Kakatiya Institute of Technology and Science, Warangal

Course Research Project (2023-24)

Course: BASIC ELECTRICAL ENGINEERING – U18EE105

Project Title: Mesh and Nodal Analysis using MATLAB Program

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Contents

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Introduction

This project aims to demonstrate how to use MATLAB for calculating currents and voltages of a given DC circuit using Mesh and Nodal Analysis.

Mesh and Nodal Analysis are the basic methods of solving DC circuits.

Mesh analysis involves the use of Kirchoff Voltage Law which states that the algebraic sum of voltages around a loop is zero. We will be considering meshes in the given DC circuit, form equations and solve it to find unknown currents and voltages.

Nodal Analysis involves the use of Kirchoff Current Law which states that the current entering the junction is equal to current leaving the junction. We will be considering nodes in the given DC circuit, form equations and solve it to find unknown currents and voltages.

I'm doing this project purely because of my interest in Electrical Engineering and my dream to pursue it as a minor. I hope doing this project gives me more knowledge about electrical engineering.

Problem Definition

Mesh analysis and Nodal analysis can be difficult for new people. They require a lot of practice and lots of trial and error to get good at them. Students often find Basic Electrical Engineering hard because of this.

There are multiple ways to solve circuits using mesh and nodal analysis but those methods are long and prone to human error when done in a hurry.

It's very easy to take the wrong polarity at some point in the circuit and thereby making the whole answer wrong.

This can be minimized by learning Crammer's method.

Crammer's method, too, is a calculation intensive process which uses matrices and determinants and will consume a lot of time if done without any additional tools like scientific calculators.

Programming languages like MATLAB have built in matrices functions and other math functions to make this process very simple there by giving us nodal voltages and loop currents in a fast and efficient way without any errors.

In this project, we'll be implementing nodal and mesh analysis using a MATLAB program.

Proposed Method

To solve a circuit using Mesh analysis, we have to apply Kirchoff's Voltage Law and label the unknown currents.

After labeling the unknown currents, we have to apply KVL to form loop equations for the loops that we have discovered.

We have to write these loops in a matrix form for Crammer's method and write a MATLAB program to substitute the matrices into the program, apply Crammer's rule and finally find the unknown currents.

The currents, later, need to be verified using theoretical calculations.

To solve a circuit using Nodal analysis, we have to apply Kirchoff's Current Law and label the unknown node voltages.

After labeling the unknown voltages, we have to apply KCL to form node equations for the loops that we have discovered.
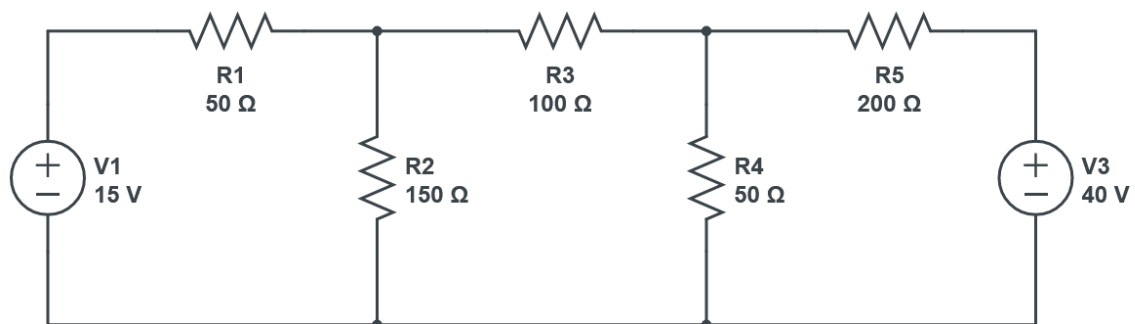
Similarly, we have to write a MATLAB program for these equations and later verify the unknown nodal voltages.

I built my own circuit for this project and I'll be applying Nodal and Mesh analysis for solving it.

