TRANSFORMING ELECTRIC POWER SYSTEMS ENGINEERING EDUCATION IN NIGERIA VIA AN INDIGENOUS R-BASED SOFTWARE PROJECT

Ubah Ben C.
Europa-Universität Viadrina, Frankfurt (Oder)

ABSTRACT
This paper presents propositions towards the transformation of electrical power system engineering education in Nigeria’s tertiary institutions based on the adoption of a home-grown software project whose development is inspired by the inadequacies experienced in the country’s power system engineering academia. The application of the software project for both student and lecturer utilization in study and research are highlighted, while the prospects of inter-tertiary cooperation using its electronic media offerings for delivering quality education and research are outlined. A scenario depicting the application of this software project for laboratory activities in time domain analysis is presented, while the benefits arising from the proposed academic transformation are reasoned to be influential to institutions’ academic credibility, graduates’ competence and industrial performance, and the nation’s technological and economic output.

Key words: Power systems engineering education, e-Learning, R, Nigeria power system software, computer simulation.

1.0 INTRODUCTION
The African continent is home to several developing nations of which Nigeria is inclusive [1], although it is the largest economy in the region with the largest population. Despite the valuable natural resources which the nation is richly endowed with, unemployment has reasonably affected a very great percentage of its citizens. Also, issues regarding incompetence or lack of hands-on skill among engineering graduates have also been widely reported [2]. It is thus deductible that several issues have restrained the training of highly qualified and internationally recognized electrical power system (EPS) engineers in Nigeria.

On the other hand, electrical power system experiments are usually based on computer simulations because of the nature of the system. It is therefore primary 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.

A personal experience as a power system engineering student in a Nigerian tertiary institution was such that there were no provisions for computer-aided power system analysis or simulations within the five-year curricular. This has been a challenge for most undergraduates in Nigeria, because, losing such important component of their learning could reasonably distort their confidence about their competence.

In many cases, many lecturers who trained using quite similar curricular and also face some challenges with the computer simulations on which the power system engineering academia and industry heavily relies on.

Furthermore, there is a lack of adequate infrastructure for power system engineering laboratories in Nigeria, mostly in the area of computer and simulation-based tools (inclusive of hardware). This situation has boycotted the practical aspects of the undergraduates’ learning with a more reliance on theoretical formulations and imaginative learning.
This paper seeks to diffuse a proposition based on the use of an indigenous software project to counter the negative effects experienced due to inadequate provision of computer-aided laboratory tools. The inception, capabilities and current state of this software project are discussed and the basis backing the selection of R as its computing environment is outlined. A demonstration showing the application of this software project to the time domain simulation topic of power system analysis is presented. The benefits of adopting the use of this application within the regular curricular of universities that offer electrical engineering are also analysed.

2.0 METHODOLOGY
2.1 The Software Project
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]. The result of the study revealed that R is well suitable for performing power system simulations as cases involving the application of Gauss-Siedel power flow technique were successfully implemented and tested using the IEEE 39-bus 10-machine New England power system. Also, the ability of R was tested by implementing the time domain simulation of the Single Machine Infinite Bus (SMIB) system using both the modified Euler’s technique and the Runge-Kutta technique. Furthermore, the problem of multi-machine transient stability analysis was solved computationally using R during this study.

Considering the capability of R in performing standalone simulation of electrical power systems, the study went further to ascertain the power and ease of which the same simulations could be achieved over the WWW still using R and its package extensions. The power flow analysis, SMIB and multi-machine transient stability programs were ported to be deployable over the Web using the ‘shiny’ package (that provides a framework for writing web-based R programs). This also proved very successful, showing more potential for online academics.

Sequel to the following findings during the study, further research and experiments resulted into several simulations in the area of power system analysis which include: transmission line computations, synchronous machine transient analysis, fault studies, economic dispatch and optimal power flow, coherent generators and dynamic equivalents, contingency analysis, etc. A collection of scripts have been developed to perform computations in these areas and have been tested using IEEE test systems, examples and exercises found in popular power system analysis texts, and a real life Nigeria power system.

Currently, the project has developed more into an Internet-based technology with collaborative features that would enhance cooperation between students in a virtualized learning environment and in the best knowledge of the author, is currently the only available electric power systems analysis and simulation software project of its kind in Nigeria. The project is now known as RPowerLABS.

