenous power system simulation software has not yet been reported. The RPowerLABS hopes to be at the frontier of this development and implement customized solutions that are tailored to the ever evolving Nigeria power system. The effect of customized aggregation of related and unrelated simulations provides an operator or planner with diverse perspectives of the power system at a glance. For example, at the occurrence of a 3-phase fault near a bus, an operator or planner could view the results of power flow analysis, stability, short-circuit, N-1 contingency, economic dispatch, etc on one web-page.

D. *Setup and Deployment for RPowerLABS*

RPowerLABS is intended to be purely an Internet service and thereby provide students with private study labs that are tailored to their needs or to those of their departments as the case may be. Following this intent, a free RPowerLABS service has been deployed on a cloud computing infrastructure running Ubuntu Linux 14.04.x and could be accessed anytime at the following link: http://rpowerlabs.org/apps. For those institutions that require a web-based simulation tool for online learning with features for collaboration and learning management, the Internet-based deployment of RPowerLABS would be beneficial.

However, with demand for offline access, RPowerLABS could be deployed as a standalone application or within the lab or intranet of an institution or industry. In Nigeria, a non-mandatory stipend or donation would generally be recommended for this service to help improve the RPowerLABS project. A standalone deployment of RPowerLABS would enhance teaching and research in institutions with inadequate Internet facilities. According to [14], a free virtual lab for classroom studies could be demanded by contacting the project team.

To deploy RPowerLABS for private use online is very economical and quick. There are available options to have the user's data preloaded into his private lab, while an Internet link would be sent to the user to privately access the lab and perform his simulations. This option cuts off the need to learn the input data structures of RPowerLABS and allows the user focus on performing the most important aspects of the simulation and analysis.

III. TIME DOMAIN SIMULATION OF THE NIGERIA POWER SYSTEM

The importance for time domain simulations is two-fold: evaluating the *electro-mechanical* reaction of the power system due to large perturbations and evaluating the *electro-magnetic* response of power network components [5]. Transient stability analysis is the approach utilized for electro-mechanical response evaluation and it is the focus of this study.

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scripts were developed to construct the admittance matrix, solve Newton-Raphson power flow, perform node elimination using Kron's reduction method, and solve the non-linear electro-mechanical equation. The result of the simulation is the rotor angle variation of the generators present in the system with respect to a reference machine. Several scenarios were tested and their results are shown in the following sub-section.

A. Simulation Scenarios

The cases that depict the electro-mechanical time domain simulation of the Nigeria 330kV power system are detailed in this section.

Scenario 1: A damped case

This scenario illustrates the effect of damping on machine oscillations. A fault was initiated at Bus 26, automatically clearing the line "3 – 26" at a clearing time of 0.25 sec while the effect of damping was neglected. The simulation output is shown in Fig. 2. A similar case where the effect of damping was included after the fault is shown in Fig. 3. Both simulations lasted for 10 seconds so as show the effect of damping over a longer period of time in the post-fault state. It is observed by comparing both figures, that the inclusion of a damping factor reduces the amplitude of oscillations of the machines as time progresses. This is clearly visible for the generators at Shiroro, Jebba and Kainji whose rotor angle variations are continuously oscillating with insignificant declination in Fig.2. However, when the effect of damping is taken into consideration in the simulation algorithm, the amplitude of the machines decline steadily as shown in Fig. 3

Scenario 2: A critical clearing time case (damping neglected)

This scenario concerns a fault initiated near Bus-12 which prompts the tripping of line "12 – 16" for a simulation lasting 2 seconds with Gen.1 (Egbin) selected as reference.

Case 1.A: This case shows that a comparative delay in circuit breaker clearing time (0.38sec) leads to instability for this fault situation. The plot of Fig. 4 shows complete system disintegration into regions with Gen.6 (Jebba) , Gen.3 (Kainji) and Gen.4 (Shiroro) forming a region by accelerating together to instability.

Gen.2, Gen.5, Gen.7, and Gen.9 also form another region while also decelerating to instability subsequent to slipping their poles after about 1.5secs. (Gen.8 again appears to be non-responsive with respect to the fault. This is because: this generator is electrically very close to Gen.1 (Egbin) which is the reference on the x-axis. Therefore Gen.8 is almost aligning to the x-axis).

This case is a situation of total system collapse because the generators have totally lost synchronism by experiencing separation and a following instability. This is due to the spread of the unusual fault power to several parts of the interconnected system caused by delay in fault clearing. If the fault was cleared earlier, its effect would not quickly spread to several parts of the network – this is clearly shown in *Case 1.B* which follows.