Experiments

I have made my own circuit using Circuit Lab for this project.
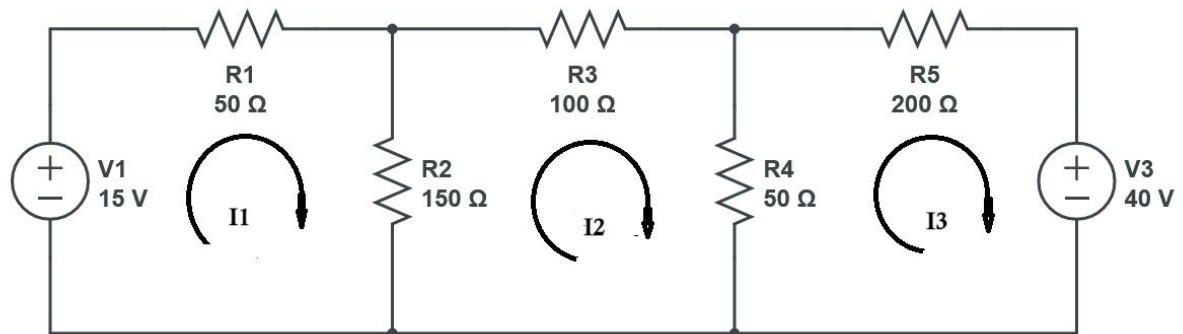
Circuit Diagram:

Analysis:

Let us analyse the given circuit.

We have two voltage sources on either side of the circuit of the rating 15V and 40V respectively.

We have 5 resistors of the rating 50Ω, 100Ω, 150Ω and 200Ω.

(a)Applying Mesh Analysis

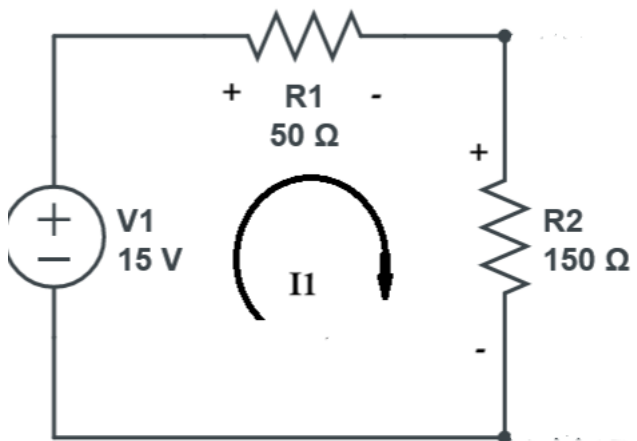Let us identify the loops and loop currents now

We have identified three loops, hence three loop currents I_1, I_2 &I_3.

Now let us assign polarities and mark the direction of flow of current.

Let us now apply Kirchoff's Voltage Law for all three loops to find the equations for loop currents.

Forming equation for Loop 1:

Current flows from lower potential to higher potential at V_1 so it's polarity will be positive whereas current at V_{R1} and V_{R2} flows from higher potential to lower potential so its polarity will be negative.
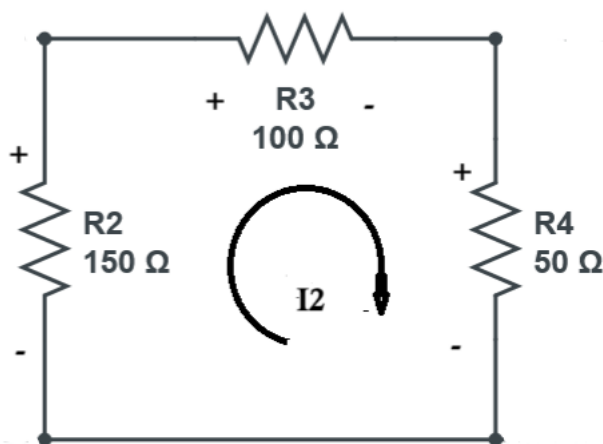
Applying KVL in Loop 1, we get:

⇨ $V_1 - V_{R1} - V_{R2} = 0$

⇨ $15 - 50I_1 - 150(I_1 - I_2) = 0$

⇨ $15 - 50I_1 - 150I_1 + 150I_2 = 0$

⇨ $15 - 200I_1 + 150I_2 = 0$

⇨ $-200I_1 + 150I_2 = -15$

⇨ $200I_1 - 150I_2 = 15$ → Equation (1)

We have obtained equation 1.

