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USING LABVIEW FOR THE STUDY OF PARTICULAR OPERATING CONDITIONS OF ELECTRICAL TRANSMISSION LINES

BY

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Abstract. The paper presents a virtual instrument realized by the authors and used to the study of the particular operating conditions of the electrical transmission lines: no load and short-circuit. Virtual instruments were used to measure voltages, currents and powers in three different sections of the single-phase test model in the laboratory: beginning, middle, end. The characteristic phenomena of these operating conditions are explained..

Key words: virtual instrument; LabView; transmission line; particular operating conditions.

1. Introduction

For long-distance electrical energy transmission, high voltages and very high voltages transmission lines are used. These lines present a range of particular functional features, which are different than normal short lines used to distribute electrical energy.

In case of AC power transmission lines, in normal operating conditions, the load is balanced for the three phases, the parameters are the same and supply system voltages is symmetrical: equal in magnitude and $2\pi/3$ rad phase shift. Therefore it is sufficient to study the functioning of only one phase, using a single line scheme that has led conductor with sequence parameters and the return conductor, a fictitious one with zero impedance. The presence of this

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conductor is fictional in order to ensure the necessary current return way, in reality there exists not, as for a three-phase (symmetrical) line, the current comes on one phase and return to the other two.

The powers to be transferred on a transmission line during operation can vary within relatively wide. Corresponding to this variation, the values of voltages and currents vary too. To appreciate the variation of voltage and current along the line in a certain situation is very useful to know some critical situations, characterized by limit values of voltage, current, or even transmitted power and length.

For these extreme regimes, quantitative conclusions regarding voltage and current variations can be finded, so to a certain regime depending near one of those extreme regimes, qualitative assessments of changes in voltage and current can be done. The most common of particular regimes are: no load and short-circuit.

Virtual instruments make use of transducers and sensors to get in touch with the physical quantity measured by any system of signal conditioning and analog–digital conversion circuits (Gromoni, 2007). Virtual instrument can be easily adapted for the use for a wide range of applications in power engineering (Barros *et al*., 2009), they are identical to functions in conventional programming languages, and sometimes are integrated into these (Vergura & Natangelo, 2010). The paper presents a virtual instrument realized by the authors and used to the study of the particular operating conditions of the electrical transmission lines.

2. Particular Operating Conditions of Electrical Transmission Lines: No Load, Short-Circuit

Transmission lines are characterized by the fact that in the analysis of operating conditions should be considered a uniform distribution of electrical parameters (resistance and inductive reactance, longitudinal conductance and transverse capacitive susceptance) along the line.

Because the line is usually the same throughout its construction, electrical parameters can be considered constant, resulting a homogenous line with the parameters R_u, X_u, G_u, B_u, uniformly distributed.

But, in steady state transmission lines are loaded symmetrically, so, the following phenomena can be followed on a single phase, three-phase symmetrical line lossless, can be characterized by the same equations as the homogeneous single phase line (Bergen & Vittal, 2000; Gainger & Stevenson, 1994)

$$\begin{cases} \underline{U}_{f1} = \underline{U}_{f2}\cos 2\pi L_r + \mathrm{j}\underline{I}_2\underline{Z}_c \sin 2\pi L_r, \\ \underline{I}_1 = \underline{I}_2 \cos 2\pi L_r + \mathrm{j}\dfrac{\underline{U}_{f2}}{\underline{Z}_c}\sin 2\pi L_r, \end{cases} \tag{1}$$

where: $\underline{U}_f$, $\underline{I}$ are, respectively, voltage and current at the start of the line; $\underline{U}_{f2}$, $\underline{I}_2$ – voltage and, respectively, current at the end of the line; Z_c – wave impedance (characteristic impedance); L_r – relative length of the line.

2.1. No Load Operating Condition

For this operating condition $\underline{I}_2 = 0$ and $\underline{Z}_2 = \infty$. Consequently, eqs. (1), for lossless line, become

$$\underline{U}_{f1}(x) = \underline{U}_{f2}\cos 2\pi L_r, \quad \underline{I}_1(x) = \mathrm{j}\frac{\underline{U}_{f2}}{\underline{Z}_c}\sin 2\pi L_r. \tag{2}$$

In Fig. 1 is presented the voltage and current variation along the line for no load operating condition.

