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Electrical Network Theorems Analysis using MATLAB/Simulink

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Abstract: - Electric Circuit Analysis (ECA) is the course that offered to the GTU students of 3rd semester in Electrical Engineering and the course passing ratio is very poor. ECA required fundamental concepts in electrical engineering that simplify the analysis of complex circuits and predict their behavior under various conditions. Traditional methods of teaching and learning these theorems often rely on manual calculations and limited experimental setups, which may not fully illustrate their practical applications or complexities due to this student lose interest in ECA & result had been reduced day by day. This paper will discuss Electrical Network Analysis in MATLAB /Simulink. The name MATLAB stands for MATrix LABoratory. MATLAB/Simulink, a powerful software suite for mathematical computation and simulation, offers an effective platform for visualizing and analyzing electrical circuits. It provides tools for creating dynamic models, performing simulations, and visualizing results, making it an ideal choice for studying electrical network theorems. This paper describes the MATLAB/Simulink realization of the DC Network Theorems, namely Superposition, Thevenin's, Norton's and Maximum Power Transfer Theorems. These simulation models are developed as a part of a software laboratory to support and enhance all electrical engineering Courses for the benefit of students [16].

Keywords: Electric Circuit Analysis (ECA), MATLAB (Matrix Laboratory), DC, Theorems, Software

I. INTRODUCTION

ECA serves as the core of all Electrical Engineering programs. The primary goal of the ECA course is to familiarize students with the concepts of passive elements and the governing laws that determine circuit behaviour when these elements are connected in a network or circuit. During the course, students learn to simplify complex networks and calculate parameters such as current, voltage, power, and total resistance. Prior to this, they are introduced to the fundamentals of Basic Electrical Engineering, including both DC and AC concepts.

Traditionally, the course was conducted using conventional methods, such as problem-solving, laboratory experiments, and performing calculations with scientific calculators. While effective, this approach often left upper-division students lacking a solid foundation in basic circuit theory, which is crucial for success in the ECA course [3].

If students grasp essential concepts like Series and Parallel Circuits, Nodal and Mesh Analysis, Maximum Power Transfer Theorem, Thevenin's Theorem, Norton's Theorem, and the Superposition Theorem, they can leverage tools like MATLAB Simulink [1] & SimPower system [2] to analyse and interpret network data more effectively. By capitalizing on students' growing interest in computer-based learning, educators can enhance their engagement with the course material.

There is a wide range of software available, such as Multisim, PSPICE, and PSIM, which are excellent for simulating circuits. However, fostering a deeper understanding of circuits can be achieved if students are encouraged to write their own code in environments like MATLAB and simulate circuit behaviour in Simulink. This approach not only promotes better comprehension but also equips students with valuable skills for analysing and interpreting circuit behaviour [15] [16].

This paper focuses on analysing four key network theorems—Kirchhoff's Law, Thevenin's, Superposition, and Maximum Power Transfer—using MATLAB/Simulink.

The objectives are to:

1) Demonstrate the implementation of these theorems in Simulink.

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2) Validate the theoretical concepts through simulation result.

3)Highlight the benefits of simulation-based learning in electrical engineering education.

II. THEORETICAL PRINCIPLES BEHIND THE SELECTED THEOREMS

There are some basic Law and Theorems in ECA course. Whose statement and some basic theoretical principles are as follows:

1. Kirchhoff's Current Law (KCL)

Statement: The algebraic sum of currents entering and leaving a junction is zero.

- **Theoretical Principle**:
  - Rooted in **Conservation of Charge**: Charge cannot accumulate at a node.
  - Mathematically, for a node: $\sum Iin=\sum I$ out.
  - Simplifies analysis of complex circuits by focusing on current distribution.

2. Kirchhoff's Voltage Law (KVL)

Statement: The algebraic sum of all voltages in a closed loop equals zero.

- **Theoretical Principle**:
  - Based on the **Conservation of Energy**: The total energy gained equals the total energy lost in a closed loop.
  - Mathematically, $\sum V=0$ for any closed loop.
  - Essential for analysing series circuits and determining unknown voltages.

