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Physical Modeling of HV Bus-Ducts for Obtaining Frequency Response Using Simulink®

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Abstract: **This paper proposed a physical model for high voltage bus-ducts to obtain frequency response. The model were transformed to a block diagram which can be implemented in MATLAB® Simulink environment where it was subjected to BODE operation. Also an experiment were executed for comparing the trend of achieving resulted curves in theory and in practice.**

Keywords: **Bus-duct, Frequency Response Analysis (FRA), Simulink, electrical modeling.**

I. INTRODUCTION

Frequency response analysis (FRA) method offers some useful insights into situations and conditions of electrical elements and devices. This method allows us to understand the system behavior in the presence of more complex inputs [1-3]. This method is widely used for the devices whose the inner constructions are not actually accessible like power transformers [1,4,5]. Bus-ducts are such devices that may be too long and are very simple in construction.

After installation, bus-ducts are not usually accessible and we do not expect any failure in them which may be occurred by the time. In this work, an electrical model was proposed for bus-ducts like [2] and a block diagram derived from this model was developed in simulink environment [6-8]. This block diagram where connected to a measuring model [9-11] and the whole diagram were subjected to BODE operation that achieved the amplitude and phase curves of frequency response analysis [12].

Finally the results were investigated as a pattern of frequency response variation comparing with the results of a former experiment. The layout of this paper is as follows:

In section 2 a review of theorical subjects were done; section 3 addressed to MATLAB® Simulink implementation for using BODE operation.

Model of bus-duct is mathematically investigated in section 4, then the developed model were implemented in simulink described in section 5, and the output were investigated. Section 6, states an experiment which were executed in Dez-hydropower plant and discusses about the results. Finally the conclusions and considerable point are presented in section 8.

II. THEORICAL

A. Frequency Response Analysis (FRA):

Consider a continuous-time, linear time–invariant system between the input x(t) and the output y(t) as shown in Fig.1.

The function G(jω) is called the frequency response of the system, where x(jω), y(jω) and G(jω) are the Fourier transform of input x(t), output y(t), and impulse response g(t), respectively.

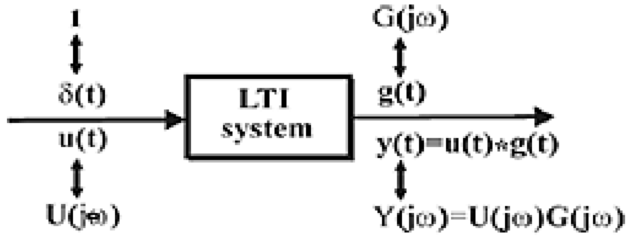

Fig.1: Relationships between inputs and outputs in a LTI system.

The Frequency Response Analysis (FRA) is a simple method for obtaining detailed information about the considered linear system. Recall that in the case of mono-frequency sinusoidal input signal x(t) as below:

$X(t) = a\cos(\omega t)$ (1)

The steady-state response of a linear, stable system with transfer function G(s) is :

$Y(t) = b\cos(\omega t + \Phi)$ (2)

The amplitude and phase of the system frequency response can be computed giving:

$G(\omega) = 20 * \log\left|\frac{b}{a}\right|, \Phi(\omega) = \Phi$ (3)

that will be presented by two waveforms.

B. Physical Model of Bus-Ducts:

Bus-ducts are similar to cables in shape and can be electrically modeled by elements used in circuits like inductances, capacitors and resistances.

For a single line bus-duct shown in Fig.2, series inductance and parallel capacitance of electrical model is calculated for each meter of length as following relations:

