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5.	Title of the work	:	ELECTRICAL CIRCUIT ANALYSIS
6.	Language of the work	:	ENGLISH
7.	Name, address and nationality of the author and if the author is deceased, date of his decease	:	DR. P. SANTOSH KUMAR PATRA , PRINCIPAL & PROFESSOR, DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING, ST. MARTIN'S ENGINEERING COLLEGE, DHULAPALLY, SECUNDERABAD, T.S-500100 INDIAN DR. N. RAMCHANDRA , PROFESSOR & HOD, DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING, ST. MARTIN'S ENGINEERING COLLEGE, DHULAPALLY, SECUNDERABAD, T.S-500100 INDIAN MRS. T. V. SAI KALYANI , ASSISTANT PROFESSOR, DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING, ST. MARTIN'S ENGINEERING COLLEGE, DHULAPALLY, SECUNDERABAD, T.S-500100 INDIAN MR. K. V. GOVARDHAN RAO , ASSISTANT PROFESSOR, DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING, ST. MARTIN'S ENGINEERING COLLEGE, DHULAPALLY, SECUNDERABAD, T.S-500100 INDIAN
8.	Whether the work is published or unpublished	:	PUBLISHED
9.	Year and country of first publication and name, address and nationality of the publisher	:	2021 INDIA M/S SRIKRISHNA TECHNO BOOKS , 326/C, III FLOOR, SURNENI NILAYAM, NEAR B K GUDA PARK, S R NAGAR, HYDERABAD, TS-500038 INDIAN
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Spectrum EDUCATION

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Electrical Circuit Analysis

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SriKrishna

M/s SriKrishna Techno Books

A Part of StudentsHelpline Publishing House (P) Ltd.

(An ISO 9001 : 2015 Certified Company)

Head Office

326/C, III Floor, Surneni Nilayam
Near B K Guda Park, S R Nagar, Hyderabad - 500 038, INDIA
P.No:+91 40 23710657, 238000657 Fax: +91 40 23810657

Reg. Off

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mail:studentshelpline.in@gmail.com
www.**studentshelpline.**org

First Edition-2021

ISBN: 978-81-953919-4-3

Rs. 999/-

Printed at StudentsHelpline Group, S R Nagar, Hyderabad-38
Published by Surneni Mohan Naidu for SriKrishna Techno Books, Hyderabad - 38

Unit-I

Network Theorems

Léon-Charles Thévenin *(b.Meaux, France, 30th March 1857, d. Paris, 1926) was a French telegraph engineer and educator. He was the one to propose the equivalent generator theorem in 1883, 43 years before Norton's complementary theorem. The theorem is commonly called Thévenin's Theorem in his honour, but, in fact Hermann Von Helmholtz proposed it first in an 1853 paper. Thevenin graduated from the École Polytechnique in 1876 and became one of the first students to enrol in the École Superieure de Telegraphie (EST) to be prepared for a career in the Government owned telegraph service. In the two-year program at the EST, he was introduced to Gustav Kirchhoff's laws of circuit analysis. His duties included administrative and educational activities. Thévenin devoted a considerable portion of his time to teaching, for which he had a liking. In connection with his teaching, he undertook an investigation of Kirchhoff's laws as applied to electric networks. This study resulted in his formulation of the equivalent generator theorem.*

Mesh analysis, Super-mesh analysis, Nodal analysis, , Super-node analysis, NETWORK THEOREMS: Superposition theorem, Thevenin's and Norton's theorems , Maximum power transfer theorem, Millman's theorem, Reciprocity theorem, Tellegen theorem and Compensation theorem with DC excitation and with dependent sources.

1.0 OBJECTIVES

After completion of this chapter we should be able to:

- Understand and apply Superposition theorem.
- Understand and apply Reciprocity theorem.
- Understand and apply Thevenin's and Norton's theorem.
- Understand and apply Maximum power transfer theorem.
- Understand Tellegen's theorem.
- Understand Milliman's and compensation theorems for DC excitations.

