Improving the Teaching/Learning of Power System with the Approach of Virtual Laboratory

Amevi Acakpovi, Olufemi O. Fatonade, and Ahmed Gedel

***Abstract*—The objective of this paper is to develop a basic virtual laboratory in Power System on the topic: "Simulation of voltage drops on Power Transmission Lines". This comes as a result of the inability of many tertiary institutions to provide adequate laboratory facilities to their students in technical fields like Power System. Virtual laboratory is a major approach in solving this problem as it provides more flexibility and almost the same quality of teaching and learning while keeping the implementation cost very low. The virtual laboratory developed in this article was done with Matlab/SimPowerSystem. A model of a real power transmission line was described and the setting of simulation components was also clearly shown. Normally encountered instruments in Real Power Laboratory including Oscilloscope, Wattmeter, Frequency Analyzer and others were also manipulated in the simulation approach. Results were displayed in term of graphs/tables and were also compared to real life scenario in order to measure the quality of education afforded. Also a cost analysis was added at the end to emphasize on the reduction of cost brought by the simulation approach. This study confirms the advantages of virtual laboratory in Power System and therefore encourages most of tertiary institutions to adopt it in order to improve on their quality of teaching.**

***Index Terms*—Matlab simulation, power system, virtual laboratory, implementation cost & quality of education.**

I. Introduction

Increasing complaints related to practical skills have been coming up from industries to training centers, of recent. Especially for Polytechnics, industries recommended that their training should really address the gap in practical knowledge given to students in order to prepare them effectively for the world of work. Others have also complained that most Polytechnic graduates have to undertake additional training in industry before meeting the minimum requirement for engagement. In fact, Education in some fields requires much hands-on practical experiments. In traditional academic settings, for example, students offering a lot of technical subjects such as physics and engineering subjects are required to do extensive experiments compared to their counterparts in the humanities [1], [2]. Moreover, with the evolution of ICT, virtual labs evolved as one of those technological mediums to afford technically oriented students the opportunity to conduct experiments, even from remote locations [3].

Gomes and Garcia-Zubia [2], confirm that this development came in two approaches based on simulated laboratories and remote laboratories. Chen *et al.*, [4], postulate that "a simulated laboratory corresponds to one or more computer applications providing a graphical representation of both the instruments and objects under experimentation, and returning results according to a model description of the behavior and interaction of those elements". They differentiate this from a remote laboratory which "corresponds to the situation where the control and observation of the physical instruments and objects under experimentation is mediated through a computer, and adequate remote access to the computer is provided through a specific communication network" which in most cases is the internet [2], [4]. Virtual labs are similar to simulated laboratories and therefore can enhance and improve teaching and learning of technical courses significantly, [5]. This paper investigates this fact by adopting a particular virtual laboratory on power system extracted from SimPowerSystem user guide and improved upon.

II. Problem Statement

The ever-increasing number of private and public tertiary institution, teaching technical courses in developing countries without necessarily meeting all the required laboratory facilities, has become a major challenge to the quality of education given to students. This has created a gap in the acquisition of necessary practical skills that meet industry requirements. It is not surprising to know universities and polytechnics offering both degree and Higher National Diploma Programmes in technical fields like Electrical Engineering, Mechanical Engineering, Telecommunications and others not having one laboratory equipped with basic equipment for teaching and learning. What educational qualities are the students attending those programmes being exposed to? This paper therefore explores virtual laboratories as a key solution to improve upon quality of teaching and ensure effective learning for students offering technical courses.

III. Objective

The main objective of this work is to demonstrate through the setting-up of a virtual laboratory in Electrical Engineering (Power System), the impact of Virtual Laboratory on teaching of technical courses. Specifically the work will consist of:

- Simulating a power transmission line with shunt inductive compensator for varying line length

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- Comparing results to real laboratory scenario and providing recommendations

IV. Methodology

Transmission lines in power system are often taught to be ideal by having zero resistance, capacitance and inductance. However, real transmission lines have nonzero values of all these three elements. Therefore, power line are often modeled as R, L,C series or parallel lines having an impedance per unit length which varies according to the inductive or capacitive effect of the line. The formulas below show respectively how the resistance of a cylindrical conductor, the capacitance and the inductance of a pair of wire, are calculated for transmission line.

$$R = \frac{\rho l}{A} \quad (1)$$

$$C = \frac{\pi \varepsilon}{log(s/r)} \quad (2)$$

$$L = \frac{u}{\pi} log(s/r) \quad (3)$$

with ρ, the resistivity of the line, l, the length of the line, A, the cross-sectional area, ε, the permittivity of the material, μ, the permeability of the area, r, the radius of a single conductor and finally, s, the distance between the pair of conductors.

A model of RLC transmission line fed by a 161KV, 50Hz source (typical transmission voltage in west Africa) supplying a load will be constructed and simulated under SimPoweSystem of Matlab. Results will be recorded for varying length of the line without compensation to show the voltage drops caused by the transmission line itself and finally a compensation circuit made of a shunt inductor at the receiving end, will be applied to show one way of overcoming the problem of voltage drops. To simplify matters, only one of the three phases is represented as shown by Fig. 1.