Forming equation for Loop 2:

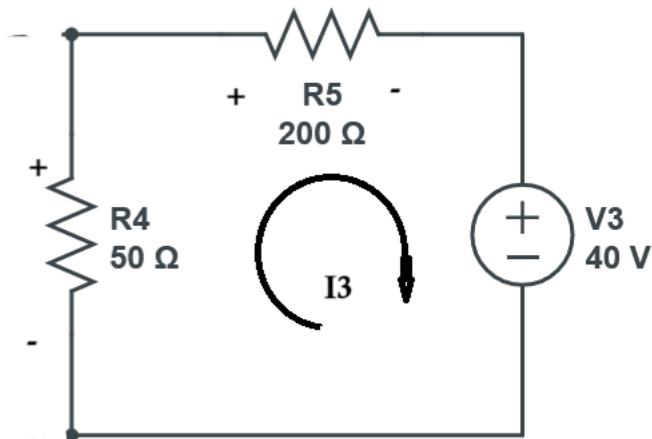We assume the current to be flowing in clockwise direction.

Hence, the current will flow from lower potential to higher potential at V_{R2} making its polarity positive whereas the current will flow from higher potential to lower potential at V_{R3} and V_{R4}.

Applying KVL in Loop 2:

⇨ $V_{R2} - V_{R3} - V_{R4} = 0$

⇨ $150(I_1 - I_2) - 100I_2 - 50(I_2 - I_3) = 0$

⇨ $150I_1 - 150I_2 - 100I_2 - 50I_2 + 50I_3 = 0$

⇨ $150I_1 - 300I_2 + 50I_3 = 0$ → Equation (2)

We have obtained equation 2.

Forming equation for Loop 3:

We assume the direction of current to be flowing in clockwise direction.

Current flows from lower potential to higher potential at V_{R4} hence its polarity will be positive whereas current flows from higher potential to lower potential at V_{R5} and V_3. Hence the polarity will be negative.

Applying KVL in Loop 3:

$\Rightarrow$ $V_{R4} - V_{R5} - V_3 = 0$
$\Rightarrow$ $50(I_2 - I_3) - 200I_3 - 40 = 0$
$\Rightarrow$ $50I_2 - 50I_3 - 200I_3 = 40$
$\Rightarrow$ $50I_2 - 250I_3 = 40$ $\rightarrow$ Equation (3)

We have obtained equation 3.

Converting Equations to Matrices for Crammer's Method

The formed equations are

(i) $200I_1 - 150I_2 = 15$ $\rightarrow$ $200I_1 - 150I_2 + 0I_3 = 15$
(ii) $150I_1 - 300I_2 + 50I_3 = 0$
(iii) $50I_2 - 250I_3 = 40$ $\rightarrow$ $0I_1 + 50I_2 - 250I_3 = 40$

$$\Delta I = \begin{bmatrix} 200 & -150 & 0 \\ 150 & -300 & 50 \\ 0 & 50 & -250 \end{bmatrix} \begin{bmatrix} I1 \\ I2 \\ I3 \end{bmatrix} = \begin{bmatrix} 15 \\ 0 \\ 40 \end{bmatrix}$$

$$\Delta I_1 = \begin{bmatrix} 15 & -150 & 0 \\ 0 & -300 & 50 \\ 40 & 50 & -250 \end{bmatrix}$$

$$\Delta I_2 = \begin{bmatrix} 200 & 15 & 0 \\ 150 & 0 & 50 \\ 0 & 40 & -250 \end{bmatrix}$$

$$\Delta I_3 = \begin{bmatrix} 200 & -150 & 15 \\ 150 & -300 & 0 \\ 0 & 50 & 40 \end{bmatrix}$$

Now that we have our equations in matrix form, let us write a MATLAB program to solve the matrix using Crammer's Method.

