

Blended Learning Method for Medium Power Transmission Line Performance Study

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Abstract - In a blended learning method of instruction, multiple approaches to learning or delivery methods are combined. In this paper, a medium power transmission line study experiment is designed with an experimental component in line performance through simulation of medium transmission line with verification through experiments on a hardware circuit model. Measurements are done on the hardware for the parameters and the equivalent circuit model is simulated using a hardware trainer module and the results compared with that of the analytical calculations and software simulation of the model based on measurements using MATLAB/SIMULINK. A medium line is considered and nominal π Model of the line is used.

A 100km line is simulated using an SLE/2 Energy transmission line simulator and the results verified with analytical and simulation results. Efficiency and regulation for voltage level 220kV are obtained at nominal load and compared with that of simulation results. Ferranti effect during capacitive loading is also observed. The experimentation involves analytical calculations by students without teacher's assistance with students in a group, simulation with teacher's supervision in a computer network environment and experiment in a power lab with instructor assistance. The lesson is designed for diploma, advanced diploma and undergraduate e degree level students.

Key Words: Power system laboratory, Learning methods, power line simulation, medium power transmission line, Ferranti effect.

1. INTRODUCTION

In a blended learning method of education, multiple approaches to learning or delivery methods are combined [1] [2]. Important and challenging tasks include teaching power system engineering laboratory to students specializing in electrical power. New and more effective methods of laboratory instruction are to be developed, for hands on experiments in a modernized educational laboratory and are a challenge to academic staff [3]. High voltage power lines are usually studied by simulating the models of them [4]. So it is important for power system engineers to be thorough with its mathematical modeling. Power system engineering deals with the transmission of

electrical power from one particular place to another, like substations or distribution units with maximum efficiency. Power engineers are to be thorough with the analysis of these systems.

Experimentation part in a typical power system course involves mathematical model of a power transmission line simulated using a digital or an analog computer. There are dedicated packages developed for studying power systems by simulating the models of power lines [5]. The students should also be able to visualize a high voltage line and get a feel of doing an experiment on it. For this, power laboratories include circuit simulators. They consist of circuit models that are reduced equivalents of a high voltage line of various lengths. Experiments on them give a feel of working on the actual line almost due to a line diagram on the panel with contactors or isolators mimicking circuit breakers and line isolators. Actual outcome depends purely on the learners' imagination while doing the experiment, unlike in the case of experiments on machines or engines. It is more so when only MATLAB simulation of the model of the line is involved. Even though experiments on circuit simulators give the students a feel of experimenting on the line to some extent, the scope is limited. Also computer simulation cannot effectively replace hands-on experiment wholly [6]. A blended course with a combination of circuit simulation and mathematical modeling with computer simulation is suggested with analytical part and programming as group activity [7] [8]. A medium line of length between 80 km to 250 km can be modeled as a nominal π network and considered here.

1.1 Nominal π Model

A nominal π representation is shown in Fig 1. The line impedance is placed as a lumped element Z at the middle of the circuit and the halved shunt admittance at either end as Y/2. The shape of the circuit so formed resembles that of symbol π . It is mainly used for determining the general circuit parameters and performing load flow analysis.

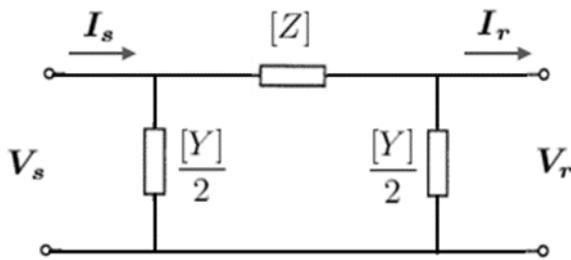


Fig -1: Nominal π representation of a medium line

1.2 ABCD Constants

The transmission system can be simplified to a two port network as shown in Fig.2.

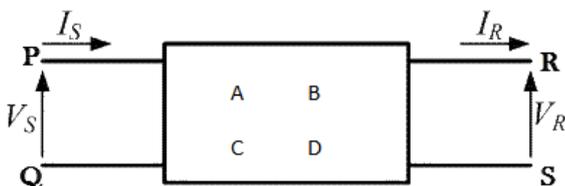


Fig -2: Transmission system as two port network

A two port network consists of an input port PQ and an output port RS. Each port has two terminals to connect itself to the external circuit and hence it is a four terminal circuit, having a sending end voltage of VS and a sending end current of IS at the input port P Q, The receiving end voltage is VR and receiving end current is IR at the output port R S.

