A Basic Power System Analysis by Using LabVIEW

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Abstract: *This paper will present a project which is a virtual instrument (VI) of several power system analyses by using LabVIEW version 8.5. LabVIEW has been chosen as the main platform of this project because it is a user friendly programming language and easy to be learnt by new programmers. This project is designed to concurrently familiarize the students with the use of LabVIEW and with electrical power systems. This paper will discuss design and development of interactive instructional virtual instrument (VI) modules to study (a) load analysis, (b) single phase circuits, (c) Three-phase electrical power generation by Delta and Wye generators with combinations of Wye and Delta loads. Both balanced and unbalanced loads are simulated. Using VI modules, a visual demonstration has been created that shows the resulting consequences of what occurs when balanced loads become unbalanced, (d) and finally modeling of transmission lines (short, medium and long model). This project is hopefully can assist students and lecturers in their learning and teaching.*

Keywords: *Power system analysis, LabVIEW software, virtual Instrument, educational virtual laboratory.*

1. INTRODUCTION

Because of the recent advances in computers and technologies, the complexity in all areas of the electrical power industry (generation, transmission, distribution, control, etc.) has increased, and the graduates of engineering and technology must be well-trained to address the needs of the industry. To address this need, most of the engineering programs and some of the engineering technology programs have introduced courses, programs, and laboratories in power systems to provide the graduates with the theoretical and practical knowledge, as well as experience. The study of electrical power systems requires a good background on advanced mathematics, and since most of the engineering technology programs do not require advanced mathematics, it is difficult to teach electrical power systems in these programs.

To deal with this subject, many text driven software programs are currently used in university to design and analyze different systems. A good example of such programs is Matlab software. With the advent of object-oriented programming, we have now programs that are interactive and user-friendly. Using such computer programs allows students to spend less time writing the code to solve a problem and spend more time understanding the concepts. As example of such programs is LabVIEW software which is a graphical programming environment and is based on the concept of data flow programming. Originally designed for test and measurement applications, the program has been modified over the last 15 years to design and analyze various complex systems. It is widely accepted by industry, university, and research laboratories around the world as a standard for data acquisition (DAQ) and instrument control software [1]. Users of LabVIEW can build instrumentation called virtual instruments (VIs) using software objects. With proper hardware, these VIs can be used for remote data acquisition, analysis, design, and distributed control. The built-in library of LabVIEW has a number of VIs that can be used to design and develop any system. LabVIEW can be used to address the needs of various courses in a technology and science program [2] [3] [4] [5] [10] and [11]. The objective of this paper is to discuss the application of built-in VIs in LabVIEW to develop VI modules for use in electrical power systems course.

2. APPLICATION AREAS OF LABVIEW

LabVIEW is extremely flexible and some of the application areas of LabVIEW [5] are Simulation, Data Acquisition, and Data Processing. The Data Processing library includes signal generation, digital signal processing (DSP), measurement, filters, windows, curve fitting, probability and statistics, linear algebra, numerical methods, instrument control, program development, control systems, and fuzzy logic. These features of LabVIEW will help provide an interdisciplinary, integrated teaching and learning experience that integrates team-oriented, hands-on learning experiences throughout the engineering technology and sciences program, engaging students in the design and analysis process beginning with their first year.

LabVIEW can command DAQ boards to read analog input signals (A/D conversion), generate analog output signals (D/A conversion), read and write digital

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signals, and manipulate the on-board counters for frequency measurement, pulse generation, etc. The voltage data goes into the plug-in DAQ board in the computer, which sends data into computer memory for storage, processing, or other manipulation.

3. SYSTEM LOAD ANALYSIS

Generally, the power systems loads can be divided into industrial, commercial and residential. 'the greatest value of load during a 24-hour period is called the peak or maximum demand'. The load factor which is defined as the ratio of average load over a designated period of time to the peak load occurring in that period has been introduced in order to assess the usefulness of the generating plant.