3. Superposition Theorem

Statement: In a linear circuit with multiple sources, the response (voltage or current) in any element is the algebraic sum of the responses caused by each source acting independently.

- **Theoretical Principle**:
  - Based on the **Principle of Linearity**: The output is proportional to the input, and independent sources can be treated separately.
  - Each source is considered while others are replaced by their internal impedances (voltage sources as short circuits, current sources as open circuits).
  - Applicable for linear circuits only.

4. Maximum Power Transfer Theorem

Statement: Maximum power is transferred to a load when the load resistance equals the internal resistance (or Thevenin resistance) of the source.

- **Theoretical Principle**:
  - Based on **Ohm's Law** and **Power Calculation** ($P=V^2/R$).
  - Derivation involves finding the condition for maximizing power $P=I^2R_L$, where R_L is the load resistance, leading to $R_L=R_{Th}$ (Thevenin resistance).
  - Practical in applications like impedance matching for efficiency in communication systems.

5. Thevenin's Theorem

Statement: Any linear bilateral circuit can be reduced to a single voltage source (V_{Th}) in series with a resistance (R_{Th}).

- **Theoretical Principle**:

- Derived from the **Superposition Theorem** and **Linearity of Circuits**.
- Simplifies complex networks into simpler equivalent circuits.
- Useful for analysing power systems and load variations.

6. Norton's Theorem

Statement: Any linear bilateral circuit can be reduced to a single current source (I_N) in parallel with a resistance (R_N).

- **Theoretical Principle**:
  - Similar to Thevenin's Theorem but uses current sources.
  - I_N is the short-circuit current, and R_N (Norton's resistance) is identical to R_{Th}.
  - Can be used interchangeably with Thevenin's theorem for equivalent circuit analysis [9][6].

Each of these principles builds on foundational laws (Ohm's Law, conservation principles, and linearity) and provides methods to simplify or analyze electrical circuits effectively.

III. OUTLINES THE MATLAB/SIMULINK MODELING APPROACH

Here's an outline combining the use of the **MATLAB Command Window** for programming and **Simulink** for performing electrical circuit analysis:

1. Understand the Circuit

- **Analyze the Circuit Schematic**: Identify all components (resistors, capacitors, inductors, sources, etc.).
- **Define the Objective**: Determine the type of analysis required:
  - ➢ DC/AC analysis
  - ➢ Transient response
  - ➢ Power calculation
  - ➢ Frequency response

2. Open Simulink and Set Up a Model

- **Launch Simulink**:
  - ➢ Open MATLAB and start Simulink using the simulink command or from the MATLAB interface.
- **Create a New Model**:
  - ➢ Use the Simulink Editor to start with a blank model.
- **Save the Model**: Save it with an appropriate name for future use.

3. Select and Place Components

- **Access the Library Browser**:
  - ➢ Navigate to **Simscape** > **Electrical** > **Specialized Power Systems** or **Simscape** > **Electrical** > **Fundamental Blocks**.
- **Drag Components**:
  - ➢ Place the necessary components (resistors, capacitors, inductors, sources, measurement blocks) onto the workspace.
- **Use Connectors**:
  - ➢ Connect components with lines to replicate the circuit diagram.

4. Set Component Parameters

- **Configure Blocks**:
  - Double-click each component to set values (e.g., resistance, inductance, capacitance, voltage source amplitude and frequency).
- **Define Source Parameters**:
  - For AC/DC sources, set appropriate waveform characteristics.
- **Adjust Measurement Blocks**:
  - Add **Voltage Measurement** and **Current Measurement** blocks for desired outputs.

5. Configure Simulation Settings

- **Solver Settings**:
  - Open **Simulation > Model Configuration Parameters**.
  - Choose a suitable solver (e.g., **ode45** for smooth circuits, **ode23tb** for stiff circuits).
  - Set the simulation time frame.
- **Step Size**:
  - For transient analysis, choose an appropriate step size to capture detailed behaviour.

6. Perform Specific Circuit Analyses

- **DC Analysis**:
  - Use steady-state DC sources to analyse static currents and voltages.
- **Transient Analysis**:
  - Introduce time-dependent sources or switches to observe transient behaviours.
- **AC Analysis**:
  - Use sinusoidal voltage/current sources and measure responses at different frequencies.
- **Frequency Response**:
  - Add sweep functions or parametric variations for resonance or filter analysis.
- **Thevenin/Norton**:
  - Simulate portions of the circuit with equivalent source representations.

