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Transient Analysis of a Transmission line

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Abstract- In high-current, high-voltage power systems a very clear differentiation between steady-state and transient behavior of circuits is made. This is based on the concept that steady state behavior is normal and transients arise from the faults. The operation of most electronic circuits (such as oscillators, switch capacitors, rectifiers, resonant circuits etc.) is based on their transient behavior, and therefore the transients here can be referred to as ''desirable''. The transients in power systems are characterized as completely ''undesirable'' and should be avoided; and subsequently in some very critical situations, they may result in the electrical failure of large power systems and outages of big areas. It is with the belief that transient analysis of power systems is one of the most important topics in power engineering analysis.

It is found that there are many way to analyze the transient of transmission network. This paper proposes for simulation using MATLAB is done by considering the transient of transmission line. Simulation results will be provided by using Simulink in MATLAB software.

Index Terms- Transient Analysis, circuit equipment, linear circuit, transmission line, instantaneous, load current, steady-state.

I. Introduction

Transient analysis (or just transients) of electrical circuits is as important as steady-state analysis. When transients occur, the currents and voltages in some parts of the circuit may many times exceed those that exist in normal behavior and may destroy the circuit equipment in its proper operation. It's distinguished the transient behavior of an electrical circuit from its steady-state, in that during the transients all the quantities, such as currents, voltages, power and energy, are changed in time, while in steady-state they remain invariant, i.e. constant (in d.c. operation) or periodical (in a.c. operation) having constant amplitudes and phase angles. The cause of transients is any kind of changing in circuit parameters and in circuit configuration, which usually occur as a result of switching (commutation), short, and open circuiting, change in the operation of sources etc. The changes of currents, voltages etc. during the transients are not instantaneous and take some time, even though they are extremely fast with duration of milliseconds or even microseconds.

These very fast changes cannot be instantaneous since the transient processes are attained by the interchange of energy, which is usually stored in the magnetic field of inductances or the electrical field of capacitances. Any change in energy cannot be abrupt otherwise it will result in infinite power (as the power is a derivative of energy, p=dw/dt), which is in contrast to physical reality. All transient changes, which are also called transient responses, vanish and, after their disappearance, a new steady-state operation is established. The transient describes the circuit behavior between two steady states, an old one, which was prior to changes, and a new one, which arises after the changes.

II. TRANSIENT ANALYSIS

The behavior of the circuit as a function of time is studied under transient analysis.The inductors in the circuit are replaced by their equivalent current sources and resistances. The capacitors in the circuit are replaced by their equivalent voltages sources and resistances. The circuit voltages and currents are calculated at the time of switching (usually at t = 0). This is the initial condition solution. The voltages across the capacitors and the currents across the inductors are used to calculate the circuit voltages and currents at each time step.This is done repeatedly for a designated amount of time and the results are then plotted.

A network needs to be analyzed in order to derive information about it so that its predicted behavior can be verified. The need for this analysis arises from the need of the circuit designer to verify the conceived design and to predict the effect of changes in a circuit. The task of analysis starts off with a mathematical model chosen by the designer to represent the behavior of an actual circuit. If the behavior of the model does not reflect the behavior of the actual circuit, the circuit parameters of the model are adjusted in order that the response conforms to the specification. Once the response of the model is within acceptable limits, detailed analysis of the circuit responses and detailed calculations of the effects of component variations must be made. If there is a discrepancy, the circuit is re-modelled and analyzed. The mathematics involved is the solution of a set of simultaneous differential equations. These equations can be line arise for linear circuits.

A circuit with an excitation voltage or current of x and an output voltage or current y is linear if y is proportional to x i.e. if y = f(x) or ky = f(kx). Any circuit which is not linear is called non-linear. Almost all physical components in the circuit are non-linear owing to effects such as aging, internal heating, voltage breakdown and magnetic core saturation, which alter the component value and depend on the applied voltage and its frequency. However, the linearity assumption greatly simplifies circuit analysis. It is important to make this assumption even if the circuits are only approximately linear. Analytical techniques, some of which apply exclusively to linear circuits, are used to gain insight into the circuit behavior. The linearity assumption has several important consequences. If we consider a change of Δx in the excitation x, a corresponding change Δy is produced in y. In a linear circuit the changes are proportional. Therefore

$\Delta y / y = \Delta x / x = k$ and
$\Delta y = f(\Delta x)$.