1.1 INTRODUCTION

Most of the electrical networks are very complex. Need of circuit theorems and techniques are very important to analyze them. Theorems used for network analysis. Network theorems are useful to find voltage and currents in multi-loop circuits. These theorems use fundamental rules or formulas and basic equations of mathematics to analyze basic components of electrical (or) electronics parameters like voltages, currents, resistance and so on.

These theorems not only used to solve networks, but they also provide an opportunity to determine the impact of a particular source or element on the response of the entire system. In most cases, the network to be analyzed and the mathematics required to find the solution are simplified. All of the theorems appear again in the analysis of AC networks. In fact, the application of each theorem to AC networks is very similar.

The techniques like KVL, KCL, mesh and nodal analysis are useful for finding the voltage and current of a network. All the above stated techniques form the basic methods of performing the network or circuit analysis. However these methods are not alone sufficient for solving a network, which is complex and advanced. For example, if a network with two (or) more alternating voltage (or) current sources with different operating frequencies are there, the so called conventional methods like KCL, KVL, mesh and nodal analysis are alone not sufficient for solving the network. Some special techniques has to be employed in order to solve it.

Suppose there is a huge complex network with a variable load, in which the load current has to be calculated. Calculation becomes tedious if the above methods are alone used, as the whole network remains the same every time with a new value of load.

Special techniques (or) theorems can be used along with the conventional methods to solve the network. Over a period of time, engineers formulated some methods (or) theorems of analysing the network in order to avoid the laborious job of solving it. These theorems have many applications in the field of analog electronics, comminications, power electronics, power systems, etc. Network theorems presented in this chapter are

1. Superposition theorem
2. Thevenin's theorem
3. Norton's theorem
4. Maximum power transfer theorem

5. Reciprocity theorem
6. Millman's theorem
7. Tellegen's theorem
8. Compensation theorem.

1.2 LINEARITY

Linearity is the property of an element describing a linear relationship between cause and effect. The property is a combination of both the homogeneity (scaling) property and additive property.

Homogeneity property requires that if the input (also called the excitation) is multiplied by a constant, then the output (also called the response) is also multiplied by the same constant.

For example ohm's law relates the input 'i' to the output V.

$$V = iR$$

If the current is increased by a constant K, then the voltage increases correspondingly by K i.e.,

$$KiR = KV$$

Additive property requires that the response to a sum of input is the sum of the responses to each input seperately.

Using the voltage - current relationship of a resistor, if

$$V_1 = i_1R \;\&\; V_2 = i_2R$$

Then applying $(i_1 + i_2)$ gives

$$V = (i_1 + i_2)R = i_1R + i_2R = V_1 + V_2$$

The resistor is a linear element because it satisfies both homogeneity and the additive properties. In general, a circuit is linear if it is both additive and homogeneous. A linear circuit consists of only linear elements, linear dependent sources and independent sources. A linear circuit is the one whose output is linearly related (or) directly proportional to its input.

1.3 MESH ANALYSIS BY KIRCHHOFF'S LAWS

The method of loop or mesh currents is generally used in solving networks having some degree of complexity. Such a degree of complexity already begins for a network of three meshes. It might even be convenient at times to use the method of loop or mesh currents for solving a two-mesh circuit. In the loop current method, unknown currents are assumed to be flowing around closed loop in the network. Thus, an equal number of voltage equations can be written around the loop.

Mesh-current method is preferred to general or branch-current method because unknowns in the initial stage of solving a network are equal to number of meshes, i.e., the mesh currents. Necessity of writing the node-current equations, as done in the general or branch current method where branch currents are used, is obviated. There are as many mesh-voltage equations as these are independent loop or mesh, currents. Hence, the 'M' mesh currents are obtained by solving the M-mesh voltages or loop equations for 'M' unknowns. After solving for the mesh currents, only a matter of resolving the confluent mesh currents into the respective branch currents by very simple algebraic manipulations is required. This method eliminates a great deal of tedious work involved

2. If the poles and zeros are imaginary or complex, they should be conjugate. Let polynomial p(s) be a real function. Now let one of the zeros of p(s) be complex say, (-x-jy). Then its conjugate, namely, -x+jy, must also form a zero of the same polynomial p(s), failing which p(s) will have same complex co-efficient.
3. (a) The real parts of poles and zero should either be zero or negative, it should not be positive.