MATLAB Program:

```
%Solving Mesh circuit using crammer's method
%defining the equation matrix
di = [200 -150 0; 150 -300 -50; 0 50 -250];
x = [15;0;40];

%finding determinant of di
DELi= det(di);

%declaring and finding determinant of delta i1
di1= [15 -150 0; 0 -300 50; 40 50 -250];
DELi1 = det(di1);

%declaring and finding determinant of delta i2
di2= [200 15 0;150 0 50;0 40 -250];
DELi2 = det(di2);

%declaring and finding determinant of delta i3
di3 = [200 -150 15; 150 -300 0; 0 50 40];
DELi3 = det(di3);

%finding i1
i1 = DELi1/DELi;
sprintf("Value of I1: %f",i1)
%finding i2
i2 = DELi2/DELi;
sprintf("Value of I2: %f",i2)
%finding i3
i3 = DELi3/DELi;
sprintf("Value of I3: %f",i3)
```

By executing the above MATLAB program, we get

$I_1 = 0.079A$

$I_2 = 0.016A$

$I_3 = -0.140A$

Finding values of voltage drops across resistors

$V_{R1} = 50I_1 = 50 \times 0.079 = 3.95V$

$V_{R2} = 150(I_1-I_2) = 150 (0.079-0.016) = 150 \times 0.063 = 9.45V$

$V_{R3} = 100I_2 = 100 \times 0.016 = 1.6V$

$V_{R4} = 50(I_2-I_3) = 50 (0.016 + 0.14) = 50 \times 0.156 = 7.8V$

$V_{R5} = 200I_3 = 200 \times -0.140 = -28V$

Verification

   (i)   **Verifying Loop 1**
⇨ $V_1 - V_{R1} - V_{R2} = 0$
⇨ $15 - 3.95 - 9.45 = 0$
⇨ $15 - 13.4 = 0$
⇨ 1.6

Not verified at loop 1

   (ii)   **Verifying Loop 2**
⇨ $V_{R2} - V_{R3} - V_{R4} = 0$
⇨ $9.45 - 1.6 - 7.8 = 0$
⇨ 0

Verified at loop 2

   (iii)   **Verifying Loop 3**
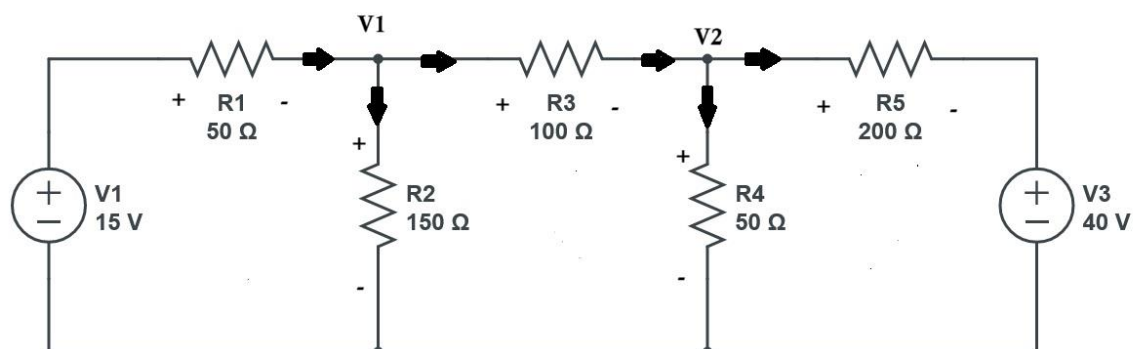⇨ $V_{R4} - V_{R5} - V_2 = 0$
⇨ $7.8 + 28 - 40 = 0$
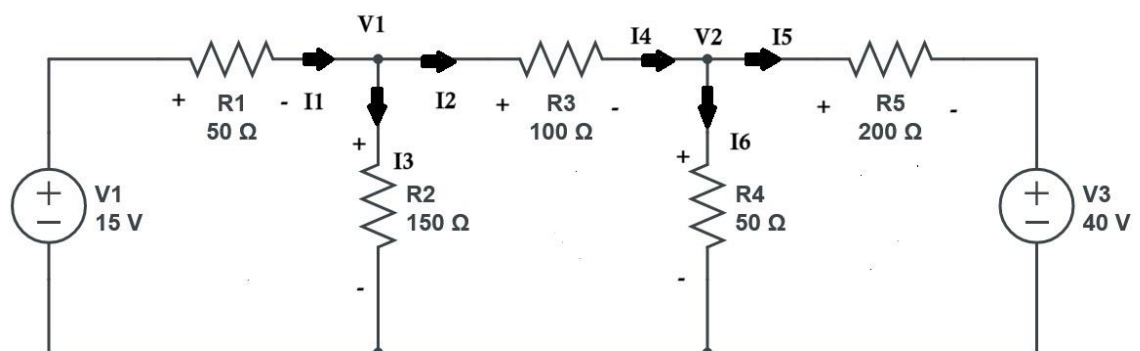⇨ -4.2

Not verified at loop 3

We have tried to verify the values using KVL but two of the verifications were false.