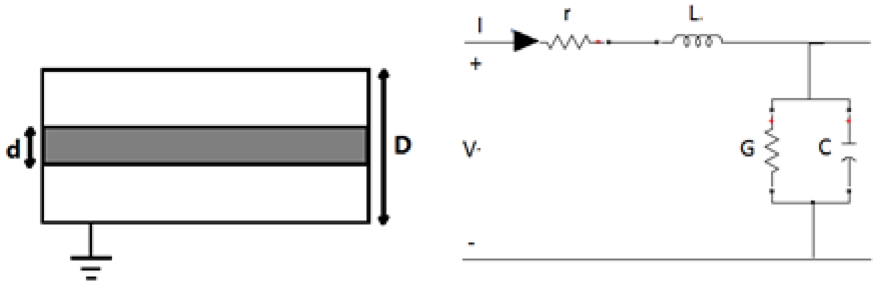

Fig.2 : A single line bus-duct and its electrical model

$$L = 2 * 10^{-7} Ln\left[0.5 + Ln\left(\frac{D}{d}\right)\right] \quad (4)$$

$$C = \frac{2\pi\varepsilon_0\varepsilon r}{Ln(D/d)} \; (F/m) \quad (5)$$

Where

L is the amount of series inductance per meter,

C is the amount of parallel capacitance per meter,

D is the diameter of outer layer of duct,

and d is the diameter of inner conductor.

If the ducts have other shapes, calculation of L and C will make other relations regarding to the number of phases, shape, size of crest, location of phases and ….

III. MATLAB® AND SIMULINK

MATLAB is a powerful software that has been prepared for a wide range of researches through its professional calculating tool boxes. Also this software profits SIMULINK which is a comfortable work space for modeling most physical environments.

Simulink environment is capable to achieve FRA by applying BODE operator and presents the resulted amplitude and angle curves.

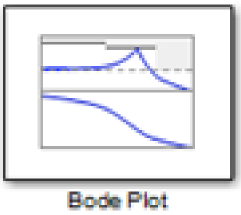

Fig.3: BODE operator available in SIMULINK for FRA studies

When we are applying BODE operator, we need to obtain Laplace transformed models of the circuit. Therefore, next steps we have to separate bus-ducts into parts and obtain block diagrams of each part for our study.

IV. MODELING

Fig. 4 shows a simple type construction of a bus-duct as the bus is held by insulating support which are usually porcelain based.

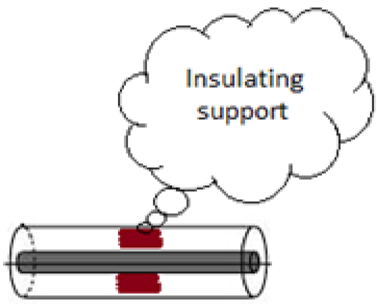

Fig. 4: A simple construction of bus-duct

Insulating supports can be modeled by a dissipating capacitor (C) as shown in Fig 5 which is in series with a large amount resistor (R) that represents the effect of the painting thin layer of inner crest of bus-duct as it could not be negligible.

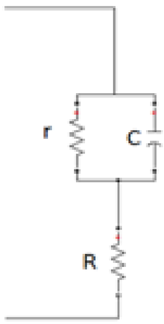

Fig. 5: Electrical model of insulating supports

Therefore according to the model of electric conductors which has been also applied for overhead lines and cables,the developed electrical model of each part of bus-ducts is presented in Fig. 6 for a single insulating support.

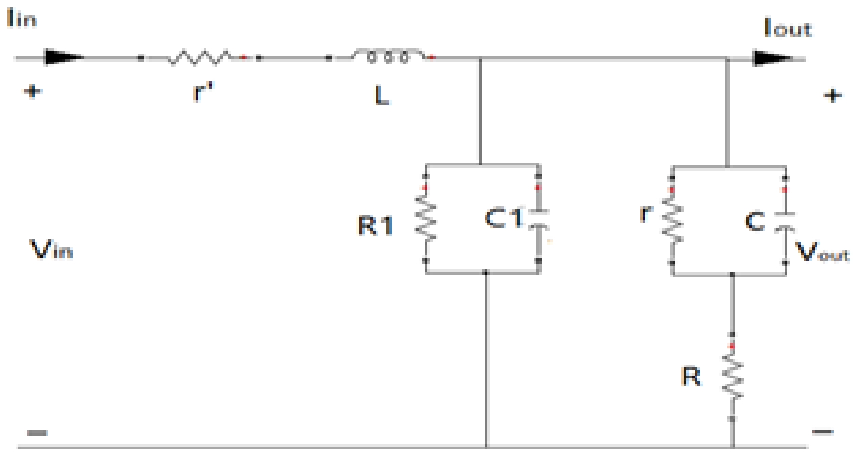

Fig. 6: Electric model for each part of bus-duct

The following equations describe the behavior of each part of bus-ducts although we know that the above models could be more complex through different items such conductor shape, outer earth connection and ….

$$V_{in} = (\acute{r} + sl)I_{in} + V_{out} \quad (6)$$

$$(I_{in} - I_{out}) = \left(\frac{1}{R+\frac{r}{scr+1}} + sc1 + \frac{1}{R1}\right).V_{out} = K.V_{out} \quad (7)$$

After that, Transmission matrix (T), can be defined by the following equations which is presented inFig. 7.