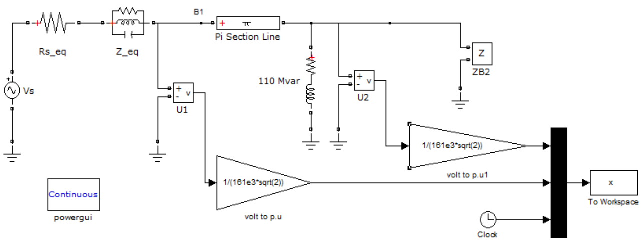


Fig. 1. Simulation diagram of a single phase power transmission line.

The circuit above represents an equivalent power system feeding a 300 km transmission line. The line is compensated by a shunt inductor at its receiving end. A circuit breaker allows energizing and de-energizing of the line. The parameters shown in figure 1 are typical of a 161 kV power system. Details about the construction of the circuit and the setting up of parameters are shown as follow. These data are collected from the user manual of Power System toolbox, [6].

$$V_S = 161.10^3 \sin(100\pi t)$$
$$R_{s\_eq} = 20\Omega$$

- Transmission line parameters

Resistance per unit length R=0.011Ω/km Capacitance per unit length C = 13.41nF Inductance per unit length L=0.8674mH Line length l = 300km

Number of pi element n = 1

- Model of compensator

The shunt reactor which serves for the compensation is modeled by a resistor in series with an inductor. This is done by selecting an RLC load and setting its parameters as follow

Nominal voltage $V_n = 161.10^3$V

Nominal frequency $f_n = 50$Hz

Power $P = 100.10^6/300$

Inductive power $Q_L = 100.10^6$

Capacitive power $Q_C = 0$

V. Results

A. Simulation Results

Simulations were run in first instance for the transmission line only without considering the compensation circuit as shown by Fig. 2 and this was done for four different distances 300 km, 500 km, 700 km and 1000 km respectively. The result obtained are shown if Fig. 3.

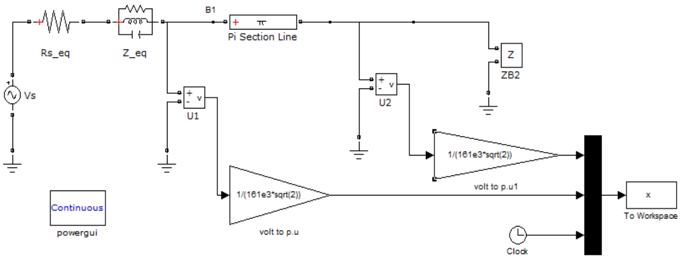


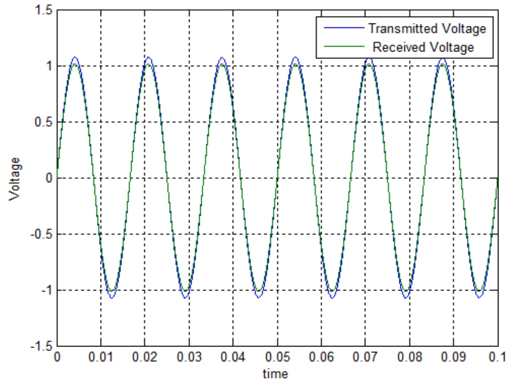
Fig. 2. Simulation diagram without inductive compensation reactor.

However, in the second simulation scenario the compensation circuit was added to the 300 km line and this shows a big improvement as illustrated by Fig. 4.

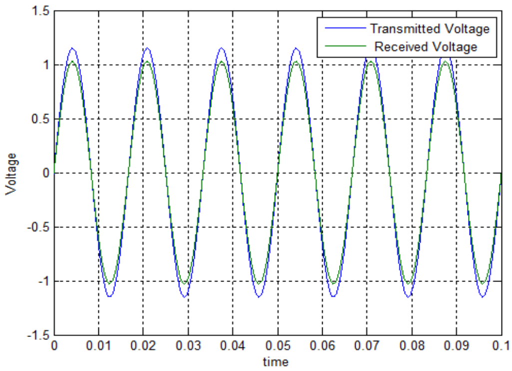
B. Comparison with Physical Laboratories

If the virtual lab discussed in this paper were to be physically implemented, the cost estimate of the physical laboratory will cover a very high voltage generation station with its transmission network together with Voltage transformers to take an image of the measured voltages. This is not affordable for a common tertiary institution in most developing countries. However, for a simulation approach, one needs a computer with the Matlab software installed and other accessories. The implementation cost is therefore illustrated in Table I. Moreover, instead of providing the real power station and others to run the physical lab, a similar laboratory on power transmission lines could be run at reduced price. H. Matzner *et al.*, [5] for instance proposes one approach to perform this experiment. Their experimental set-up was very close to the concept simulated in this paper.