Case 1.B: This case shows that the critical clearing time for this fault condition (of Scenario 2) is 0.37 sec and if the circuit breakers act after this time, the system would plunge into instability. This is evident in Fig. 5 from which we see that the generators in the northern part of Nigeria accelerate at first swing, while the generators in the opposite region (the south) decelerate at first swing; and as such the phase difference between Gen.6 (Jebba) and Gen.7 (Afam) rose up to 250^{o}.

Generally, in the first swing the effect of the fault was quite pronounced as the northern-region generators are moving out of phase with the generators in the southern region of Nigeria – this is a tendency towards an unstable condition, but could be contained by adequate controls. This lack of harmony in '*swinging together'* of the generators within the two areas of the power system, reveals a significant interchange of power between the two areas. By observing the power system of Fig. 1, the network could be seen as consisting of two areas (northern and southern) connected by a link (the lines between Bus-12 and Bus-16) and a fault on this link could significantly lead to asynchronous power swings.

The results obtained within this section, depict the capability of the tools provided by the RPowerLABS project to simulate real-life power systems.

IV. Conclusion

A free virtual lab for electric power system studies in Nigeria has been presented. Several features of this virtual lab as an Internet technology have been outlined. As an Internet technology, RPowerLABS is believed to be beneficial for distance (online) learning in the field of electrical engineering for studies in developing nations.

The results of Section III have shown how the desktop version of RPowerLABS simulates the transient stability analysis of the Nigeria power system with a reasonable mimicry of its real operation. This exposes the potentials of RPowerLABS for industrial applications. RPowerLABS would be beneficial for operator self-training in

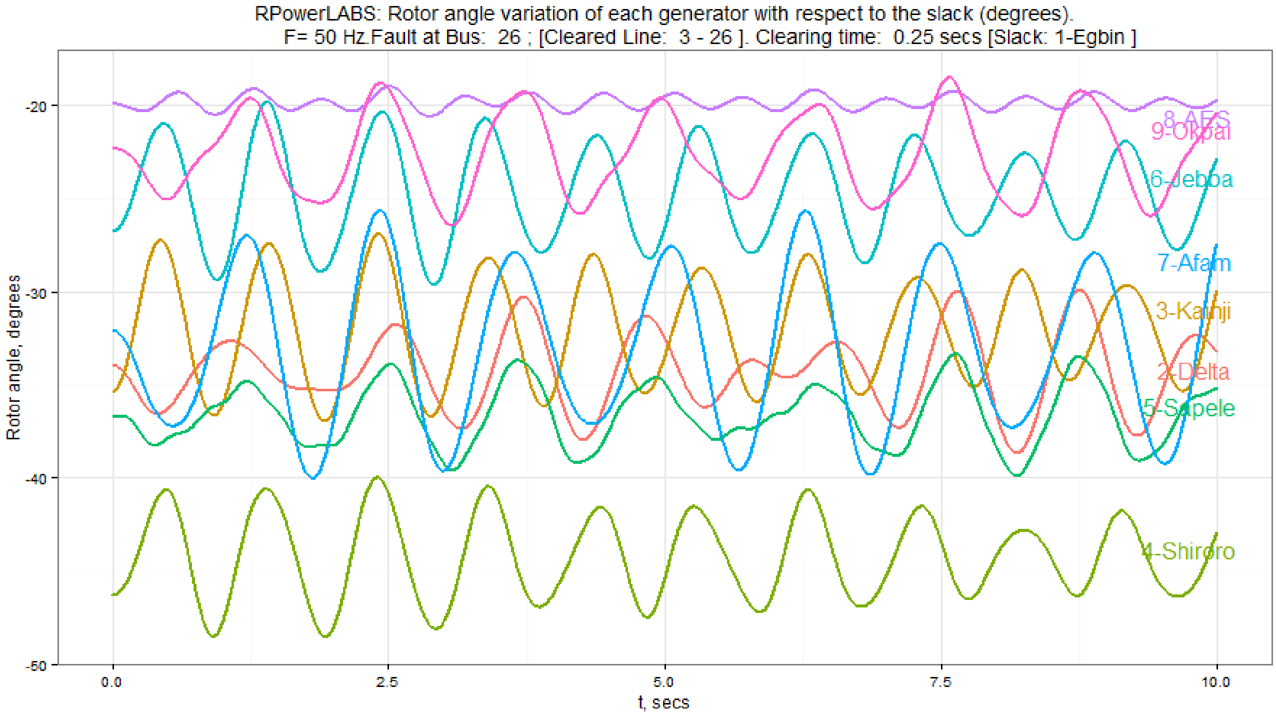

Figure 2: Rotor angle variation of all generators for Scenario 1 (damping neglected)