The load factors may be calculated for a day, a month or a year, so, in our analysis each of these three settlement periods has been taken into account for the analysis. Therefore, the name of the VI for this analysis has been given as System Load Analysis.

The System Load Analysis VI has been developed with several features of inputs and outputs. The front panel of the daily system load analysis VI is shown in Fig. 1.

4. SINGLE PHASE (VI) MODULE

The study of electric power systems requires a good understanding of single phase and three phase circuits, and courses in electric circuits and electric machines are usually the prerequisite courses, among others, for the introductory power systems course. Almost every introductory electric power systems text provides a brief overview of electric circuits, and the instructors spend one to two weeks of their lecture time reviewing electric circuits.

Depending upon the student demographics, the instructor may spend more time discussing these topics. Use of programs to display waveforms of voltage, current, and power are common in the study of electric power systems because their use enhances the instruction process and student comprehension. The VI modules presented below are developed to assist students in this process.

4.1. Power in Single-Phase AC Circuits

The equations used in this VI are the following:

$$v(t) = V_m \cos(\omega t + \theta_v) \quad (1)$$

$$i(t) = I_m \cos(\omega t + \theta_i) \quad (2)$$

$$p(t) = v(t) \times i(t) \quad (3)$$

Where: v(t) is the instantaneous voltage.

V_m = maximum value of the voltage, θ_v = angle of voltage in degrees, $i(t)$ = instantaneous current,

I_m = maximum value of the current, θ_i = angle of current in degrees and $p(t)$ = instantaneous power.

The other equations that are used in this VI are equations to calculate the rms values of voltage and current, the maximum value of current from voltage and impedance information, and the real power (P), reactive power (Q), total power (S) and the per unit quantities.

$$|V| = \frac{V_m}{\sqrt{2}},\ |I| = \frac{I_m}{\sqrt{2}} \quad (4)$$

$$I_m = \frac{V_m \angle \theta_V}{Z \angle \theta_Z} \quad (5)$$

$$P = |V||I|\cos\theta,\ Q = |V||I|\sin\theta,\ S = P + jQ \quad (6)$$

Where: $|V|$ is the rms value of voltage and $|I|$ is the rms value of current.

For the system per unit values the following equations are used in this VI.

$$V_{pu}\angle\theta_V = (V\angle\theta_V)/V_{base} \quad (7)$$

$$I_{pu}\angle\theta_I = (I\angle\theta_I)/I_{base} \quad (8)$$

$$Z_{base} = V_{base}/I_{base} = V_{base}^2/S_{base} \quad (9)$$

$$S_{pu}\angle\theta_S = ((V\angle\theta_V)/V_{base}) \times ((I\angle -\theta_I)/I_{base}) \quad (10)$$

The subscript pu indicates per-unit values.