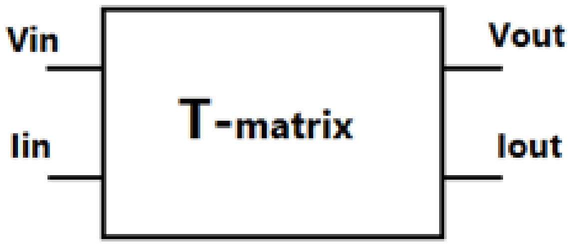

Fig. 7: Block diagram of Transmission matrix (T)

$$T = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \quad (8)$$

$$\begin{bmatrix} V_{out} \\ I_{out} \end{bmatrix} = T \begin{bmatrix} V_{in} \\ I_{in} \end{bmatrix} \quad (9)$$

where

$$T_{11} = 1 \quad (10)$$

$$T_{12} = -(\acute{r} + sl) \quad (11)$$

$$T_{21} = -k \ (12)$$

$$T_{22} = 1 + (\acute{r} + sl).k \quad (13)$$

Consequently an overall T-Matrix can be defined for series partial T-Matrices shown in Fig.8 that can be calculated as below:

$$T = T_1 \times T_2 \times \ldots \times T_n \quad (14)$$

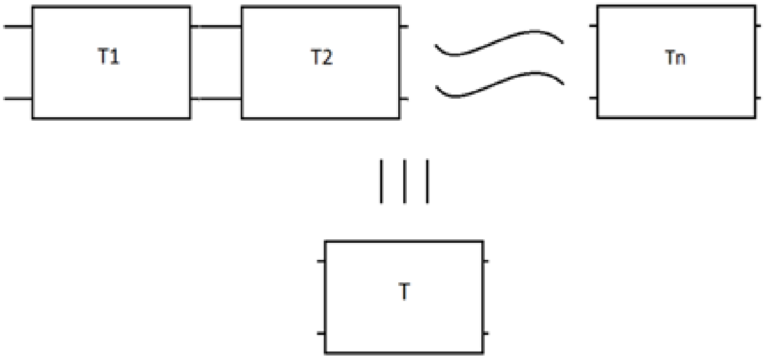

Fig. 8 : overall T-Matrix for the whole bus-duct

Fig. 9 shows the block diagram representing the behavior of circuit in Fig. 5 that can be implemented in Simulink environment. Regarding to this technique the whole block diagram of each part of bus-ducts in Fig. 6 with single insulating support can be shown in Fig 10.

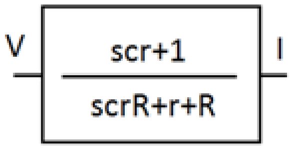

Fig. 9 : Block diagram of circuit in Fig. 5

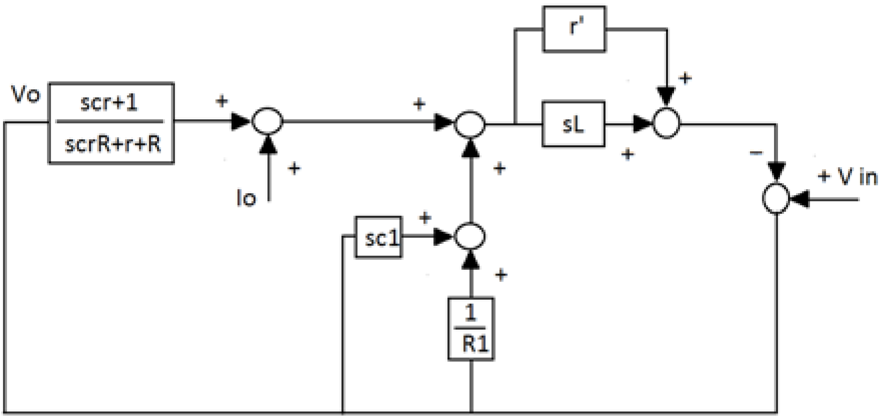

Fig. 10: Block diagram of each part of bus-duct with single insulating support like Fig.6