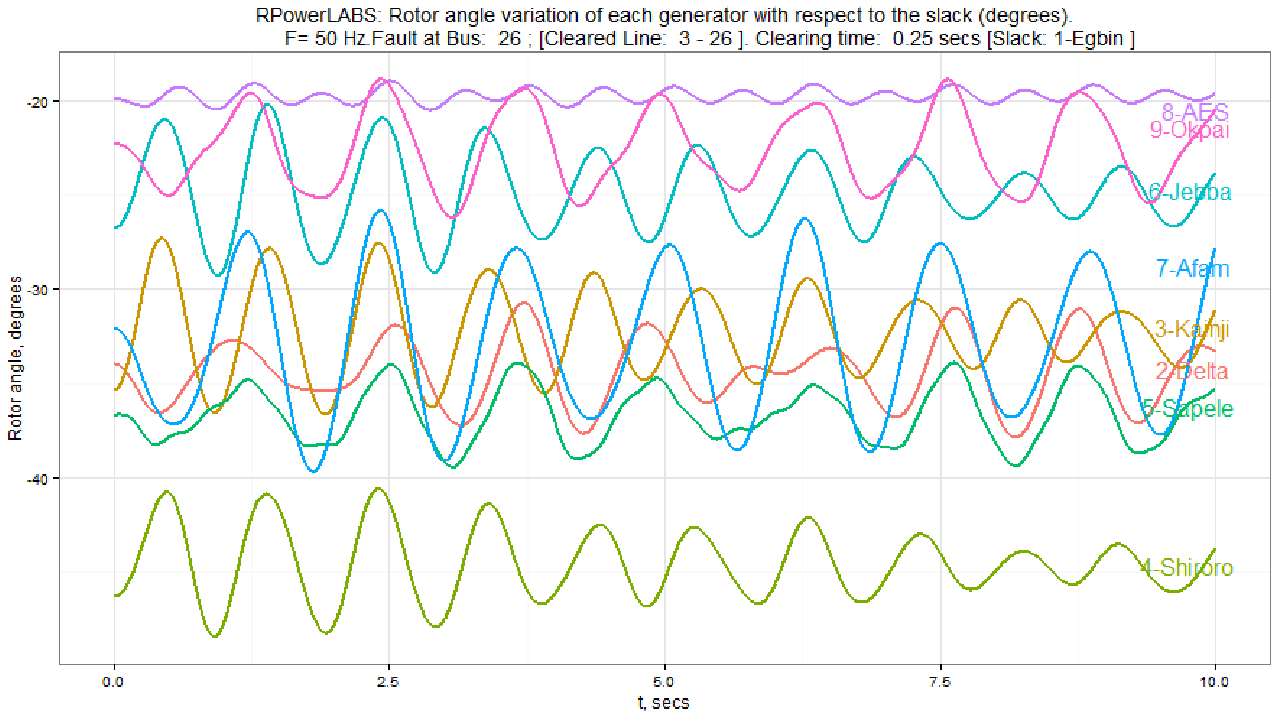

Figure 3: Rotor angle variation of all generators for Scenario 1 (damping inclusive)