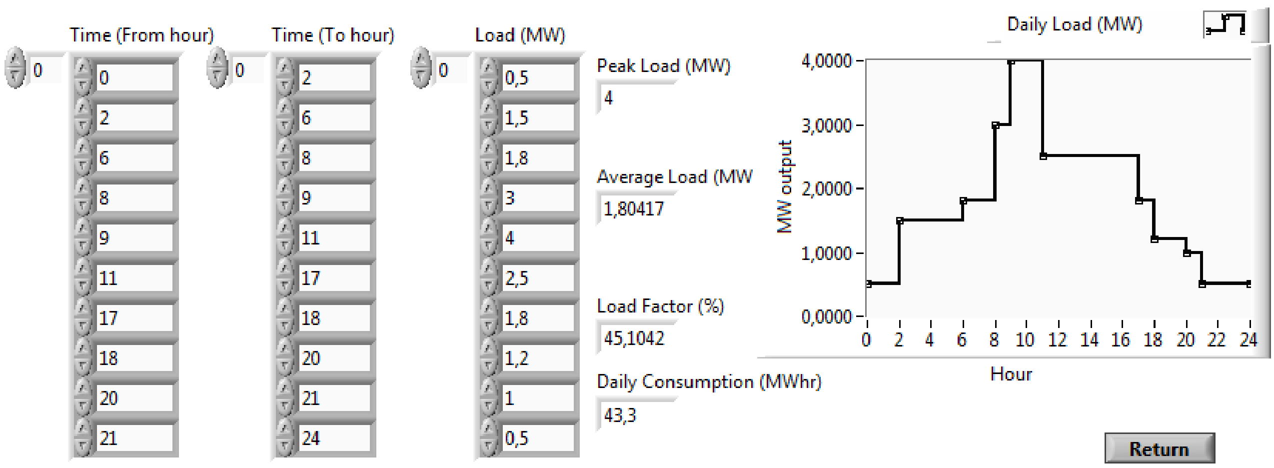

Fig. 1. Front panel and outputs waveforms for the daily system load analysis VI.

The front panel of this VI consists of (a) the user inputs (controls) such as maximum voltage, angle of the voltage, voltage base, MVA base, impedance, angle of the impedance, frequency and graph control, (b) the display (indicators) such as *P*, *Q*, *S*, and graphs such as *v*(*t*) and *i*(*t*), *p*(*t*) and phasor diagram in system per unit.

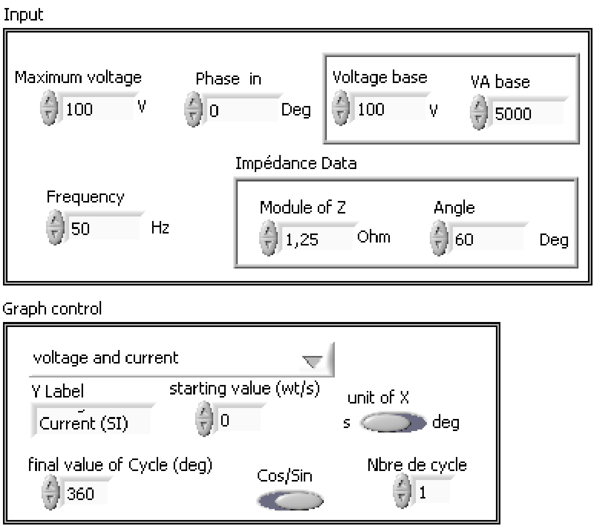

Fig. 2.a. User Input of the single phase module.

This VI was simulated with the input values from an example in [6], and the results from the VI matched with the example results. The front panel of this VI is shown in figure 2 (figure 2.a – User Input, and figure 2.b – VI Output results and phasor diagram).

5. THREE PHASE CIRCUITS (VI) MODULE

VIs were developed using the equations from [6] [7] and [8]. These are standard three phase equations which can be found in any electric circuits and/or electric power systems book. This VI simulated both the Delta and Star connection and calculated the line parameters and total power from the given phase parameters and show the phasor diagrams of voltages and currents of both sending and receiving ends. The Star/Delta VI was simulated with input values from examples in [6] [7], and the results matched the example results. The front panel of this VI consisted of controls for user input of phase parameters and load information and indicators to display calculated parameters. The diagram panel simulated various equations through the use of built-in arithmetic icons and other icons to deal with complex notations. It consisted of various cases structures and tab control to decide between the type of connection, the SI or per unit system, the type of system (balanced or unbalanced) and to decide if the neutral is joined or not joined. The front panel of this VI indicating the simulation results of the Star connection is shown. The three phase voltage VI [8] is designed to demonstrate the voltage relationships in Star/Star connection. The diagram panel of this VI is large and difficult to fit on a standard size paper. As a result, we are presenting the front panel of this VI in figure 3.a, 3.b et 3.c below.