V. IMPLEMENTATION OF MODEL

Simulink environment is capable to achieve FRA by applying BODE operator and presents the amplitude and angle curves. Fig. 11 shows measuring circuit in which the connection of input and output are determined.

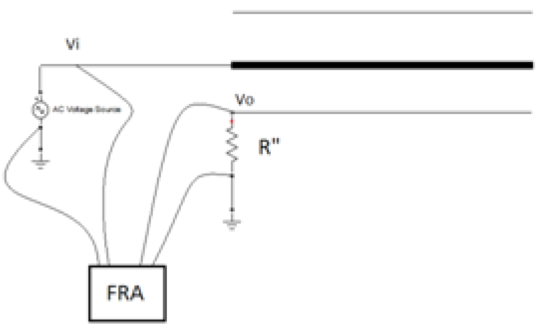

Fig. 11: Measuring circuit for achieving frequency Response of bus-duct

In Fig. 11 sinusoidal power supply is directly connected to the head of conductor as input, when the tail of the duct is open. The outer crest of the duct is connected to the earth of the circuit via resistor (R") and the voltage on resistor (R") is measured as output.

According to the above statements, following points are implemented to complete the project in Simulink:

a-To make the whole block diagram of the bus-duct a series combination of diagram shown in Fig. 12 should be applied.

b-As mentioned, in the last block diagram Iout is zero to satisfy the open circuit condition.

c-Like what is presented in figure (12) a sampling and feedback connection has been added to make the behavior of proposed measuring circuit.

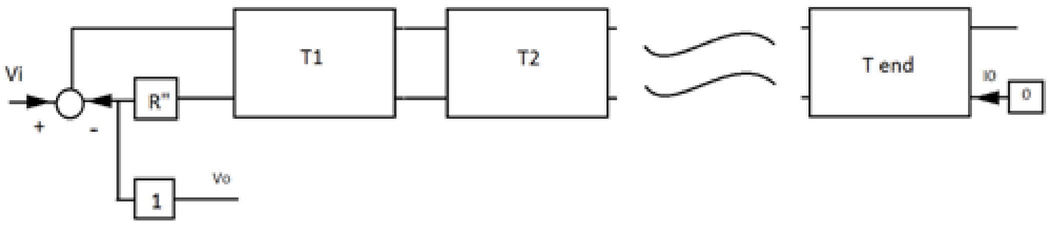

Fig.12: Presenting the last considerations a, b and c

After the completed project is executed, frequency response curves of proposed measuring circuit can be observed like Fig. 13.