7. Add Outputs and Visualization Tools

- **Scopes**:
  - Use **Scope** blocks to visualize voltages and currents in real-time.
- **Data Logging**:
  - Export data to the MATLAB workspace for further processing.
- **Display Blocks**:
  - Use **Display** blocks for instantaneous numerical outputs.

8. Run the Simulation

- **Start Simulation**:
  - Click **Run** to execute the simulation.

- **Monitor Results**:
  - Observe output waveforms and data on scopes and displays.

9. Post-Processing in MATLAB

- **Export Data**:
  - Use the **To Workspace** block to export simulation results.
- **Analyze in MATLAB**:
  - Write MATLAB scripts for detailed analysis, plotting, or comparison with theoretical results.

10. Documentation and Reporting

- **Save Models**:
  - Save the final Simulink model for documentation.
- **Generate Reports**:
  - Use MATLAB tools to create automated reports of analysis.

This workflow provides a comprehensive approach to leveraging MATLAB/Simulink for electrical circuit analysis [7],[12],[13],[14].

IV. DISCUSSES SIMULATION RESULTS AND THEIR VALIDATION

Here we see some of the theorems in MATLAB/Simulink and MATLAB code for some theorems.

1. Thevenin's Theorem

Problem Statement:

Find the Thevenin equivalent voltage (Vth) and Thevenin equivalent resistance (Rth) for the circuit shown below. Assume a voltage source of 15 V1, a series resistor R1=100Ω, and a load resistor R_L=100Ω.

Solution Using MATLAB:

1. Remove the load resistor (R_L).
2. Calculate Vth: Voltage across open terminals.
3. Calculate Rth: Equivalent resistance with all sources replaced by their internal resistances.

MATLAB Simulation:

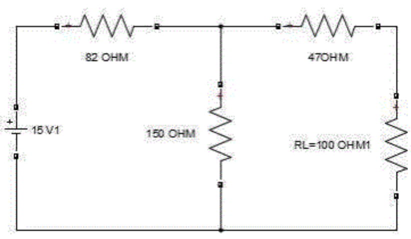

Fig1. Verification of Thevenin theorem.

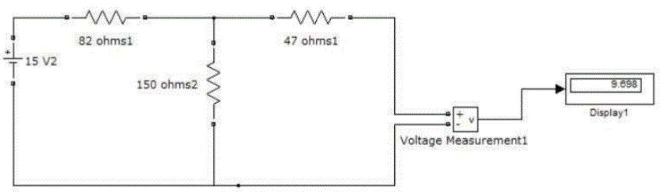

Fig.2 Measurement of Voc

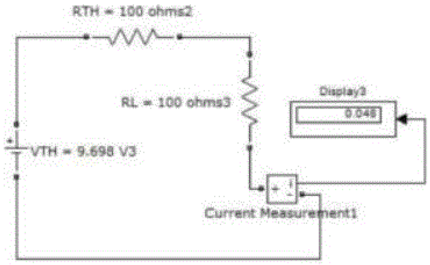

Fig.3 measurement of Load Current IL

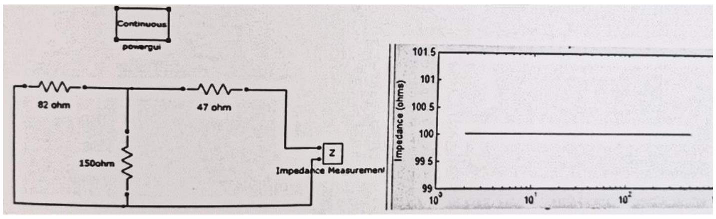

Fig.4 measurement of RTh

Table-1 Parameters Results of Thevenin theorem.

Parameters	Practical Values
Voc	9.698 V
R_{Th}	100 Ω
I_L	0.0048 A

2. Superposition Theorem

Problem Statement:

For a circuit with two sources, V1=15V and V2=10V find the voltage across a resistor R=47Ω.