Assuming the circuit elements to be linear, ABCD or the transmission line parameters, link the supply and receiving end voltages and currents as

$$V_s = AV_R + BI_R \quad (1)$$

$$I_s = CV_R + DI_R \quad (2)$$

A, B, C & D can be obtained by imposing the circuit conditions in different cases [9]. A&C can be obtained with receiving end open circuited i.e., with $I_R = 0$, and B&D can be obtained with receiving end short circuited i.e., with $V_R = 0$.

1.3 Efficiency and Regulation

Efficiency and regulation are important characteristics of transmission lines. Poor efficiency and regulation result in maintenance and reliability problems apart from losses and other limitations. An over voltage can reduce life of electronic devices and lamps.

Under well loaded conditions, probable under voltage levels lead to inadequate illumination, starting problems, and overheating in induction motors.

Efficiency-

Power efficiency is defined as the ratio of the output power divided by the input power:

$$\% \eta = (PR / PS) 100\% \quad (3)$$

PS is the sending end real power in watts (W).

PR is the receiving end real power in watts (W).

1.4 Simulation with MATLAB/SIMULINK

MATLAB contains sophisticated toolboxes and can easily perform array and matrix manipulations. It is a language for technical computing, which allows interfacing with programs written in other languages. Typical applications include computation, algorithm development, modeling, simulation, and scientific and engineering graphics application development. MATLAB is intended primarily for numerical computing and an additional package, SIMULINK, adds graphical simulation for dynamic systems. Simpowersystems toolbox can be used for simulation of power system networks.

1.5 Energy transmission line simulator

The SLE/2 Energy Transmission Line module can be used for experiments on single or double circuit medium transmission line [10]. The equipment is provided with switches and breakers to work with single or parallel lines. It has facilities for measurements at sending and receiving end. It also includes power supply with two reduced voltage levels corresponding to 120kV and 220kV and inductive and capacitive loads and hence it can be used as standalone equipment.

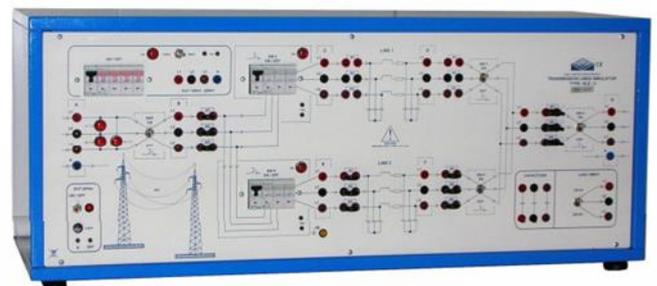


Fig -3: Energy transmission line module SLE/2

A transmission line of 100km length is considered for experiment and studied using the circuit simulator and its model is simulated using MATLAB. For a medium line, nominal π Model is considered.

ABCD constants and analytical results of the transmission line considered are included in II. Simulation results are included in III. Results of hardware simulation using SLE/2 Energy Transmission line module is included in IV.

2. TRANSMISSION LINE MODELING

2.1 Analytical

A transmission line of length 100km is modelled as a nominal π network. For a line length of 100km, the resistance is neglected and the inductance and capacitance of the line are based on the details of the hardware simulator. Measurements are first done on the simulator to obtain the line inductance L and capacitance C. These measurements are taken to be that of a transmission line with a length of 100km. The line data is provided in Table 1. All values correspond to reduced model of a high voltage transmission line to laboratory level KVA and Voltage levels built in, including simulations, through per unit calculations not elaborated here.