To conduct various analyses, the source and load must be of same type (Star/Star or Delta/Delta). However, sometimes the source and load may not be of the same connection type, and a transformation must be carried out to convert both the load and source to the same type using standard equations. figure 2.a present the user input (source and load control), the simulation results are presented in figure 3.b, 3.c and 3.d, figure 3.b present the VI output (voltage graph with control), phasor diagram of source and load currents and

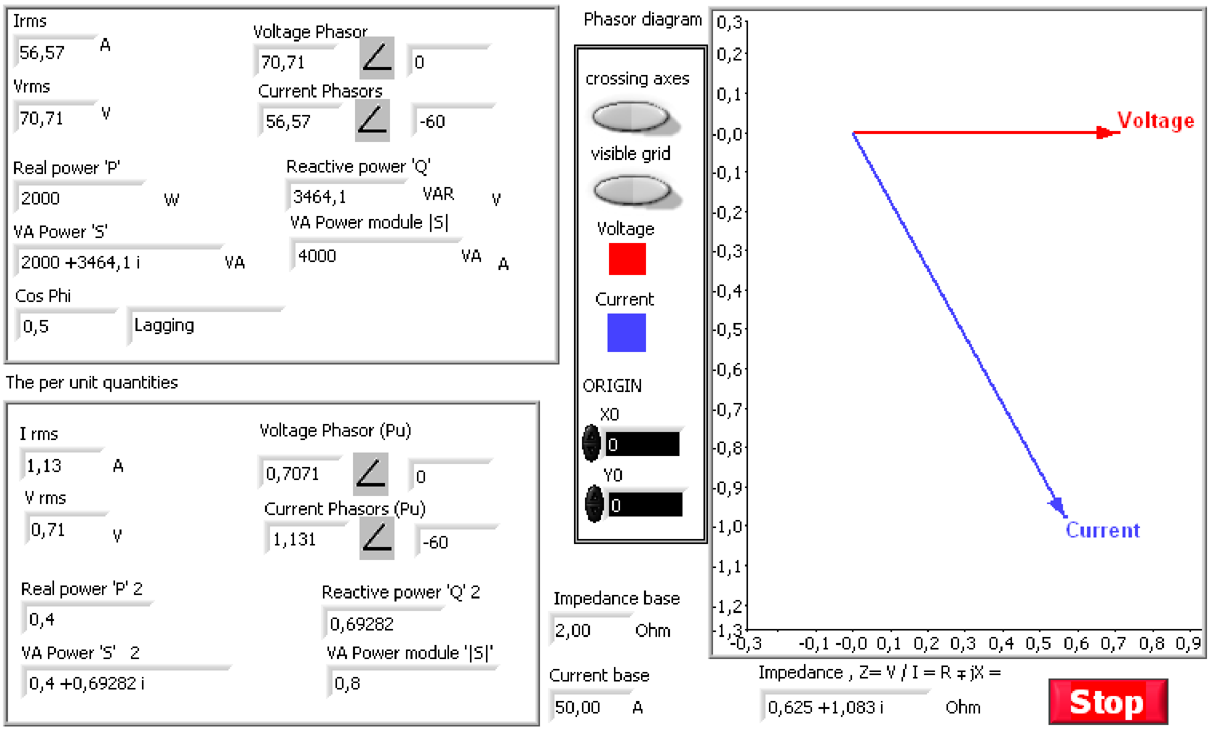

Fig. 2.b. VI Output results and phasor diagram.

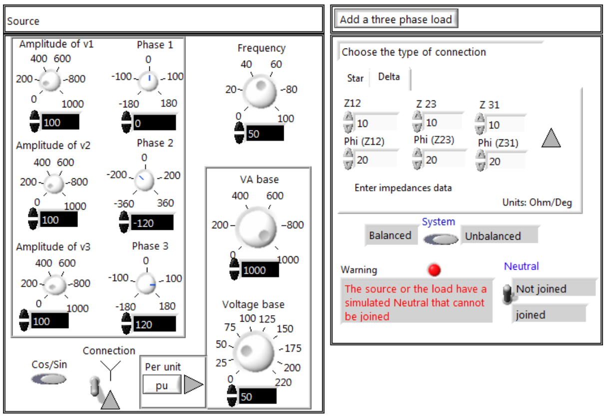

Fig. 3.a. VI user input (source and load controls).