The changes in the circuit voltages and currents produced by variation of the fixed sources are therefore independent of the nominal values which exist in the circuit. Also since

$$1 + (\Delta y / y) = 1 + (\Delta x / x) = 1 + k,$$
$$(y + \Delta y) = f(x + \Delta x),$$

The effects of source variation are additive to the nominal values. If the variations Δy and Δx are small compared with the nominal values x and y, the analysis for variation only is called small signal analysis. As noted earlier, all practical circuits are non-linear. Fortunately, many circuits operate in regions of near linearity and distortion due to non-linearity is usually small enough to ignore. Circuits in which this cannot be assumed cause major errors when linear analysis is employed and special analysis techniques are required. Models of non-linear elements such as diodes can be line arise by replacing the non-linear element with a combination of sources and linear elements. The resulting linear circuit is valid, provided that small signals are assumed that do not deviate significantly from the nominal or bias values.

III. ANALYSIS OF LINEAR CIRCUITS

The "node" method of analysis is used for systematic analysis of *lumped component circuits*. In any circuit, current varies with time, and the electromagnetic energy is radiated and lost. When the wavelength of the generated electromagnetic wave is usually large in comparison with the physical dimensions of the circuit, the energy loss is negligible.

The basic relations for circuit analysis are the first two laws of Kirchoff.

a) The sum of all currents entering a node must equal the sum of all currents leaving it. (current law or KCL)
b) The sum of all voltages in a given loop must be equal to zero. (voltage law or KVL)

In analyzing a network, one or the other of the above laws is applied to every independent node or independent loop of the network. The number of independent nodes is generally less than the number of independent loops in a network and hence there are fewer node equations than loop equations. Circuit analysis programs generally use node voltage equations for analysing the network.

IV. BASIC RELATIONSHIPS

Let the branches in the network be labelled uniquely and sequentially starting from one (1). Let the nodes be labelled uniquely and sequentially starting from 0. The node given the number zero (0) is the reference node or the ground node. The circuit connections can be represented by

$$A_a I_b = 0 \qquad (1.1)$$

where $\mathbf{I_b}$ is the branch current matrix (the current i_j is the current flowing in branch j). The elements of the matrix $\mathbf{A_a}$ are given by :

$$a_{mn} = \begin{cases} 1 & \text{if the current } i_n \text{ leaves node } m \\ -1 & \text{if the current } i_n \text{ enters node } m \\ 0 & \text{if the current } i_n \text{ neither enters nor leaves node } m. \end{cases} \qquad (1.2)$$

These valuations hold for all the nodes in the circuit. Each equation is the application of Kirchoff's current law (KCL) for the m^{th} node. For N independent nodes, Eq. (1.1) is represented by:

$$AI_b = 0 \qquad (1.3)$$

where matrix **A** has the elements given by Eq.(1.2) and contains *N* columns (number of branches) and *M* rows (number of independent nodes).

Voltage-current relationships for passive elements in a linear circuit are characterized by a single (complex) number (the number is complex for alternating current (AC) circuit analysis):

$$i = y.v \qquad (1.4)$$

with y = 1/R for a resistor, 1/(jω)L for an inductor, or (jω)C for a capacitor where R is the resistance, L is the inductance, C is the capacitance, y is the admittance and ω is the frequency; in the AC analysis, *i* and *v* are complex valued phasor representations for the current and voltage.

As a result of the branch currents flowing through the various branches, a voltage is developed across the respective branches. These voltages can be represented by:

$$V_b = B\, V_n \qquad (1.5)$$

where $\mathbf{V_n}$ represents the node voltage matrix (voltage v_j is the voltage measured at node j) and is a column vector containing n rows. Node voltages are measured with respect to the ground which is at zero potential. The elements of vector **B** are given by

$$b_{mn} = \begin{cases} 1 & \text{if the branch m leaves node } n \\ -1 & \text{if the branch m enters node } n \\ 0 & \text{if the branch m neither enters nor leaves node } n. \end{cases} \qquad (1.6)$$

From Eqs. (1.2) and (1.6) we find that

$$\mathbf{B} = \mathbf{A}^T \qquad (1.7)$$

where $\mathbf{A}^T$ is the transpose of matrix **A**.