Solution Using MATLAB:

1. Solve with V1 active and V2 turned off (short circuit).
2. Solve with V2 active and V1 turned off (short circuit).
3. Combine results to get the total voltage.

MATLAB Simulation:

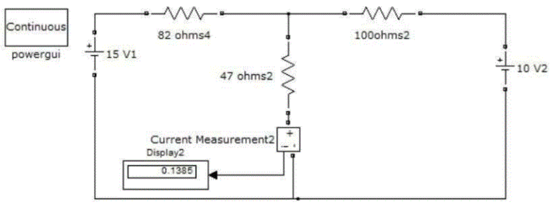

Fig5. Verification of Superposition theorem.

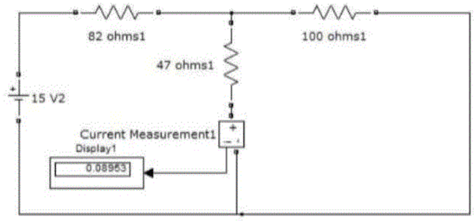

Fig.6 measurement of current I1 WHEN V1≠0 & V2=0

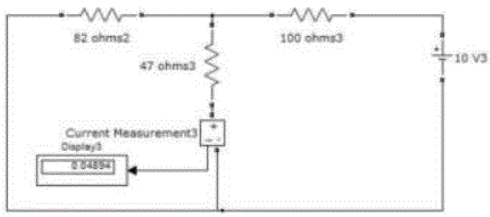

Fig.7 measurement of current I2 WHEN V2≠0 & V1=0

Table-2 Parameters Results of Superposition theorem.

PARAMETERS	WHEN BOTH V1 & V2≠0 (I)	WHEN V1≠0 & V2=0 (I1)	WHEN V1=0& V2≠0 (I2)
Current through R3	0.1385 A	0.08953A	0.04894A

3. Maximum Power Transfer Theorem

Problem Statement:
Determine the load resistance (RL) for maximum power transfer if the internal resistance (Rs) of a circuit is 100Ω. Calculate the maximum power.

Solution Using MATLAB:

1. For maximum power, R_L=Rs.

MATLAB Simulation:

Code:

```
% Given values
V=230;
Vrms=230/ sqrt(2);
Rth=100;
Rl=50:1:200;
Il=Vrms./(Rth+Rl);
Pmax=(Il.^2).*Rl;
plot(Rl,Pmax,'*')
hold on
title('maximum power transfer');
xlabel('Load resistance Rl');
ylabel('power transfered to load');
gtext('Rth=Rl=100')
legend('Pmax')
grid on
```

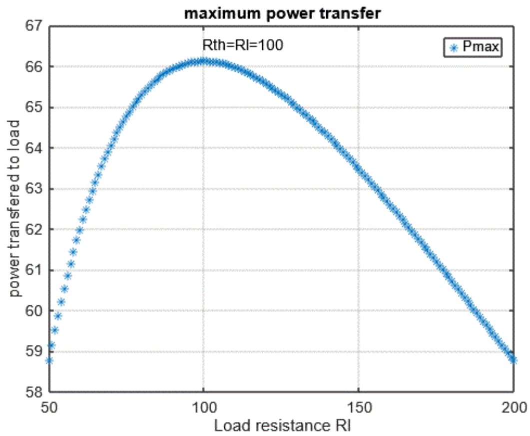

Fig.8 Graph for Pmax when R_{Th}=R_l

4. Kirchhoff's Law Example Using MATLAB

Problem Statement

Consider a mesh analysis and node analysis ckt.