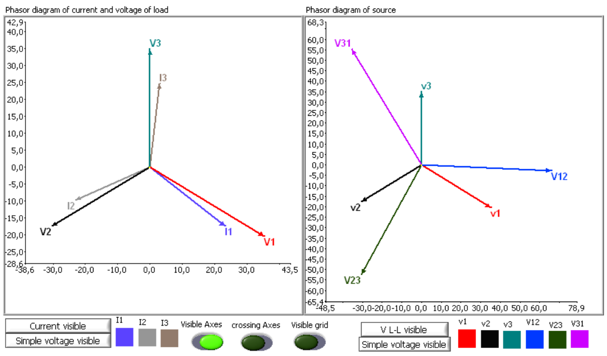

Fig. 3.b. VI output (phasor diagram of source and load currents and voltages).

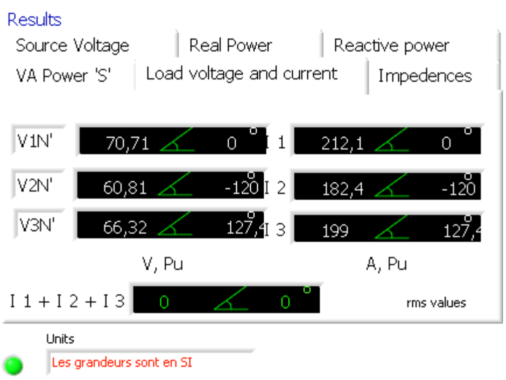

Fig. 3.c. Front Panel result of Balanced Three Phase (Star/Delta) Circuit VI.

voltages are presented in figure 3.c, figure 3.d present front panel result of balanced three phase (Star/Delta) Circuit.

6. TRANSMISSION LINE (VI) MODULE

One of the requirements of the operation of any power system is the maintenance of the voltage within specified limits at various points in the system [7]. This requires understanding the mathematical model of the transmission line and solution of various equations used to calculate voltage, current, and power at various points of a transmission line. The exact analysis of the transmission line involves a distributed parameter analysis, as the parameters of the line (series capacitance, shunt capacitance, inductance, and resistance) are uniformly distributed over the length of the line. The exact analysis is complicated and time consuming. Fortunately, depending on the length of the line, some of these parameters can be lumped, resulting in a simplified model with reasonably accurate results.

6.1. Short Transmission Line Model

If the length of the line (l) is less than or equal to 80 km, then a short transmission line model is used for analysis [7] as shown in figure 3. In this type of modeling, the capacitances have negligible effect, and they are ignored. The resistances and inductances are lumped and represented by single units. The per-phase model of the line is basically a series circuit with a much simpler voltage, current, and power equations. figure 4 represents the diagram of such a line.

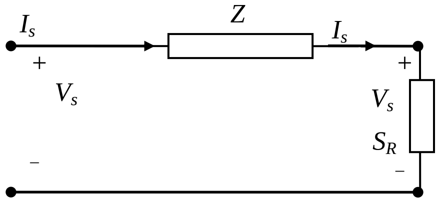

Fig. 4. Short transmission line model.

The line equations are as follows [6]:

$$Z = (r + j\omega L)l = R + jX \tag{11}$$

$$I_R = S^*_{R(3\phi)} \; / \; 3\, V_R \tag{12}$$

$$V_S = V_R + Z \times I_R \tag{13}$$

$$I_S = I_R \tag{14}$$

$$VR(\%) = (\; (\; |V_{R(NL)}| - |V_{R(FL)}| \;) \; / \; |V_{R(FL)}| \;) \times 100 \tag{15}$$

$$S_{S(3\phi)} = 3\, V_R I_R^* \tag{16}$$

$$S_{L(3\phi)} = S_{S(3\phi)} - S_{R(3\phi)} \tag{17}$$

$$\eta = (P_{R(3\phi)} \; / \; P_{S(3\phi)}) \times 100 \tag{18}$$

Where: Z is the total line impedance, l is the line length, I_R is the receiving end current, V_s is the voltage at the sending end, I_s is the current at the receiving end, VR(%) is the percentage voltage regulation, $S_{L(3\phi)}$ is the sending end power, $P_s + jQ_s$, $S_{L(3\phi)}$ is the total line loss and η is the transmission line efficiency.