This implies that the direction of the current in each branch is the direction of positive voltage to negative voltage in each branch and the number of elements in I_b and $\mathbf{V_b}$ are the same. (i.e. i_2 refers to the current in branch 2 and v_2 refers to the voltage in branch 2); hence the same branch numbering and the same node numbering apply to both Eqs. (1.3) & (1.5).

A branch can represent either an active element (i.e. a voltage or current source) or a passive element (i.e. an inductor or a capacitor or a resistor). If a branch has an independent current source (represented by the vector $\mathbf{I_g}$), then the current leaving that branch is the difference of the currents caused by the independent source and all other currents (represented by $\mathbf{I_b}$). The branch current will then be

$$\mathbf{I_b} = \mathbf{I\ b^*} - \mathbf{I_g} = \mathbf{Y_b V_b} - \mathbf{I_g} \qquad (1.8)$$

where $\mathbf{Y_b}$ is the *branch admittance matrix*.

Combining Eqs. (1.8), (1.5) and (1.3) we get the relationship

$$\mathbf{A Y_b A^T V_n} = \mathbf{A I_g} \qquad (1.9)$$

$\mathbf{A Y_b A^T}$ is called the *node-admittance matrix* $\mathbf{Y_n}$.

V. ANALYSIS OF A NETWORK

In the analysis of linear networks, various element types must be considered. The elements that are used in this analysis is a minimum subset of elements that are present in a network . The elements used in our program are:

Passive Elements

a) Resistance (R)
b) Inductance (L)
c) Capacitance (C)

Active Elements (Sources)

a) Independent voltage source (V)
b) Independent current source (I)

The definitions of the various elements are:

1) An element is a resistance if it is characterized by a single real number R, such that the voltage across the element is R times the current through that element. The reciprocal of R is called conductance and is denoted by G. R is measured in ohms and G in mhos.
2) An element is an inductance if it is characterized by a single real number L, such that the voltage across the element is L times the current through the element. L is measured in henries. For the purpose of transient analysis, the inductor has an initial current through it which is measured in amperes and is denoted by I_0.
3) An element is a capacitance if it is characterized by a single real number C, such that the current through the element is C times the voltage across the element. C is measured in farads. The capacitance can have an initial voltage across it measured in volts and is denoted by V_0.
4) An element is an independent voltage source, if the voltage across it is independent of the current through it. The voltage is measured in volts.
5) An element is an independent current source, if the current through the element is independent of the voltage across it. The current is measured in amperes.

There are two types of sources: accompanied and unaccompanied sources. If a source is accompanied, it implies that there is a small resistance in series with a voltage source and a small resistance in parallel with a current source. Unaccompanied sources are pure current and voltage sources and do not have any accompanying resistances. In our analysis we will consider only accompanied voltage sources as unaccompanied sources present difficulties when forming the branch admittance matrices. Since the accompanying resistance (R) is zero, the admittance (1/R), becomes infinite and the current through the branch becomes indeterminate. The element definitions are consistent with the universally used definitions of the basic network elements and are valid for direct current (DC) transient analysis.

A general network of the type shown in Fig. 1 and made up of M branches and N nodes will be considered for analysis. The voltages and currents in each branch of the network are related as follows:

$$i_b = i_e - i_g \quad (1.10)$$

$$v_b = v_e - v_g \quad (1.11)$$

he element voltage and current also satisfy the relationship

$$i_e = y_e . v_e \quad (1.12)$$

where y_e is the conductance of the passive element in the branch. The above three equations hold for all branches in the network. The branch currents i_{b1}, i_{b2} ... i_{bM} , are represented by a matrix as:

$$\mathbf{I}_b = \begin{bmatrix} i_{b1} \\ i_{b2} \\ \cdot \\ \cdot \\ i_{bM} \end{bmatrix} \quad (1.13)$$