(b) Applying Nodal Analysis

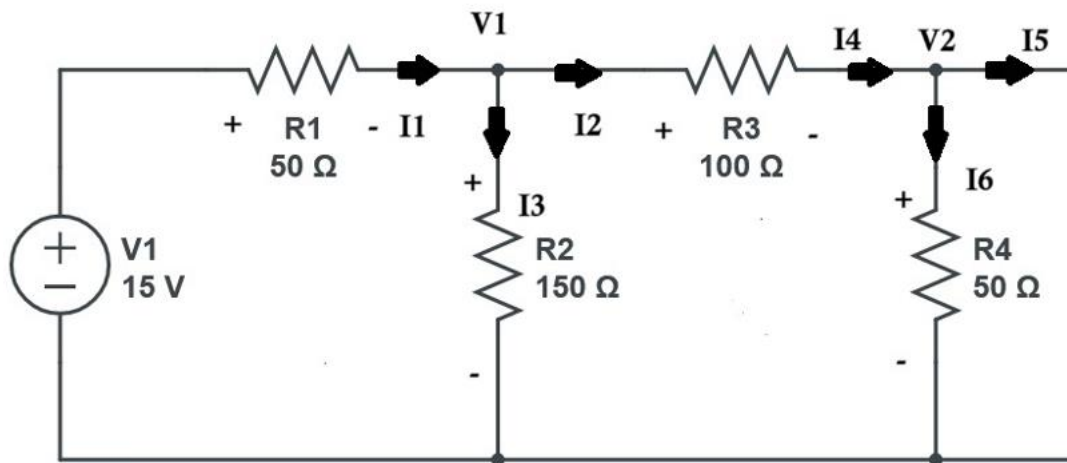Let us identify the nodes and nodal voltages of the circuit now

Let us label the flow of currents. We have two nodal voltages, V_1 and V_2.

Let us now apply Kirchoff's Current Law to form the equations

Forming equation in Node 1:

Applying KCL, we get

$\Rightarrow$ $I_1 - I_2 - I_3 = 0$

$\Rightarrow$ $\frac{15-V1}{50} - \frac{V1}{150} - \frac{V1-V2}{100} = 0$
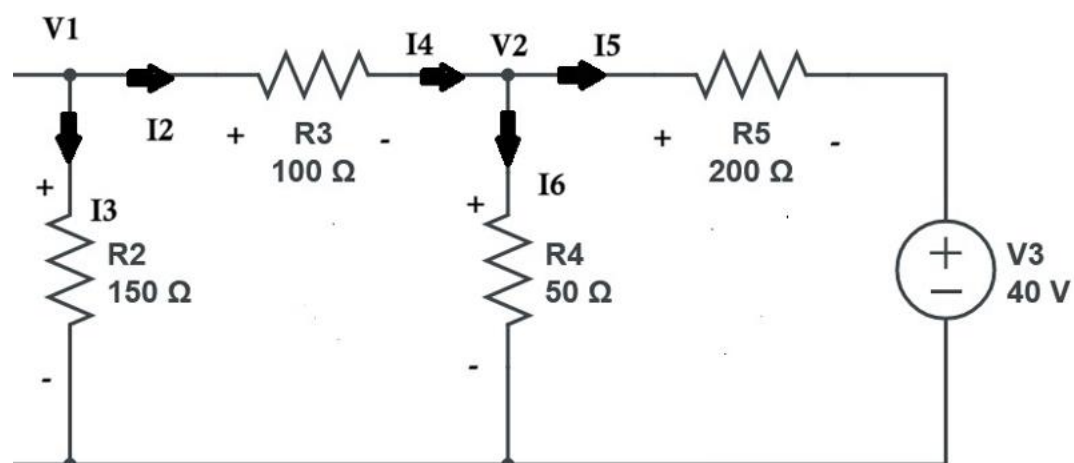
$\Rightarrow$ $\frac{90-6V1-2V1-3V1+3V2}{300} = 0$