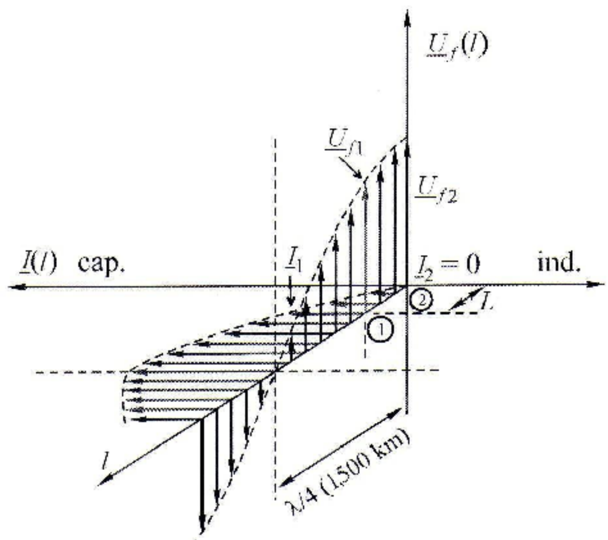

Fig. 1 – Voltage and current variation along the line for no load operating condition.

Analysing expressions (2) and Fig. 1 it results that

a) the voltage at the beginning of the line and at every point of it is in phase with the voltage at the end of the line and the voltage at any point;

b) voltage and current vary satisfying a sinusoidal law along the line, and the current lead the voltage with a phase shift of $\pi/2$ electrical radiants;

c) at the end of the line voltage is greater than at the beginning of the line, a phenomenon known as the Ferrantti effect (increase of voltage that occurs along the line at no load condition due to the capacitive character of the current which passes through the inductive reactance of the line);

d) the current varies satisfiying sinusoidal law along the line and is zero at the end of the line;

e) active power transmitted on the line is zero, as in any section of line the current lead the voltage with a phase shift of $\pi/2$ (the real line absorbs from the source the active power necessary to cover losses).

2.2. Short-Circuit Operating Condition

For this operating condition $\underline{U}_{f2} = 0$ and $\underline{Z}_2 = \infty$. Following, eqs. (1), for lossless line, becomes

$$\underline{U}_{f1} = \mathrm{j}\underline{I}_2 \underline{Z}_c \sin 2\pi L_r, \quad \underline{I}_1 = \mathrm{j}\underline{I}_2 \cos 2\pi L_r. \tag{2}$$

In Fig. 2 is presented the voltage and current variation along the line for short-circuit operating condition.

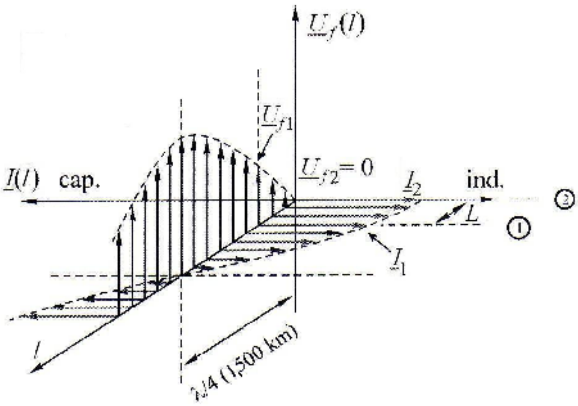

Fig. 2 – Voltage and current variation along the line for short-circuit operating condition.

The analysis of relations (3) and Fig. 2 shows that

a) current at the beginning of the line and current at any point of the line are in phase with the current at the end of the line;

b) current and voltage vary satisfying sinusoidal low along the line and to the end of line (at the short-circuit point) the current is maximum;

c) in any section of the line the current is inductive, the current lags the voltage with a phase shift of $\pi/2$ electrical radiants;

d) active power transmitted on the line is zero.

2. Application

A 400 kV transmission line with 500 km length was modeled. The equivalent electric parameters per unit have the following values:

$R_u = 0.0345$ Ω/km; $X_u = 0.3446$ Ω/km;
$B_u = 3.347 \times 10^{-6}$ S/km; $G_u = 0$; $C_u = 10.66 \times 10^{-9}$ F/km.