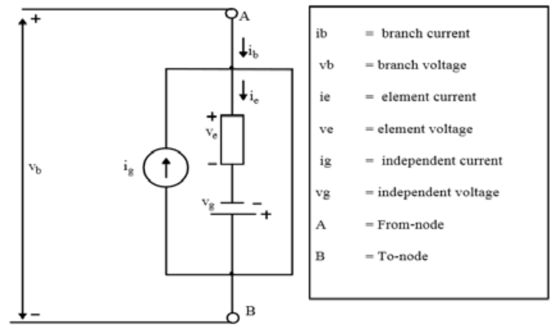

Figure 1: A Network Branch

Similarly the M-vectors for $\mathbf{I}_e$, $\mathbf{I}_g$, $\mathbf{V}_e$, $\mathbf{V}_b$, $\mathbf{V}_g$ are defined. The currents and voltages for all the network branches satisfy the following vector equations:

$$\mathbf{I}_b = \mathbf{I}_e - \mathbf{I}_g \quad (1.14a)$$

$$\mathbf{V}_b = \mathbf{V}_e - \mathbf{V}_g \quad (1.14b)$$

The voltage-current relationships for the passive elements lead to the matrix equation

$$\mathbf{I}_e = \mathbf{Y}_e . \mathbf{V}_e \quad (1.14c)$$

$\mathbf{Y}_e$ is a diagonal matrix of M rows and M columns if the network consists solely of resistors, inductors and capacitors.

Form Eqs (1.14 a, b & c) we get

$$\mathbf{I}_b = \mathbf{Y}_e (\mathbf{V}_b + \mathbf{V}_g) - \mathbf{I}_g \quad (1.15)$$

By Kirchoff's current law

$$\mathbf{A}\mathbf{I}_b = \mathbf{0} \quad (1.16)$$

where **A** is the MxN *incidence* matrix of the network. Hence

$$\mathbf{A} [\mathbf{Y}_b (\mathbf{V}_b + \mathbf{V}_g) - \mathbf{I}_g] = \mathbf{0} \quad (1.17)$$

The node voltages are related to the branch voltages by:

$$\mathbf{A}^T \mathbf{V}_n = \mathbf{V}_b \quad (1.18)$$

Thus, the node voltage expression becomes

$$\mathbf{A}\mathbf{Y}_b\mathbf{A}^T\mathbf{V}_n + \mathbf{A}\mathbf{Y}_b\mathbf{V}_g - \mathbf{A}\mathbf{I}_g = \mathbf{0} \quad (1.19)$$

If the interconnection of the circuit (i.e. the incidence matrix) and the independent voltages and currents are known, then the node voltages can be solved using the above equation. If the node voltages are known then, the branch voltages and currents can be solved from eqs. (1.18) and (1.15). Finally, the element voltages and currents can be solved for using eqs. (1.14b) and (1.14c).

The relationships hold for DC as well as AC analysis with the major differences being that the voltages, currents and admittances are all complex quantities in AC analysis, and that the branch matrix will no longer be a diagonal matrix because of mutual inductances. The analysis is also similar for networks with dependent current sources and voltage sources. The branch currents would then be the difference between the element currents, the dependent currents and independent currents. Also, the branch voltages plus the independent voltage sources would be equal to the element voltages and the dependent sources.

VI. INTRODUCTION OF MATLAB

The availability of modern digital computers has stimulated the use of computer simulation techniques in many engineering fields. In electrical engineering the computer simulation of dynamic processes is very attractive since it enables observation of electric quantities which cannot be measured in live power system for strictly technical reasons. Thus the simulation results help to analyses the effects which occur in transient (abnormal) state of power system operation and also provide the valuable data for testing of new design concepts. In case of computer simulation the continuous models have to be transformed into the discrete ones. The transformation is not unique since differentiation and integration may have many different numerical representations.

MATLAB, developed by Math Works Inc., is a software package for high performance numerical computations and visualation. The combination of analysis capabilities, flexibility, reliability, and powerful graphics makes MATLAB the premier software package for electrical and electronics engineers. SIMULINK is a graphical mouse-driven program for the simulation of dynamics system. SIMULINK enables students to simulate linear, as well as nonlinear, systems easily and efficiently.