$\Rightarrow$ $90 - 6V_1 - 2V_1 - 3V_1 + 3V_2 = 0$

$\Rightarrow$ $-11V_1 + 3V_2 = -90$

$11V_1 - 3V_2 = 90 \rightarrow$ Equation (i)

We successfully obtained an equation for node 1

Forming equation in node 2:

Applying KCL, we get

⇨ $I_4 - I_6 + I_5 = 0$

⇨ $\frac{V1-V2}{100} - \frac{V2}{50} + \frac{40-V2}{200} = 0$

⇨ $\frac{2V1-2V2-4V2+40-V2}{200} = 0$

⇨ $2V_1 - 2V_2 - 4V_2 - V_2 = -40$

⇨ $2V_1 - 7V_2 = -40$ → Equation (ii)

We have obtained the equation for node 2.

Converting Equations to matrices for Crammer's method

We got the following equations by using KCL on the two nodes.

(i) $11V_1 - 3V_2 = 90$
(ii) $2V_1 - 7V_2 = -40$

Now let us convert them into matrix form.

$$\Delta V = \begin{bmatrix} 11 & -3 \\ 2 & -7 \end{bmatrix} \begin{bmatrix} V1 \\ V2 \end{bmatrix} = \begin{bmatrix} 90 \\ -40 \end{bmatrix}$$

$$\Delta V1 = \begin{bmatrix} 90 & -3 \\ 40 & -7 \end{bmatrix}$$

$$\Delta V2 = \begin{bmatrix} 11 & 90 \\ 2 & 40 \end{bmatrix}$$

Now let us substitute these equations in a MATLAB program to find out the nodal voltages.

MATLAB Program

```
%solving nodal using crammers method
%declaring the v
v = [11 -3;2 -7];
x = [90;40];

%finding determinant of v
```

```
dv= det(v);

%declaring delta v1
dv1 = [90 -3;-40 -7];
delv1 = det(dv1);

%declaring delta v2
dv2 = [11 90;2 -40];
delv2 = det(dv2);

%finding value of v1
v1 = delv1/dv;
sprintf("Node Voltage V1: %f",v1)

%finding value of v2
v2 = delv2/dv;
sprintf("Node Voltage V2: %f",v2)
```

We get the values as

Node Voltage V_1 = 10.56V

Node Voltage V_2 = 8.73V

Finding Currents across the Circuit

$I_1 = \dfrac{15-V1}{50} = \dfrac{15-10.56}{50} = \dfrac{4.44}{50} = 0.08A$

$I_2 = \dfrac{V1-V2}{100} = \dfrac{10.56-8.73}{100} = \dfrac{1.83}{100} = 0.01A$

$I_3 = \dfrac{V1}{150} = \dfrac{10.56}{150} = 0.07A$

$I_4 = \dfrac{V1-V2}{100} = \dfrac{10.56-8.73}{100} = \dfrac{1.83}{100} = 0.01A$

$I_5 = \dfrac{40-V2}{200} = \dfrac{40-8.73}{200} = \dfrac{31.27}{200} = 0.15A$

$I_6 = \dfrac{V2}{50} = \dfrac{8.73}{50} = 0.17A$

Verification

Verification at Node 1:

⇨ $I_1 - I_2 - I_3 = 0$

⇨ $0.08 - 0.01 - 0.07 = 0$

⇨ 0

Verified at Node 1

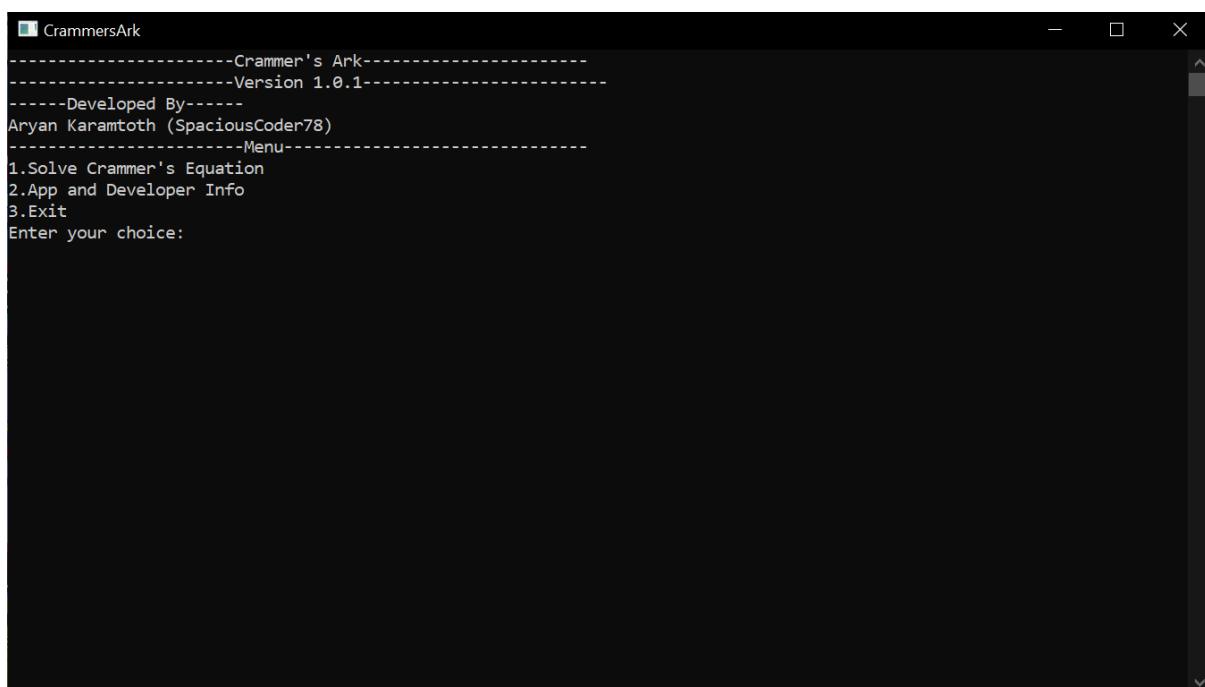Verification at Node 2:

> ⇨ $I_4 - I_6 + I_5 = 0$
> ⇨ $0.01 - 0.15 + 0.17$
> ⇨ 0.03

Not verified at Node 2.

We have successfully verified the values of the Node 1 using KCL but KCL has failed for Node 2.

Software to Simplify this process

In order to further simplify this program, I've developed an app using MATLAB that automatically asks the user to input the equations and then solve the equations for the user

The app asks for user input whether they want to solve a 2 or a 3 variable equation and then solve nodal or mesh equation and give the output.

```
CrammersArk
Aryan Karamtoth (SpaciousCoder78)
------------------------Menu-------------------------------
1.Solve Crammer's Equation
2.App and Developer Info
3.Exit
Enter your choice: 1
-----------------Solving Crammers Equation------------------
Choose number of variables:
1.Two Variables
2.Three Variables
Enter your choice: 1
---------------------Two Variable Calculation-----------------
Choose type of circuit analysis:
1.Mesh Analysis
2.Nodal Analysis
Enter your choice2
----------------Two Variable Nodal Analysis-----------------
Enter the 2x2 matrix:
Crammer's Matrix of 2x2: \n[A1 B1] [V1] = [C1]\n[A2 B2] [V2] = [C2]
Enter A (Coefficient Matrix):
Enter A1: 2
Enter B1: 5
Enter A2: 6
Enter B2: 4
Enter C (Constant Matrix)
Enter C1: 20
Enter C2: 30
Value of V1: 3.181818 Volts
Value of V2: 2.727273 Volts
```

The app is available for download at:

https://github.com/SpaciousCoder78/crammers-ark

Results And Analysis

We obtained the following values for Mesh analysis:

V_{R1} = 3.95V

V_{R2} = 9.45V

V_{R3} = 1.6V

V_{R4} = 7.8V

V_{R5} = -28V

However, all of the verification attempts made at two loops failed due to getting the values above 0 or below 0.