For simplicity, the line will be considered lossless, so that $R_u = 0$. Wave impedance for the lossless line is

$$Z_u = \sqrt{\frac{x_0}{b_0}} = 320.87\ \Omega. \tag{4}$$

Usually, to analyse the particular operating conditions of a transmission line, two-port give good results for 300 km length (Şora, 1982). In our case, in the laboratory we used two Π test models. The current and voltage channels of the three-phase acquisition equipment was installed at the beginning of the test model, at its middle (between the two two-ports), respectively at the end of the test model (Fig. 3).

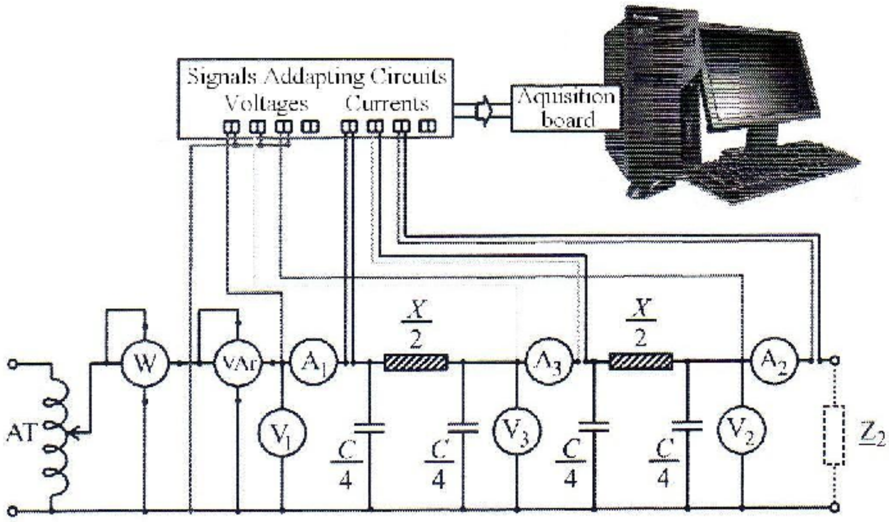

Fig. 3 – The schema of the test model for the transmission line.

Laboratory test model of the transmission line is built to the following scales:

a) Impedance scale: $s_Z = \dfrac{Z_{\text{model}}}{Z_{\text{real}}} = l\dfrac{\Omega_{\text{model}}}{\Omega_{\text{real}}}$.

b) Voltage scale: $s_U = \dfrac{U_{\text{model}}}{U_{\text{real}}} = \dfrac{200\ \text{V}_{\text{model}}}{400\ \text{kV}_{\text{real}}} = 0.5\dfrac{\text{V}_{\text{model}}}{\text{kV}_{\text{real}}}$.

c) Power scale: $s_S = \dfrac{S_{\text{model}}}{S_{\text{real}}} = \dfrac{U_{\text{model}} I_{\text{model}}}{\sqrt{3} U_{\text{real}} I_{\text{real}}} = \dfrac{1}{4}\cdot\dfrac{\text{VA}_{\text{model}}}{\text{MV}_{\text{real}}}$.

d) Current scale: $s_I = \dfrac{I_{\text{mod el}}}{I_{\text{real}}} = \dfrac{U_{\text{mod el}} / Z_{\text{mod el}}}{U_{\text{real}} / \sqrt{3} Z_{\text{real}}} = \dfrac{\sqrt{3}}{2} \cdot \dfrac{\text{A}_{\text{mod el}}}{\text{kA}_{\text{real}}}$.

The date acquisition system is composed by current and voltage transducers and a PCI acquisition board. The acquisition board is a National Instrument type 6023-E, having the sampling rate 200 kS/s, 12-Bit, 8 I/O lines.

In Fig. 4 the three-phase virtual instrument's front panel presents the results determined using LabView for the no load operating condition.