   (b) If the real part is zero then that pole or zero should be simple. Taking the above example,

   $$p(s) = (s + x + jy)(s + x - jy) \ = (s + x)^2 + y^2 = s^2 + 2sx + (x^2 + y^2)$$

   In order to make p(s) a real function, the second term, namely, 2sx should be positive. Hence (-x) must be negative.
4. The real part of a complex pole or zero must be either negative or zero. Therefore, the real parts of poles and zeros may have zero value, that is, the poles and zeros may lie on the boundary dividing half of the s-plane.
5. The polynominals p(s) or q(s) should not have any missing terms between those of highest and lowest degree, unless all even or all odd terms are missing.
6. The degree p(s) and q(s) may differ by almost one.
7. The terms of lowest degree in p(s) and q(s) may differ in degree by one at the most.

5.15.2 Necessary Conditions for Transfer Function

The necessary condition for a network function to be a transfer function after cancelling the common factors from the numerator and denominator are:

1. The co-efficients in the polynomials p(s) and $q(s)$ of $N = \frac{p(s)}{q(s)}$ must be real, and those for q(s) must be positive.
2. It the poles are imaginary or complex, they should be conjugate.
3. (a) The real part of poles must be zero or negative.

   (b) If the real part is zero then that pole must be simple. This includes the origin i.e. at the origin the pole must be simple.
4. The polynomial of q(s) may not have any missing terms between that of highest and lowest degree unless all even or all odd terms are missing.
5. The polynomial p(s) may have terms missing between the terms of lowest and highest degree and some of the co-efficients may be negative.
6. The degree of p(s) can be as small as zero independent of the degree of q(s).
7. For G_{12} and α_{12} : The maximum degree of p(s) is the degree of q(s).

   For Z_{12} and Y_{12} : The maximum degree of p(s) is the degree of q(s) plus one.

   Here G_{12} is the voltage transfer function and α_{12} is the current transfer function.

5.16 OUTCOMES

- Relationship between different types of parameters.
- Conditions for symmetry and reciprocity.
- Concept of Series, parallel and cascade interconnection of two port networks.
- Image parameters.

5.17 REVIEW QUESTIONS

I. Short Answer Questions

1. Define two-port network.
2. Define Z and Y parameters.
3. Define h and g parameters.
4. Define T and T' parameters.
5. Draw the equivalent circuit of Z parameters.
6. Draw the equivalent circuit of Y parameters.
7. Give the equivalent circuit of h parameters which satisfies the KVL and the KCL.
8. Draw the equivalent model of g parameters.
9. Give the significance of interrelationship between parameters.
10. Give the matrix representation of Y parameters in terms of Z parameters.
11. Give the advantage of interconnection of 2 two-port networks.
12. What are the different types of interconnections?
13. Draw the block diagram of series-parallel-connected two-port networks.
14. How are the transmission parameters of the cascaded networks of N_1 and N_2 obtained ?
15. What is reciprocity?
16. What do you mean by symmetrical network?
17. Give the conditions for reciprocity and symmetry in ABCD parameters.
18. Give the conditions for reciprocity and symmetry in h parameters.
19. Define the term transfer function.
20. Define driving point impedance and transfer impedance.

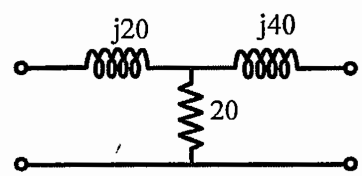
II. Long Answer Questions

1. Define different open-circuit and short-circuit parameters for a two-port network. Also, give the matrix representations of the parameters and its equivalent models in each case.
2. Explain h and g parameters of a two-port network with their equivalent models.
3. Explain different transmission parameters for a two-port network.
4. Give the expressions for Y parameters and T parameters and derive the relationship between them.