It is important to note that R was selected for the project, as its primary language and computing environment. The reason behind this can be found in the following section.

2.2 The R Language and Software
R is a free language and software environment for statistical computing and graphics [2] initially created by Ross Ihaka and Robert Gentleman at the University of Auckland, New Zealand. Currently, the R Project [6] is an international collaboration of researchers in the field of statistical computing and the formal project structure is provided by the R Foundation, a non-profit 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 [9].

The selection of R was influenced by the motive of applying an emerging, free and open source technology to the study of power systems engineering for Internet-based utilization and for economic benefits to students of developing nations. The R computing environment could also be freely used by students for mathematical and engineering computations that are not dependent on the project in question. R has good provision for complex number operations, vector and matrix manipulation, algebra and ODEs, and attractive visualization packages.

2.3 Proposed EPS Engineering Transformation Strategy in Nigeria

A Uniform Revision of the Electric Power System Curricular in Nigeria is proposed. This uniform revision would be a joint effort between the universities and the National Universities Commission (NUC). As a uniform revision, it would cut across all universities that offer electrical power engineering programs and the focus would be to adapt the use of R to the full five-year curricular in areas where computations and simulations are applicable. R is a free software and language that could be obtained freely by students, lecturers, and departments without any license restrictions (financial). The NUC would be responsible for overseeing and regulating the implementation of this revision across the tertiary nationwide. RPowerLABS [5] would provide the necessary technical support online and offline through trainings, laboratory workshops, and seminars to students and lecturers so as to facilitate the adoption of the technology. Online support would be provided through e-learning channels over the Internet, while offline support would be accomplished by organizing study meetings at the premises of the institutions at intervals. Regional meetings are also proposed to enhance inter-tertiary collaboration.

This adaptation is suggested in the following revision levels as shown in Figure 1:

Level 1: This revision level would be focused on first-year undergraduate students of electric power system engineering. The R language training would be provided through RPowerLABS’ support, online or on-premise or the students and lecturers could indulge in self-training, depending on the circumstances and decision of the institution. However, the NUC would oversee this process to certify the achievement of the revision at the student and lecturer levels. At this level, only basic knowledge of R is required for performing elementary mathematics and general physics calculations.

Level 2: This revision level would be focused on second-year undergraduate students of electric power system engineering. Support on the R language and overseeing responsibility are the same as in Level 1. At this level, intermediate knowledge of R is required for performing more advanced calculations involving differential equations, matrices, engineering mechanics, thermodynamics, introductory electrical engineering and digital logic.

Level 3: This revision level would be focused on third-year undergraduate students of electric power system engineering. Support on the R language and overseeing responsibility are the same as in Level 1. At this level, intermediate knowledge of R is required for performing applied computations to solve problems concerning numerical analysis, optimization, circuit analysis, time-frequency transformations, visualization of periodic signals, etc. The adoption of RPowerLABS’ web-based simulation tool for these applications is proposed. The inclusion of RPowerLABS’ upcoming online internships is also recommended at this level.
Figure 1: Levels of revision for the power system engineering curricular in Nigeria

Level 4: This revision level would be focused on fourth-year undergraduate students of electric power system engineering. Support on the R language and overseeing responsibility are the same as in Level 1. At this level, intermediate knowledge of R is required for performing applied computations to solve problems concerning power plants, electrical machines, etc. The adoption of RPowerLABS’ web-based power system simulation software is proposed at this level. The inclusion of RPowerLABS’ upcoming online internships is strongly recommended at this level to provide the students with insights into industrial applications of power system analysis and simulation using IEEE test systems and the Nigeria power system as case study.

Level 5: This revision level would be focused on final-year undergraduate students of electric power system engineering. Support on the R language and overseeing responsibility are the same as in Level 1. At this level, intermediate to advanced knowledge of R is required for performing applied computations to solve problems concerning power flow, fault studies, transient stability analysis, etc. The adoption of RPowerLABS’ web-based power system simulation software is proposed at this level. The use of RPowerLABS for students’ degree project is highly recommended for those who hope to research on power system analysis. Advanced knowledge of R and its packages is required for those who plan to develop their own simulation programs during their projects.