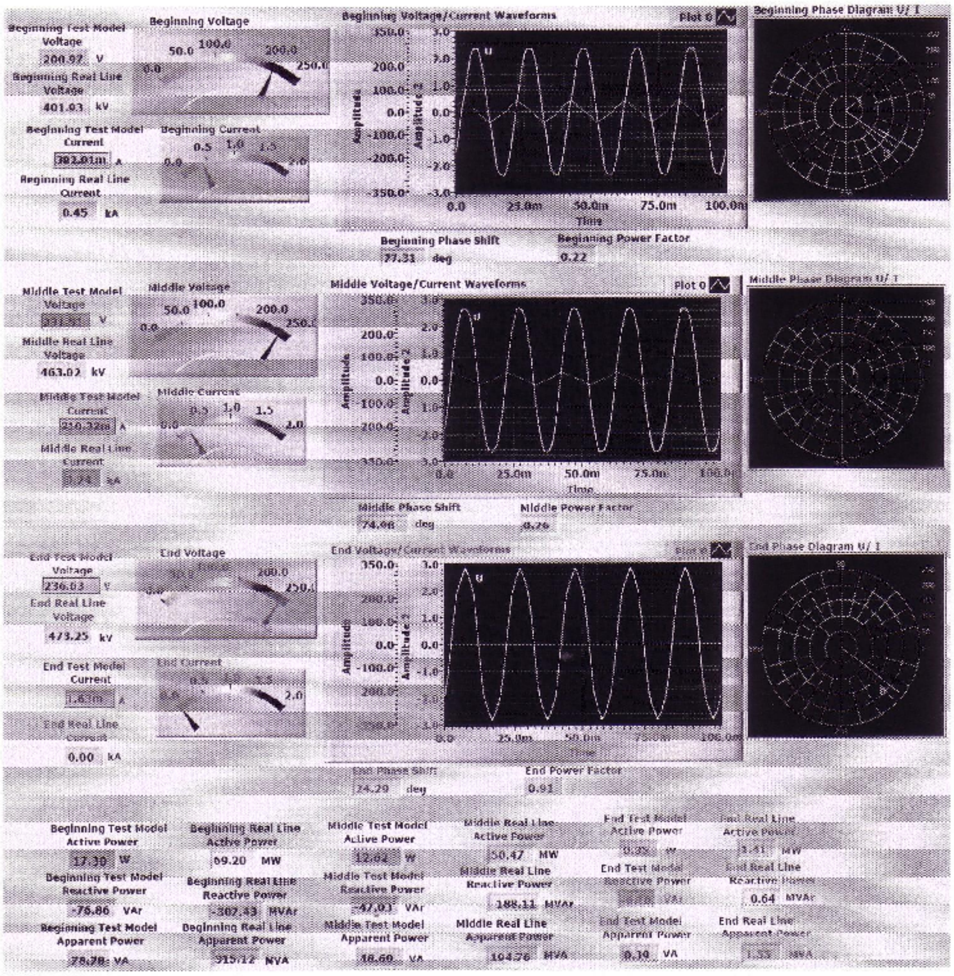

Fig. 4 – No load operating condition.

From the waveforms in Fig. 4 it results that

a) The voltage at the beginning of the line and at every point of it is in phase with the voltage at the end of the line.

b) Voltage and current vary satisfying a sinusoidal low along the line, and the current lead the voltage with a phase shift of $\pi/2$ electrical radiants.

c) The line absorbs from the system a significant capacitive reactive power and an active power corresponding to the losses.

In Fig. 5 the three-phase virtual instrument's front panel presents the results determined using LabView for the short-circuit operating condition.