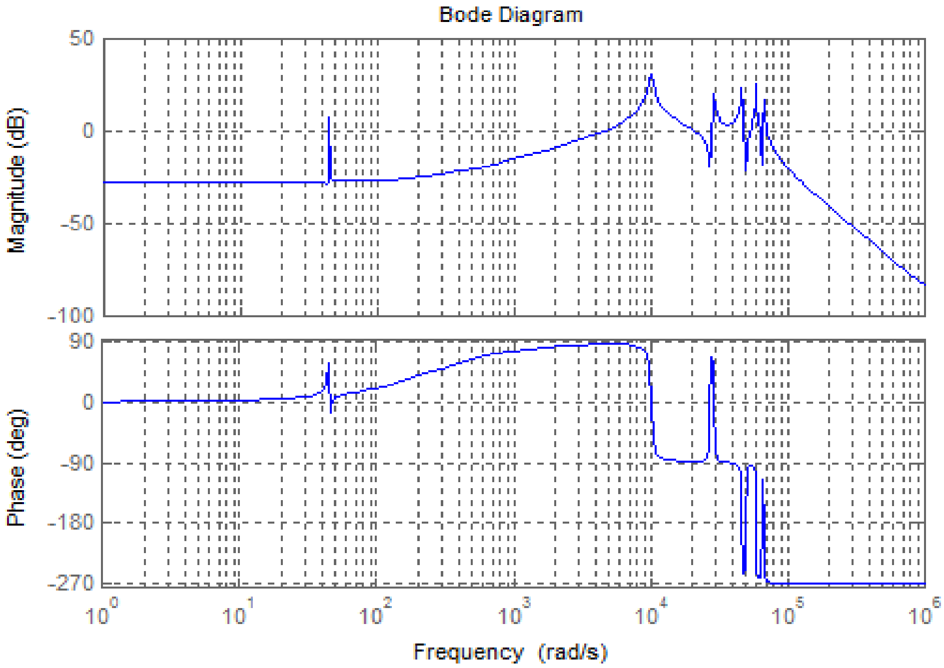

Fig. 13 : Frequency Response of bus-ducts by proposed measuring circuit

VI. EXPERIMENTAL RESULTS AND DISCUSSION

A measuring circuit was setup which is similar to the circuit shown in Fig. 14 and was applied on a separated three phase set of bus-ducts which were located between generator and unit transformer in Dez-hydropower plant, Khuzestan, Iran.

Fig. 14 shows the results of frequency response for each phase and as it can be observed the results of one phase differs from the others in low frequencies although in high frequencies the differences are less to some extent.

These three bus-ducts had been constructed similarly as we can see that their main natural frequencies are the same.

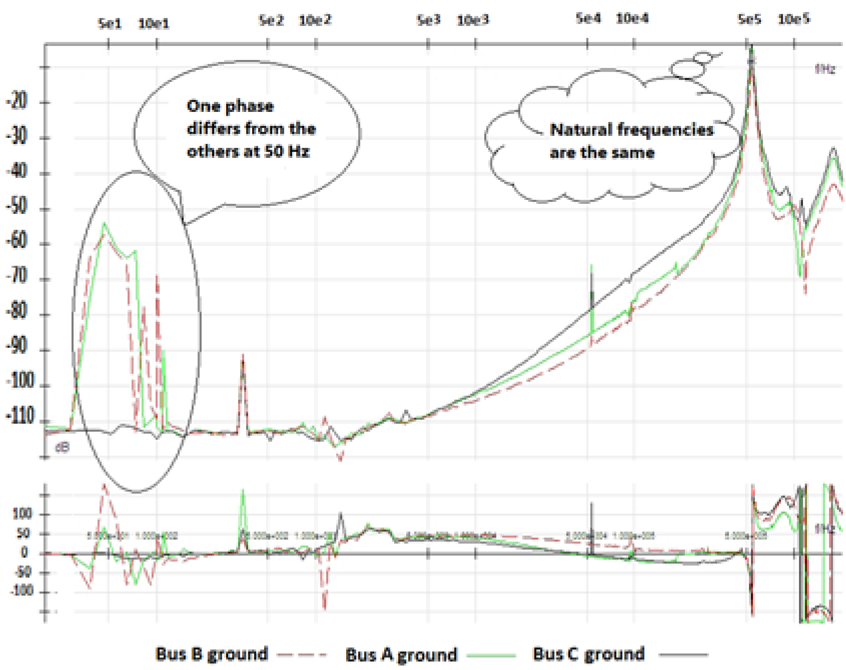

Fig. 14: Results of FRA for unit 1 in Dez-hydropower plant

The difference between phases were caused by resistances in insulating support and were exactly occurred at the operating frequency of the network (50Hz).

According to the large amount of phase currents for unit generator, this unbalances made more than 200 (A) current for neutral of unit generator.

VII. CONCLUSIONS

This paper presents modeling bus-ducts in high voltage power systems in order to obtain their frequency response for investigating the behavior of the duct in various conditions and also execution of experimental cases in industry. Results of this work will conclude the following points:

a- Bus-ducts have a complex frequency Response although their electrical constructions are simple.

b- FRA can be a determining method for bus-ducts and is more cheaper than current solutions such as electromagnetic waves.

c- Insulating supports can affect FRA at low frequencies when they are losing quality.

d- Main natural frequencies of bus-ducts occur at high frequencies.

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