Level 6: This adaptation level would be focused on postgraduate students of electric power system engineering. Support on the R language and overseeing responsibility are the same as in Level 1. At this level, intermediate to advanced knowledge of R is required for performing applied computations to solve problems concerning power flow, contingency analysis, synchronous machine transients, symmetrical components, coherency, fault studies, transient stability analysis and control, etc. The adoption of RPowerLABS’ web-based power system simulation software is strongly recommended at this level. The use of RPowerLABS for students’ thesis/dissertation is highly recommended for those who hope to research on power system analysis. Advanced knowledge of R and its packages is required for those who plan to develop their own simulation programs during their projects.
It is worth noting from Figure 1 that the levels of revision are independent and no level is a prerequisite to the other. The independent support of RPowerLABS to each level allows the transformation strategy to be implemented at any level, therefore boycotting the dependence of levels which could impede the escalation of revision.

2.4 An Application Scenario: Time Domain Analysis Simulation Laboratory Activity

Time domain analysis in the following context refers to the electro-mechanical response of a single generating machine that is connected to the grid. The electro-mechanical response here is obtained through transient stability simulation of the system when a 3-phase bolted fault occurs at the bus terminals of the generator. This section describes how R was applied simulate this situation as a laboratory activity.

2.4.1 The Single Machine Infinite Bus (SMIB) System [6][11]:

The infinite busbar is clearly fictitious and rarely exists; however, it has a great advantage in explaining many of the problems associated with power systems. When analytical solutions are sought, the infinite busbar provides a reference for all angular changes in power system parameters [10].

Considering a synchronous generator, \( i \) that is connected to an infinite bus as shown in Figure 2; if damping is neglected, the swing equation is given by:

\[
\frac{H_i \frac{d^2 \delta_i}{dt^2}}{\pi f} = P_{mi} - P_{ei} \quad (2.1)
\]

OR

\[
\frac{d^2 \delta_i}{dt^2} = \frac{\pi f}{H_i} (P_{mi} - P_{ei}) \quad (2.2)
\]

where, \( P_e \) = electrical power output; \( f \) = frequency; \( H \) = inertia constant; \( \delta_i \) = power angle

![Figure 2: SMIB system with a 3-phase fault at point F](image)

Assuming a constant mechanical power input, \( P_m \), under steady state operation \( P_e = P_m \), and the initial power angle is obtained using:

\[
\delta_0 = \sin^{-1} \frac{P_m}{P_{1\ max}} \quad (2.3)
\]

and

\[
P_{1\ max} = \frac{|E'||V|}{X_1} \quad (2.4)
\]

where \( X_1 \) is the transfer reactance under steady state (pre-fault). Change in angular velocity, \( \Delta \omega_0 = 0 \), since the rotor is rotating at synchronous speed.
At the occurrence of a 3-phase fault at point “F” as depicted in Figure 2, the power transfer capability is lowered, with an increase in the equivalent transfer reactance \( X_2 \) between the two buses. This causes the power-angle equation to become:

\[
P_{2\text{max}} = \frac{|E'||V|}{X_2}
\]

Thus, the swing equation of (2.2) becomes:

\[
\frac{d^2 \delta}{dt^2} = \frac{\pi f}{H} (P_m - P_{2\text{max}} \sin \delta)
\]

This second-order differential equation of (2.5) can be written as two simultaneous first-order equations:

\[
\frac{d\delta}{dt} = \Delta \omega
\]

\[
\frac{d\Delta \omega}{dt} = \frac{\pi f}{H} (P_m - P_e)
\]

There are now two state equations for each generator to be solved, with initial power angles \( \delta_0 \) and \( \Delta \omega_0 = 0 \). The modified Euler’s method would be applied to solve these two coupled equations.

2.4.2 SMIB Simulation using R

The time domain simulation algorithm was programmed using the RStudio IDE [12] on a personal computer (PC) running Windows. To perform the computations for the SMIB simulation, a standalone script was developed namely, SMIBmeu.R

The SMIBmeu.R program was developed to implement the modified Euler’s algorithm for the SMIB system using core R functions. It has one function named \textbf{smibmeu}(P, E, V, X1, X2, X3, H, f, Dt, ct, ft). These arguments are described in Table 1 and the result of the simulation is a rotor angle swing plot over time.