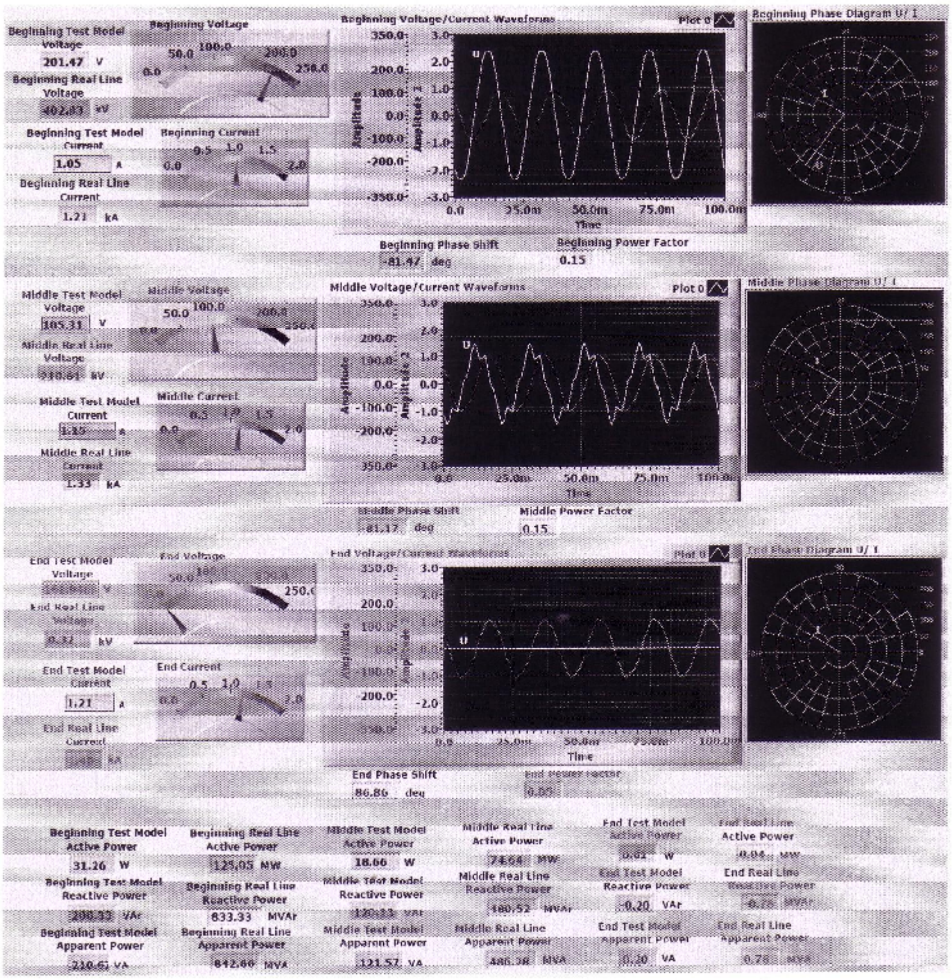

Fig. 5 – Short-circuit operating condition.

The following characteristics of short-circuit operating condition can be observed on the front panel of the virtual instrument in Fig. 5

a) The current at the beginning of the line and at every point of it is in phase with the current at end of the line.

b) The current and voltage varies satisfying sinusoidal laws along the line and at the end of the line (at short-circuit point) the current is maximum.

c) In any section of the line the current is inductive, the current lags the voltage with a phase shift of $\pi/2$ electrical radiants.

d) Active power transmitted on the line is zero.

4. Conclusions

The power to be transferred on a transmission line during operation can vary within relatively wide. Corresponding to this variation, the values of voltages and currents vary. To appreciate the variation of voltage and current along the line in a situation is very useful to know some critical situations, characterized by limit values of voltage, current and power.

For these extreme regimes, quantitative conclusions regarding the variation of voltage and current can be finded, so to a certain regime depending near one of those extreme regimes can be, quantitative assessments of changes in voltage and current can be done. The most common of particular regimes are no load, short-circuit, natural power.

Virtual instruments are particularly useful for interpreting the phenomena described above provided by the front panel interface that can present simultaneously the desired amounts in different sections of the line.

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UTILIZAREA LABVIEW LA STUDIUL REGIMURILOR PARTICULARE DE FUNCȚIONARE ALE LINIILOR ELECTRICE DE TRANSPORT

(Rezumat)

Se prezintă un instrument virtual realizat de către autori şi utilizat pentru studiul pe model al regimurilor particulare de funcționare ale liniilor electrice de transport: funcționare la gol şi în scurtcircuit. Instrumentele virtuale au fost folosite la măsurarea tensiunii, curentului şi puterilor electrice în diferite secțiuni ale modelului monofazat din laborator: început, mijloc, sfârşit. Sunt explicate fenomenele caracteristice acestor regimuri de funcționare.