Similarly,

We obtained the following values for Nodal analysis:

I_1 = 0.08A

I_2 = 0.01A

I_3 = 0.07A

I_4 = 0.01A

I_5 = 0.15A

I_6 = 0.17A

However, we had the same issue with Nodal analysis as well because only one node i.e. Node 1 passed the verification whereas Node 2 failed the test by giving a value above 0.

Despite several attempts to cross check the equations and calculations, the values that I was getting were the same.

I've even used Simulink for circuit simulation but I got a whole lot of different values.
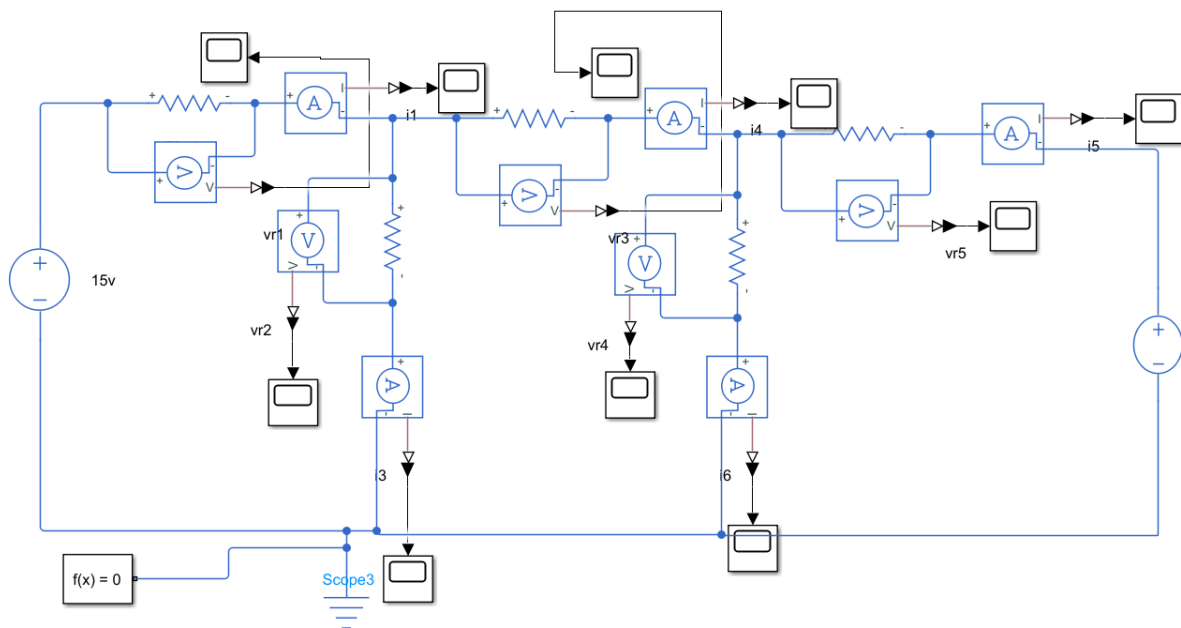
I checked only a few of the readings in the simulation but I obtained the value of V_{R1} as 4.4V but according to my theoretical calculations, the value should be 3.95V which is not the case here hence something is wrong with my simulation.

After rechecking my values, equations, circuits and current directions, I can conclude that there's nothing wrong with my calculations.

Conclusions

By performing this experiment, I learnt the following concepts:

- Application of Kirchoff's Voltage Law and Kirchoff's Current Law
- Knowledge of Mesh and Nodal Analysis
- Method of forming equations
- Prediction of current direction across loops and nodes
- Crammer's method
- MATLAB
- Simulink and Circuit Simulation

I've tried my best to demonstrate how to use MATLAB to solve Mesh and Nodal analysis.

I knew MATLAB before performing this project so it was easy for me to get started with the project, however, I seemed to have failed at the verification.

References

- Mesh Current Problems by Organic Chemistry Tutor
  [https://www.youtube.com/watch?v=k5Tlg27JDtc&t=1008s]
- Nodal Voltage Method by Organic Chemistry Tutor
  [https://www.youtube.com/watch?v=BMnFC63m1fQ]
- Electrical Engineering StackExchange Forum
  [https://electronics.stackexchange.com]