<table>
<thead>
<tr>
<th>Argument</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>Mechanical power input</td>
<td>p.u.</td>
</tr>
<tr>
<td>E</td>
<td>Constant voltage behind transient reactance</td>
<td>p.u.</td>
</tr>
<tr>
<td>V</td>
<td>Infinite bus voltage</td>
<td>p.u.</td>
</tr>
<tr>
<td>X1</td>
<td>Pre-fault reactance between buses E and V</td>
<td>p.u.</td>
</tr>
<tr>
<td>X2</td>
<td>Fault-on reactance between buses E and V</td>
<td>p.u.</td>
</tr>
<tr>
<td>X3</td>
<td>After-fault reactance between buses E and V</td>
<td>p.u.</td>
</tr>
<tr>
<td>H</td>
<td>Inertia constant of generator</td>
<td>Seconds</td>
</tr>
<tr>
<td>f</td>
<td>System nominal frequency</td>
<td>Hertz</td>
</tr>
<tr>
<td>Dt</td>
<td>Time step</td>
<td>Seconds</td>
</tr>
<tr>
<td>Ct</td>
<td>Circuit breaker fault clearing time</td>
<td>Seconds</td>
</tr>
<tr>
<td>Ft</td>
<td>Final integration time</td>
<td>Seconds</td>
</tr>
</tbody>
</table>

3.0 RESULTS AND DISCUSSION
The SMIB time domain simulation laboratory activity was performed using an example collected from [11] and the simulation was performed using the smibmeu function as follows:

\[
P = 0.80; \quad E = 1.17; \quad V = 1.0; \quad X_1 = 0.65; \quad X_2 = 1.80; \quad X_3 = 0.8; \\
H = 5; \quad f = 60; \quad Dt = 0.01; \quad ct = 0.3; \quad ft = 1.0; \\
smibmeu(P, E, V, X_1, X_2, X_3, H, f, Dt, ct, ft)
\]
3.1 Results
The result of the simulation is shown in plot of Figure 3. The generator is clearly stable for the clearing time of \( ct = 0.3 \) second as the power angle returns after a maximum swing. But for a clearing time of \( ct = 0.45 \) second, the power angle in Figure 4 is seen increasing without limit. Therefore, the system is **unstable** for this clearing time. This resembles the real-phenomena, where if the circuit breakers delay to clear the fault, the generator swings “out of step” to instability.

A web-based implementation of this same laboratory activity using the Runge-Kutta 5th order Dormand Prince numerical integration technique has already been implemented at RPowerLABS – a screenshot is shown in Figure 5.

![One machine system rotor angle variation. Fault cleared at 0.3 secs](image)

Figure 3: Rotor angle variation of SMIB system using smibmeu. *Fault cleared at 0.3s.*
3.2 Discussion
The university’s academic credibility and research output would be highly impacted with the adoption of the proposed transformation strategy since the students do not need to obtain funds to purchase R, they could easily venture into any research area that requires computer simulations using this tool, thereby increasing their research output. Their research output and practical
inclination would in turn affect their credibility. Their participation in the R community could easily enable them create useful affiliations.

Economically, R proves very suitable as it is free and open source with an ease of deploying Internet-based simulations based on cloud computing using RStudio’s infrastructure.

Putting theory into practice using a freely obtainable computing tool such as R would promote practical self-study among electrical engineering students alongside better learning outcomes.

Inter-tertiary collaborations that have been enhanced through regional tutorial meetings organized by RPowerLABS would result into students and researchers to forging useful partnerships that would lead to profitable research ventures.

Electric power system graduates that have been trained using the revised curricular would gain much practical competence through RPowerLABS’ participation and would gain insight on how to adapt to industrial simulation software in the electrical power industry.

The nation’s technological and economic output would also be impacted. Technologically, the students that have been trained with this revised curricular have been equipped to start up small-to-medium sized software and consultancy enterprises which would go on meet the software needs of the power sector and related domains. Economically, these enterprises would naturally create jobs and reduce importation of software and human expertise.

4. CONCLUSION

A time domain simulation laboratory activity has been described as a demonstration to support the transformation of electric power system engineering education in Nigeria’s universities. The transformation proposed is based on a six-level revision of the electric power system engineering curricular that spans undergraduate and postgraduate studies. The benefits of this transformation have been deducted to significantly contribute to graduates’ competence and performance at industry level, university’s credibility and the nation’s technological and economic output. RPowerLABS’ willingness and readiness to assist the academia in Nigeria alongside the expected supervision and regulation of the NUC have been established to play a prime role towards this transformation.

REFERENCES