VII. CIRCUIT DESCRIPTION

This circuit is a simplified model of a 132 kV three-phase power system. Only one phase of the transmission system is represented. The equivalent source is modeled by a voltage source (132 kV rms/sqrt(3) or 76.21 kV peak, 50 Hz) in series with its internal impedance (Rs Ls) corresponding to a 3-phase 2000 MVA short circuit level and X/R = 10. (X = 132e3^2/2000e6 = 8.71 ohms or L = 0.0702 H, R = X/10 = 0.87 ohms). The source feeds a RL load through a 150 km transmission line. The line distributed parameters (R = 0.035ohm/km, L = 0.92 mH/km, C = 12.9 nF/km) are modeled by a single pi section (RL1 branch 5.2 ohm; 138 mH and two shunt capacitances C1 and C2 of 0.967 uF). The load (35 MW - 10 Mvar per phase) is modeled by a parallel RLC load block.

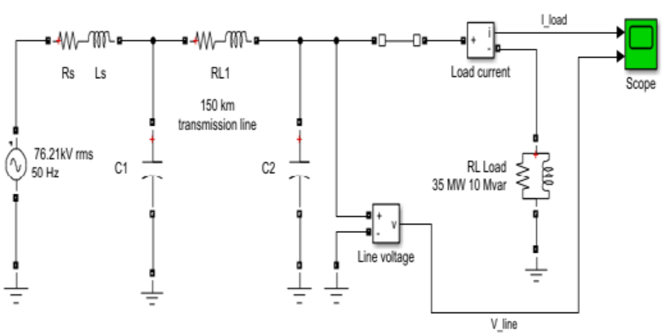

Figure 2: Simulink Model of Transient Analysis

A circuit breaker is used to switch the load at the receiving end of the transmission line. The breaker which is initially closed is opened at t = 2 cycles, then it is reclosed at t = 7 cycles. Current and Voltage Measurement blocks provide signals for visualization purpose.

Start the simulation and observe line voltage and load current transients during load switching and note that the simulation starts in steady-state. Use the zoom buttons of the oscilloscope to observe the transient voltage at breaker reclosing.

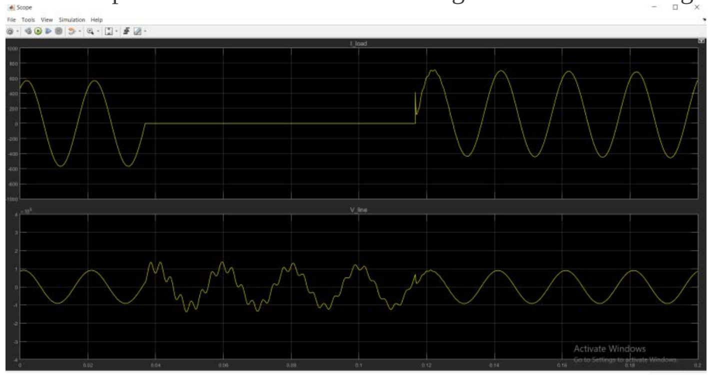

Figure 3: Transient of Voltage and Current

VIII. CONCLUSION

Transient analysis has important application to computer circuitry the switch is on a circuit with a delay line do not immediately arrive at the desired steady state value when a transmission line or a delay line. The settling time depends on the length of the line involved.

Power system transients appear in different waveform shapes and are caused by different underlying reasons. In order to better understand their origins, it is important to analyze transients according to their underlying causes (or events).

The method presented in this paper only analyzes of transients that can be modeled as damped sinusoids in noise. The technique is demonstrated by comparing the achieved results with those already available in the literature for the same case studies. In future, all other transient specifications like rise time, peak time, settling time, delay time can be calculated.

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Future work should include additional elements such as transformers and dependent sources, there by extending the range of circuits that can be analyzed. Another important extension would be the inclusion of constraints as part of the circuit description itself.

Finally, an advantage of our approach is that we are able to generate instances of circuits from general schemas and descriptions of their required behavior.

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