The voltage and current equation of the short transmission line model is as follows [7]:

$$\begin{aligned} V_s &= AV_R + BI_R \\ I_s &= CV_R + CI_R \end{aligned} \tag{19}$$

or in matrix form

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix} \Rightarrow \begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix} \tag{20}$$

6.2. Medium Transmission Line

If the length of the line is greater than 80 km and less than or equal to 240 km, then a medium transmission line model is used for analysis [7] as shown in figure 4. In this type of modeling, the shunt admittance, usually pure capacitance, is included in the calculations. If the total shunt capacitance is divided into equal parts placed at the sending end and receiving ends of the line, the circuit is called a nominal π. On the other hand, if all of the shunt admittance of the line is lumped in the shunt arm of the T and the series impedance is divided equally between the two series arms results in the nominal T, the per-phase model of the line is basically a series-parallel circuit with simpler voltage, current, and power equations. Figure 5 represents the nominal π model of such a line.

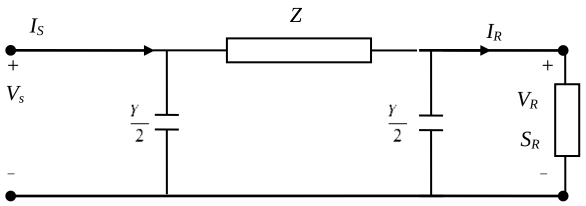

Fig. 5. Nominal π model of a medium transmission line.

The voltage and current equation of the nominal π model is as follows [7]:

$$\begin{aligned} V_s &= (1+ZY/2)V_R + ZI_R \\ I_s &= Y(1+ZY/4)V_R + (1+ZY/2)I_R \end{aligned} \quad (21)$$

Or in matrix form

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix} \Rightarrow$$
$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} (1+ZY/2) & Z \\ Y(1+ZY/4) & (1+ZY/2) \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix} \quad (22)$$

6.3. Long Transmission Line Model

The exact solution of any transmission line and one required for a high degree of accuracy in calculating of lines more than approximately 240 km long must consider the fact that the parameters of the line are not lumped but are distributed uniformly throughout the line [6]. The per phase circuit of this line is shown in figure 6.

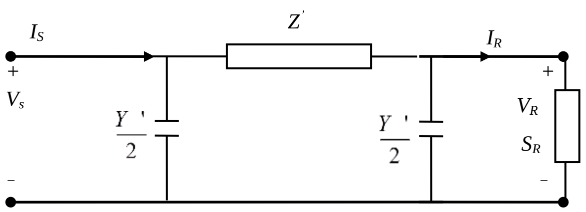

Fig. 6. Long transmission line model.

The hyperbolic form of voltage and current equations for this line are [6]:

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix} \Rightarrow$$
$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} (1+Z'Y'/2) & Z' \\ Y'(1+Z'Y'/4) & (1+Z'Y'/2) \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix} \quad (23)$$

$$\begin{aligned} A &= \cosh \gamma l, & B &= Z_c \sinh \gamma l \\ C &= (1/Z_c)\sinh \gamma l, & D &= \cosh \gamma l \end{aligned} \quad (24)$$

With:

$$\begin{aligned} Z' &= Z_c \sinh \gamma l = Z(\sinh \gamma l)/(\gamma l) \\ Y'/2 &= (1/Z_c)\tanh(\gamma l/2) \\ &= (Y/2)(\tanh(\gamma l/2))/(\gamma l/2) \end{aligned} \quad (25)$$

Where: Z (= $z\ l$) is the total series impedance (Ω), Y(=yl) is the total shunt admittance (Siemens), z is the series impedance per length unit (Ω/m), y is the shunt admittance per length unit (Siemens/m).
and:

$\gamma = \sqrt{zy}$: propagation constant (26)

$Z_c = \sqrt{z/y}$: line characteristics impedance (27)

A VI is developed using the previous equations for transmission line in one front panel. The short transmission line is detected automatically if the shunt admittance is equal to zero, else the user can decide between the medium or long transmission line using a button from the front panel, which is achieved using case structure. The VI were simulated with the input values from a medium transmission line example [9], and the results from the VI matched with the example results. The front panel for the medium transmission line simulation is shown in figure 7.a and figure 7.b, figure 7.a present the user input (line parameters and load control), the simulation results are presented in figure 7.b.

7. CONCLUSION

In this paper we have discussed design and development of interactive instructional virtual instrument (VI) modules for studying (a) load analysis, (b) single phase circuits with leading and lagging power factor , (c) Three-phase electrical power generation and (d) modeling of transmission lines.

The VI modules presented in this paper are tested with the input values from various examples in textbooks and results matched with the results of the examples. The modules presented in this paper are developed using simplified models. Although this is sufficient for introducing the concepts, elaborate models must be incorporated into the modules to address the complex real world situations. LabVIEW has features and built-in virtual instrument modules identical to most of the features found in all these software packages. LabVIEW provides a graphical environment to solve complex problems. No or minimal programming knowledge is necessary to

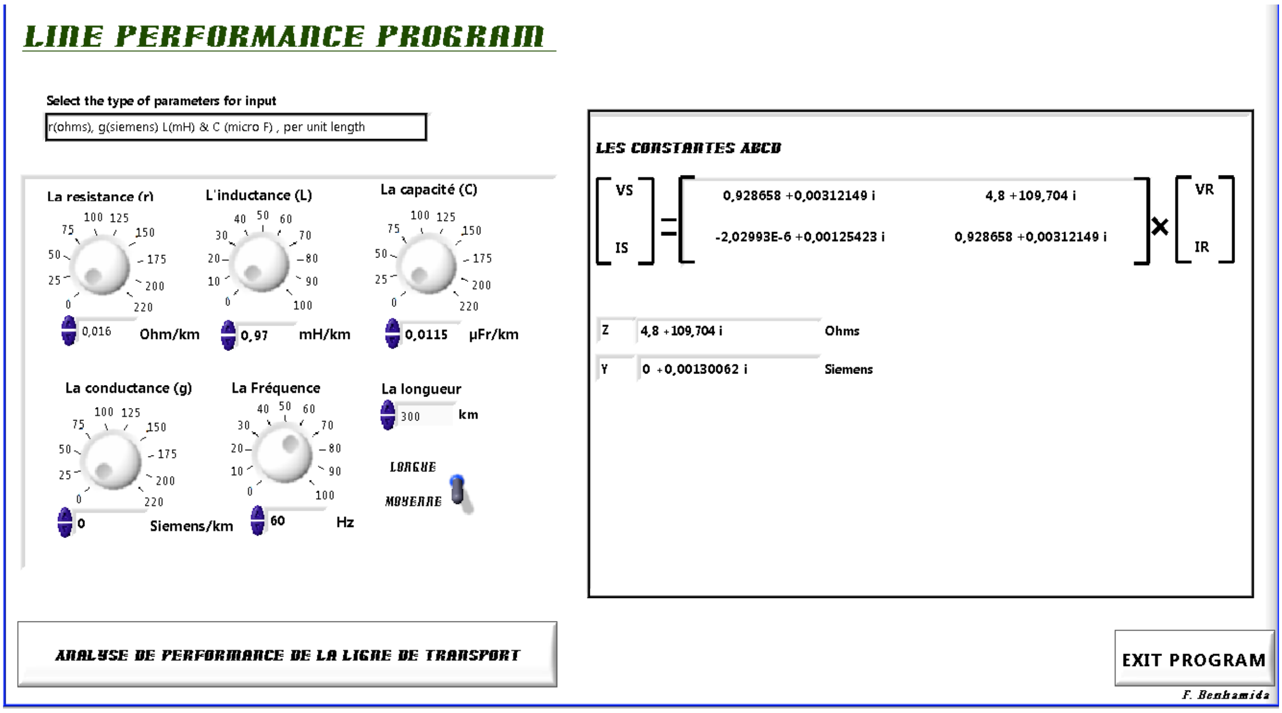

Fig. 7.a. The user input front panel for the medium transmission line simulation VI.