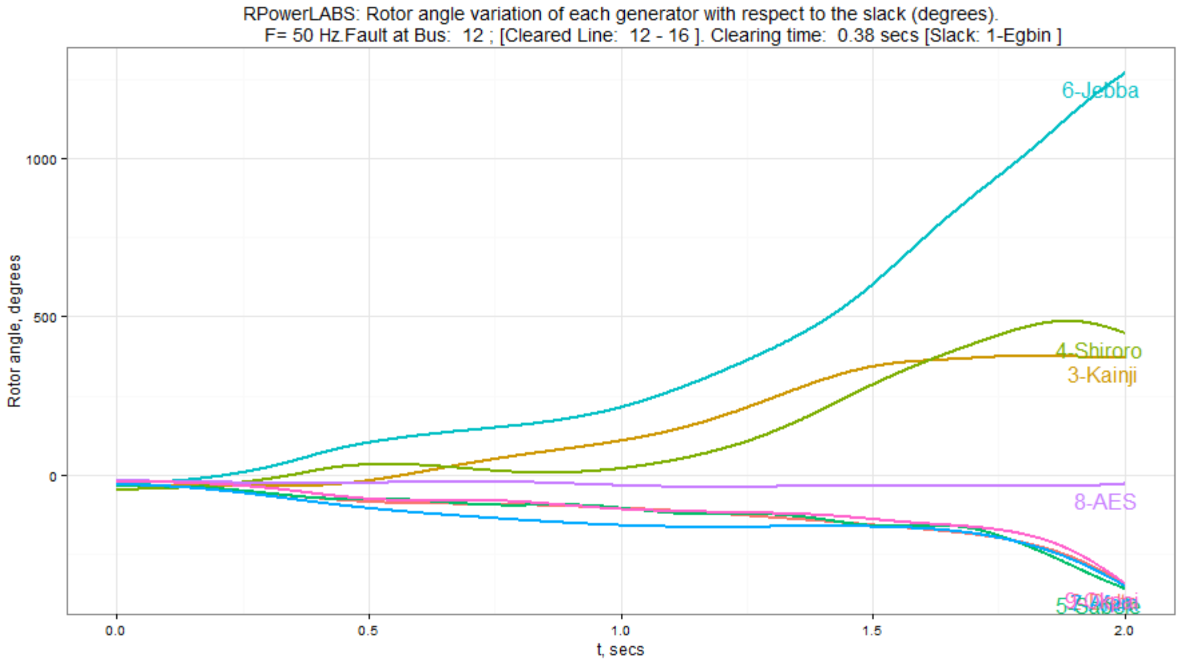

Figure 4: Rotor angle variation for Case 1.A of Scenario 2

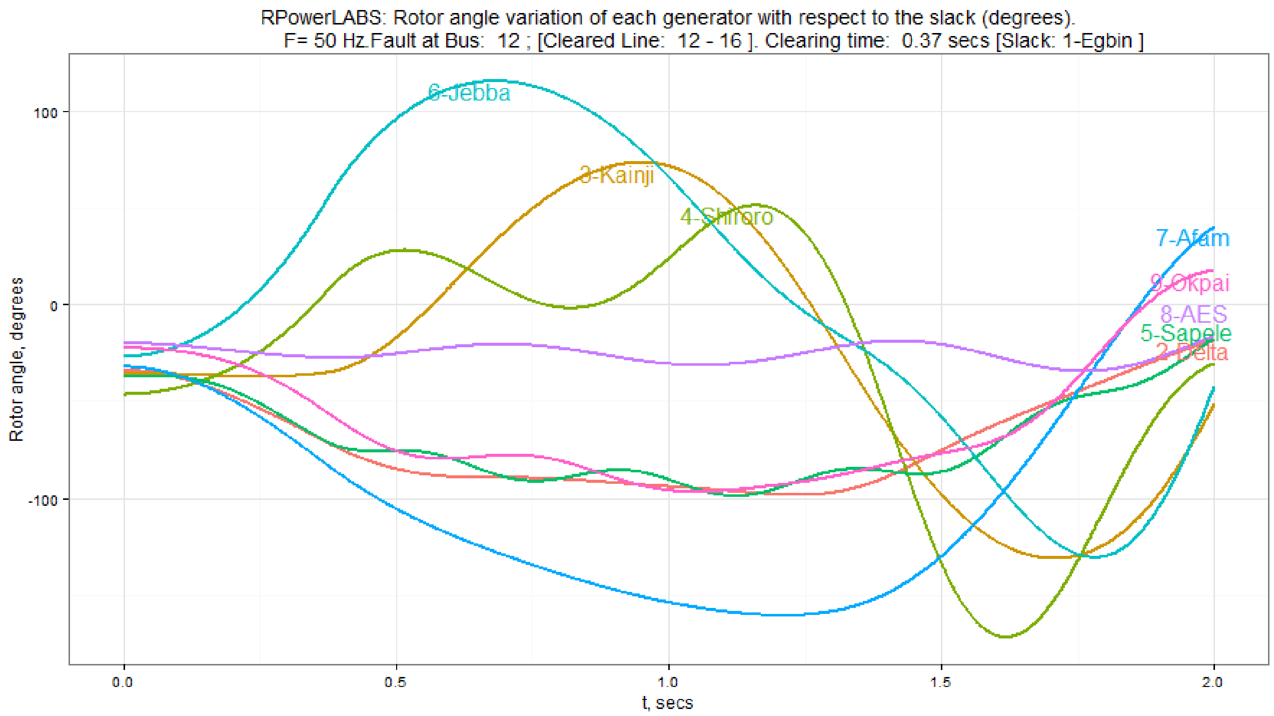

Figure 5: Rotor angle variation for Case 1.B Scenario 2

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