Table -1: Transmission line parameters

Quantity	Value	Quantity	Value
Length	100 km	Resistance	0.16 Ω /ph/km
Inductance	0.85 mH/ph/km	Capacitance	0.0033 μ F/ph/km
Frequency	50Hz	ω	314 rad/S
Xc	965 K Ω /ph/km	xL	0.267 Ω /ph/km

$$Z = l(r + xL) = (16 + j26.7)\Omega \quad (4)$$

$$Y = l(j\omega C) = -j0.104 \times 10^{-3} S \quad (5)$$

ABCD constants are calculated using

$$A = \left(1 + \frac{ZY}{2}\right) \quad (6)$$

$$B = Z \quad (7)$$

$$C = Y \left(1 + \frac{ZY}{4}\right) \quad (8)$$

$$D = A \quad (9)$$

$$A = D = 1, C = j0.104 \times 10^{-3} S, B = (16 + j26.7) \Omega$$

A MATLAB m-file is written by students to calculate the ABCD constants and the analytical results are verified as per the diagram below in Fig 3. The program takes resistance, inductance and capacitance per unit length per phase and the length of the line to calculate ABCD parameters.

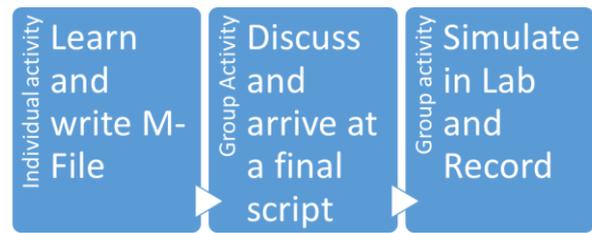


Fig -3: Typical blended leaning process

2.2 Experimental - Determination of ABCD parameters with SLE/2

SLE/2 transmission line module is used to simulate loaded and unloaded line with and without capacitance load. All experiments are done with line 1 of the two transmission lines provided in the module. Measurements are done at the sending and receiving ends using energy analyzers. The measurements are taken to be for a line with a length of 100km. With these measurements the ABC&D parameters are determined. Measurements were carried out with line receiving end open circuited to get A&C and with line short circuited to get B&D. An external source is used to set the sending end voltage and current as per the requirement.

With receiving end open circuited

$$V_s = 120.5 \text{ V}, I_s = 0.026 \text{ A}, V_r = 121 \text{ V and } I_r = 0 \text{ A}$$

With receiving end short circuited

$$V_s = 5.6 \text{ V}, I_s = 0.211 \text{ A}, I_r = 0.212 \text{ A}$$

1. When open circuit

$$V_s = AV_r$$

$$A = V_s / V_r = 120.5 / 121 = 1$$

$$C = I_s / V_r = 0.013 / 121 = 0.107 \times 10^{-3} \text{ S}$$

2. With receiving end short circuited

$$B = V_s / I_r = 5.6 / 0.212 = 26.4 \Omega$$

$$D = I_s / I_r = 0.211 / 0.212 = 1$$

Summarizing,

$$A = 1, B = 26.4 \Omega, C = 0.107 \times 10^{-3} \text{ S}, D = 1$$

ABCD parameters through analytical calculations and through measurements in SLE/2 are summarized in Table 2.

Table -2: Transmission line parameters

	A	B	C	D
Analytical	1	26.7 Ω	0.104 $\times 10^{-3}$ S	1
SLE/2	1	26.4 Ω	0.107 $\times 10^{-3}$ S	1

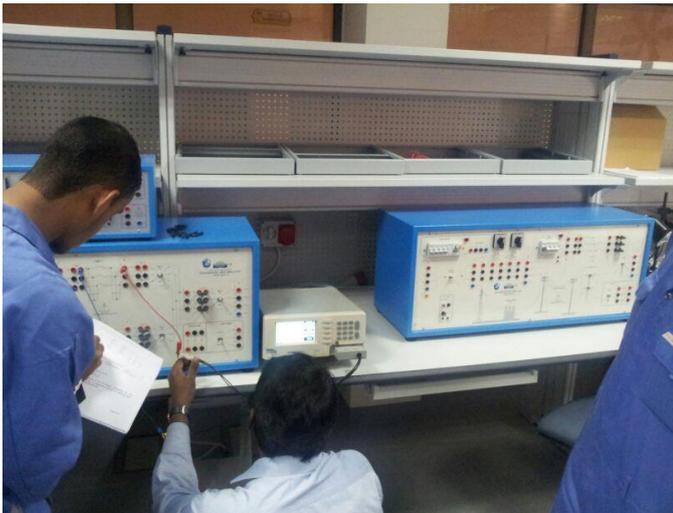


Fig -3: Measurements are done on the simulator to obtain the line inductance L and capacitance C.