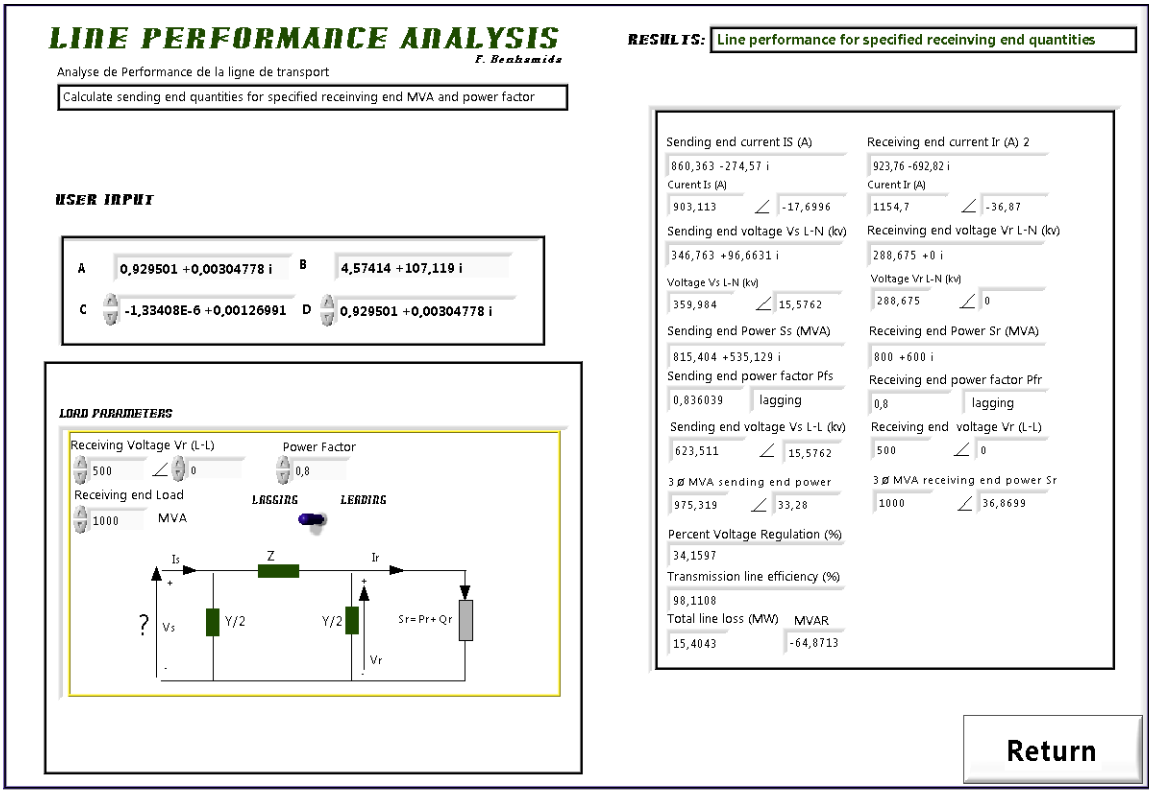

Fig. 8.b. the simulation results front panel for the medium transmission line simulation VI.

design and develop the VI modules. LabVIEW has provision to transfer data between LabVIEW, Excel, and MATLAB and call MATLAB and Excel from the LabVIEW environment. Therefore, one can use LabVIEW to address the needs of various courses. This will be beneficial for students and faculty and introduce standardization across the sciences programs.

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