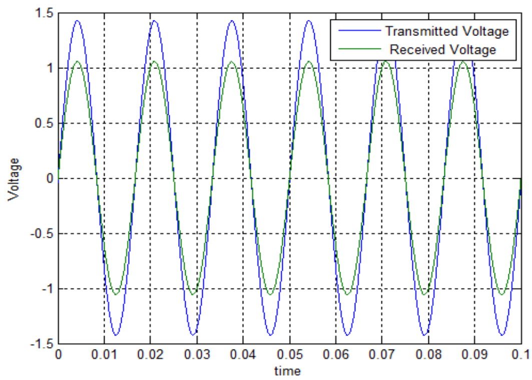
Therefore, the list of equipment used, as shown in Table I will serve to estimate the price of the physical laboratory and compare to the virtual one. The other fees may include the cost of setting up the laboratory, buying the necessary tools, providing the power supply. The approach by virtual laboratory costs almost $1725 whereas the physical lab may cost almost $3100 and more. It is therefore obvious that the simulation approach can considerably reduce the implementation cost while providing quality education.



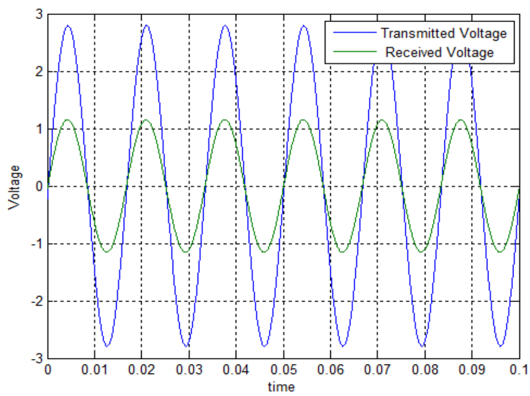
(a) voltage drops for 300 km line.



(b) voltage drops for 500 km line.



(c) voltage drops for 700 km line.



(d) voltage drops for 1000 km line.
Fig. 3. Compared results of voltage drops for 300km, 500km, 700km and 1000km line respectively.

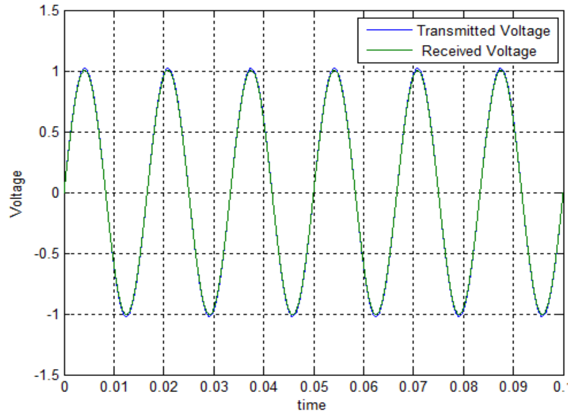


Fig. 4. Simulation result for a compensated line

TABLE I: COST ESTIMATE FOR A VIRTUAL LAB ON POWER TRANSMISSION LINES

Material	Cost Estimate ($)
Standard computer	1000
Matlab software (student edition)	625
Other (accessories)	100
Total	1725

TABLE II: COST ESTIMATE FOR A PHYSICAL LAB ON POWER TRANSMISSION LINES

Material	Cost Estimate ($)
Oscilloscope	1000
Waveform Generator	500
Line Terminator	100
Copper transmission line	500
Other	1000
Total	3100

VI. DISCUSSION

The simulation of a single phase power transmission line has been covered in all aspects in this paper including the line compensation aspect.

Results show that by increasing the length of a line, the voltage drops also increases gradually. For the 1000 km line, the voltage drops were more appreciated than the case of 300 km. The ratio of the received signal compared to the transmitted signals for the non-compensated lines were 83.33%, 76.9%, 71.4% and 41.7% for the 300km, 500km, 700km and 1000km transmission lines respectively.

However, with the compensation circuit made of the inductor and resistor in series, the received signal was approximately equal to the transmitted one for the 300km line and more which shows the necessity of similar line compensation circuits. Neglecting the compensation circuits can result in big voltage drops leading to increasing electricity fees for energy providers.

Moreover, emphasis can also be made on the flexibility afforded by using the simulation approach. Students can easily alter any parameter like the line inductance, capacitance etc. and see the effect on the voltage drops. This takes less than a minute while the real physical lab may require more settings and therefore more time. This flexibility was also prove for virtual laboratories in other areas including physics as illustrated by [8], [9].

In case of error in connecting components, the simulation will not succeed and will show error messages. However, the same error might end up with several damages in case of a physical laboratory. In short, errors are permitted with the simulation design but are not tolerated with the physical one as this can lead to severe damages of physical lab components. In addition, the implementation cost is of the physical lab is far higher than the virtual one as it is also proved by [10] and [11].

VII. Conclusion

This paper dealt with the simulation of voltage drops over a power transmission line. Simulation results show that voltage drops increase with increasing length of the line. However an inductive compensator was designed to overcome the noise effect. The simulation aspect shows flexibility in the manipulation of instrument and the possibility to correct errors. However, the huge cost of implementation of a similar design using physical lab approach added to the time required for implementation, become a limiting factor and therefore prevent the students from exploring such experiment.

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