3. LINE PERFORMANCE

3.1 Analytical:

Analytical calculations are performed to obtain the voltage regulation and efficiency of the line at a nominal voltage of 220 kV. Voltage, current and power factor are chosen to be equal to measured values in SLE/2 module. Sending end values are given and receiving end values calculated using an m-file for the nominal π model and the results verified using SIMULINK model as shown in Fig 3. From the result % Voltage regulation and % Efficiency are obtained.

$$\text{Percent voltage Reg.} = 11.8$$

$$\text{Percent efficiency} = 94$$

3.2 Line Module SLE/2:

Switch, on the receiving end, is kept closed for load and the sending end voltage is selected for a nominal 220kV position. Measurement at point B corresponds to sending end and at G corresponds to receiving end. VL1, AL1, W_{Σ} , Var_{Σ} and $P.F_{\Sigma}$ are line voltage, current, real power, reactive power and power factor respectively. The measured values are shown in table 3.

Table -3: 220kV line on load

Point	VL1	AL1	W_{Σ}	Var_{Σ}	$P.F_{\Sigma}$	VL1
B	240.6	0.48	153	133.6	0.75	240.6
G	216.9	0.5	140	128.7	0.73	216.9

$$\% \text{ Efficiency} = 91.7 \%$$

$$\% R = 12.6 \%$$

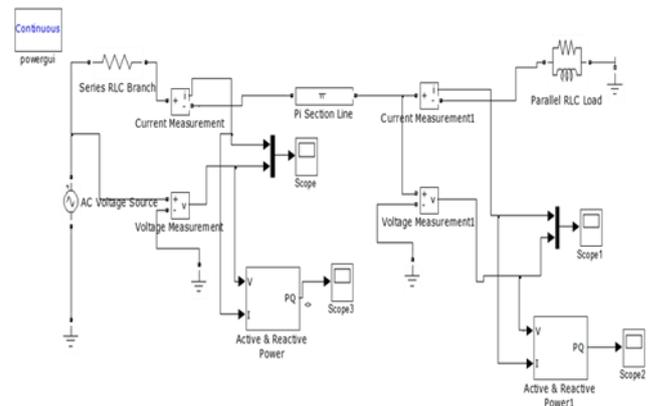


Fig -3: Typical SIMULINK line model simulation for performance.

3.3 Line at 220KV with phasing:

Switch, on the receiving end, is kept closed for load and the sending end voltage is selected for a nominal 220kV position. Measurement at point B corresponds to sending end and that at G corresponds to receiving end. Capacitor bank is connected at the receiving end to note the improved regulation. The receiving end voltage without load was found to be 244.3, which is higher than the sending end voltage at 241.5. This phenomenon is known as Ferranti effect [11].

Table -4: Line with capacitor load at the receiving end

Point	VL1-2	AL1	W_{Σ}	Var_{Σ}	$P.F_{\Sigma}$	Point
B	241.5	0.49	177	-94.27	0.88	B
G	237.4	0.48	165	-96.68	0.86	G

$$\% \text{ Efficiency} = 93 \%$$

$$\% R = 3 \%$$

Regulation has improved from 12.6% to 3% and the efficiency also improved from 91.7% to 93%.

4. CONCLUSIONS

A blended learning method that includes a portion of self-learning and group through online or internet medium with a simulation part assisted by an instructor in a computer network lab and a circuit simulation experiment involving power measurements is suggested. Performance study on a medium transmission line that is an important learning outcome for a power engineering student at advanced diploma level is considered. SLE/2 transmission line module is taken for experimentation and MATLAB/SIMULINK is used for simulation of the mathematical model.

Efficiency and regulation are obtained at nominal load and compared with that of simulation results. The hardware and software simulation results agreed with the analytical results satisfactorily. The efficiency was found to be 92% and the regulation around 12% and improved to 93% and 3% respectively with a capacitor load end and the Ferranti effect during capacitive loading was also demonstrated.

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