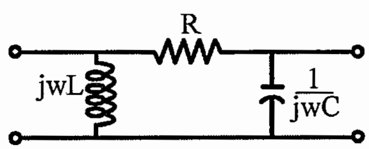
5. Give the expressions for T' parameters and g parameters and derive the relationship between them.
6. Get the expressions of ABCD parameters in terms of Z,Y, and T' parameters.
7. Show that the A' B' C' D' parameters of the networks N_1 and N_2 connected in cascade is the matrix multiplication of the A' B' C' D' parameters of the networks N_1 and N_2.
8. Write short notes on driving point impedance and transfer impedance.
9. What are the poles and zeros of the network function. Explain with diagrams?
10. Briefly discuss the restriction on pole-zero location of driving point impedance and transfer functions.

III. Exercise Problems

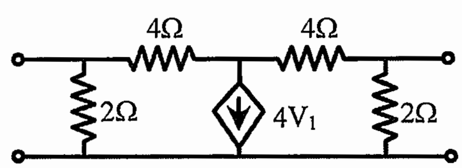
1. Determine Z and Y parameters of the circuit shown in figure.



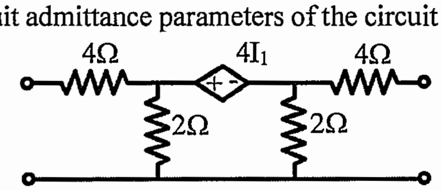
2. Determine Z and Y parameters of the circuit shown in figure.



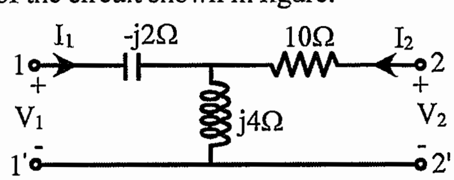
3. Find the open-circuit impedance parameters of the circuit containing a controlled source as shown in figure.



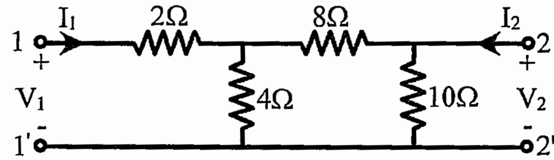
4. Determine the short-circuit admittance parameters of the circuit shown in figure.



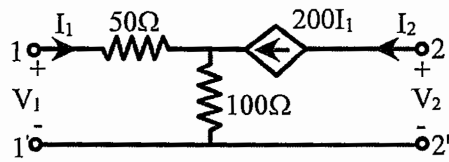
5. Obtain the h parameters of the circuit shown in figure.



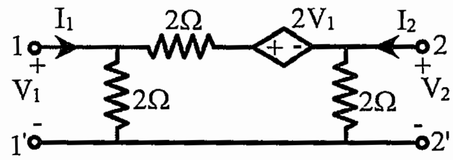
6. Find the g parameters of the circuit shown in figure.



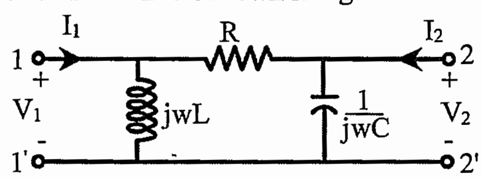
7. Find h_{11} and h_{21} parameters of the circuit shown in figure.



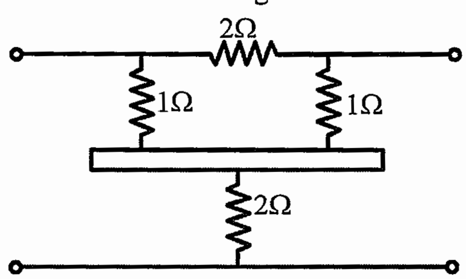
8. Find the T parameters of the circuit shown in figure.



9. Find A' B' C' D' parameters of the circuit shown in figure.



10. Find the h parameters of the circuit shown in figure.



11. Find Y parameters of the circuit shown in figure.