MATLAB Simulation:

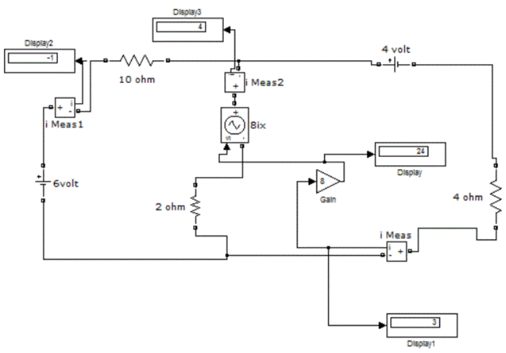

Fig.9 Verification of mesh analysis

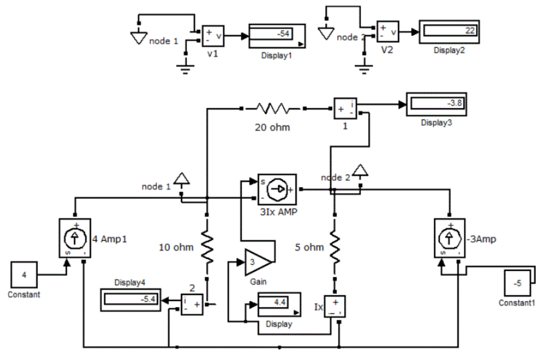

Fig.10 Verification of node analysis

Table-3 Parameters Results of mesh analysis.

Applied Voltage V (volts)	Loop current(I1)	Loop current(Ix)
6V	-1A	3A

Table-4 Parameters Results of node analysis

Node voltage (V1)	Node voltage (V2)	Current (ix)
-10V	10V	2A

The simulation results & graphs clearly demonstrate that the outcomes are consistent across all analysis methods, whether using conventional approaches like KCL and KVL or advanced techniques based on various network theorems. These simulation exercises play a crucial role in helping students develop a strong understanding of network analysis concepts and their practical applications in both DC and AC electrical systems.

V. Conclusion

The MATLAB simulations and coding examples for selected DC network theorems demonstrate that simulation models provide an effective way to explain these concepts. To enhance understanding, fundamental examples have been used, which also help improve students' simulation skills and foster greater interest in such courses. Additionally, Simulink models have been successfully incorporated into all electrical engineering courses as part of the software laboratory curriculum. The teaching of DC network theorems has been significantly enhanced through these simulation models.

References

[1] SIMULINK, Model-based and system-based design,using Simulink, MathWorks Inc., Natick, MA, 2000.

[2] SimPowerSystems for use with Simulink, user's guide,MathWorks Inc., Natick, MA, 2002.

[3] Mostafa.A. M. Fellani, Daw.E. Abaid, Using MATLAB/Simulink in the designing of Undergraduate Electric Machinery Courses International Journal of Computer and Information Technology (ISSN: 2279 – 0764)Volume 02– Issue 05, September 2013

[4] BACK TO BASICS, IEEE SPECTRUM, March 1990Brittain, J.E.Spectrum, IEEE (Volume:27 , Issue: 3)March 1990

[5] Electric networks fundamentals, 3rded., WCB/McGraw-Hill, New York, 1998.

[6] Mohammad Nuruzzaman, "Electric Circuit Fundamentals in MATLAB and Simulink", 2007, Booksurge Publishing.

[7] U.A.Patel,"Circuit and Networks",8th edition,Mahajan publication house.

[8] Robert L. Boylestad, 'Introductory Circuit Analysis",12th edition, Prentice Hall.

[9] Charles K. Alexander and Matthew N.O.Sadiku, "Fundamentals of Electric Circuits", McGraw Hill.

[10] Dorf, Richard, "Introduction to Electric Circuits', 8th edition, John Wiley & Sons

[11] Svoboda, James A.; Dorf, Richard C, "Introduction to Electric Circuits, 9th edition, John Wiley & Sons.

[12] David M. Smith, "Engineering Computation with MATLAB", 3rd edition, Prentice Hall.

[13] Duane Hanselman; Bruce Littlefield, "Mastering MATLAB', 1st edition, Prentice Hall.

[14] David, McMahon, "MATLAB Demystified", McGraw Hill.

[15] Mohammad Yasir , Mohd. Faraz Khan ,"Network Theorems using Matlab/ Simulink in the Designing of All Electrical Engineering Courses", National Conference on Advancements in Alternate Energy Resources for Rural Applications (AERA-2015). August 2015.

[16] Dr. Asad Yousuf, Dr. Mohamad A. Mustafa, Mr. William Lehman, "Electric Circuit Analysis in MATLAB and Simulink",121st ASEE Annual conference &Exposition,Indianapolls,IN june15-18,2014.