Basic Electrical Science Lab
Course Code: EE152

Laboratory Manual

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Section: B

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National Institute of Technology Goa

CERTIFICATE

This is to certify that Mr./ Ms. ______________________ of Class B.Tech 1st year (2nd Sem), Division Sec A/B, bearing Roll. No.______________, has satisfactorily completed the course experiments in the Laboratory Course Basic Electrical Science Lab (EE152) in the academic year 2020-2021 in the Institution of National Institute of Technology Goa.

Course Instructor

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Experiment 3

Verification Of Network Theorems

1. **Introduction:**
   This experiment will help us to understand various network theorem -Superposition, Thevenin and Nortan theorem and to verify through a Simulation platform, MATLAB/Simulink.

2. **Objectives:**
   a. Acquire good knowledge on the above-mentioned network theorem.
   b. Verification of the four theorems in MATLAB/Simulink Platform

3. **Simulink Blockset used:** Resistors, voltage source, ramp , AC source, current source, current measurement, voltage measurement, add, divide, display, scope, constant, powergui.

4. **Theory:**

a) Superposition Theorem:
Superposition theorem states that in any linear, active, bilateral network having more than one source, the response across any element is the sum of the responses obtained from each source considered separately and all other sources are replaced by their internal resistance. The superposition theorem is used to solve the network where two or more sources are present and connected.

b) Thevenin’s Theorem:
Thevenin's Theorem states that it is possible to simplify any linear circuit, no matter how complex, to an equivalent circuit with just a single voltage source and series resistance connected to a load.

c) Norton’s Theorem:
Norton’s Theorem states that any linear circuit containing several energy sources and resistances can be replaced by a single constant current generator in parallel with a Single Resistor.

5. **<u>Statement of Experiments:</u>**

This session consists of four parts. [V= 100 V, $R_x = (10 \times x)\ \Omega$, I = 50 A]

Consider, R_5 as **Load Resistance**.

a. Using the circuit diagram shown in Fig. 3.a, verify **Superposition Theorem** in Matlab/Simulink platform.
b. Using the circuit diagram shown in Fig. 3.a, verify **Thevenin Theorem** in Matlab/Simulink platform.

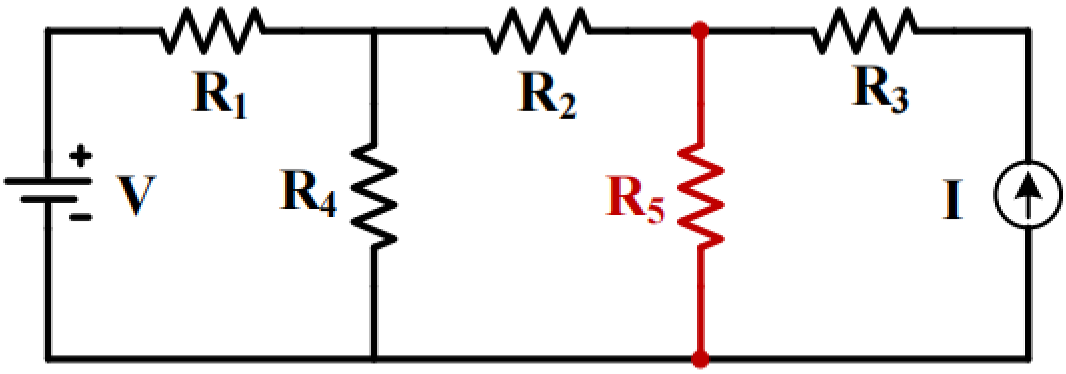


Fig. 3.a

c. Using the circuit diagram shown in Fig 3.a, verify Norton Theorem in Matlab/ Simulink platform.

6. **<u>Procedure:</u>** The procedures for the ***four parts*** are mentioned here.

a. Superposition Theorem

i. Convert the circuit shown in Fig. 3.a into experimental circuit (which includes necessary measuring instruments).
ii. Construct the experimental circuits in MATLAB/Simulink domain and simulate it.
iii. Based on the simulation, fill up the Table-3.1 to verify superposition theorem.

b. Thevenin's Theorem

i. Convert the circuit shown in Fig. 3.a into experimental circuit (necessary measuring instruments are to be incorporated in the circuit).
ii. Construct the experimental circuits in MATLAB/Simulink domain. Here, the file has to be run two times: at first it has to run to find out the open circuit voltage across the load terminal and it has to run second time to find out Thevenin's resistance across the load terminal.
iii. Based on the simulation, prepare an appropriate table and fill up it to verify thevenin's theorem.

c. Norton's Theorem

i. Convert the circuit shown in Fig. 3.a into experimental circuit (necessary measuring instruments are to be incorporated in the circuit).

ii. Construct the experimental circuits in MATLAB/Simulink domain. Here, the file has to be run to find out the short circuit voltage across the load terminal.

iii. Based on the simulation, prepare an appropriate table and fill up it to verify norton's theorem.

➢ Superposition Theorem:

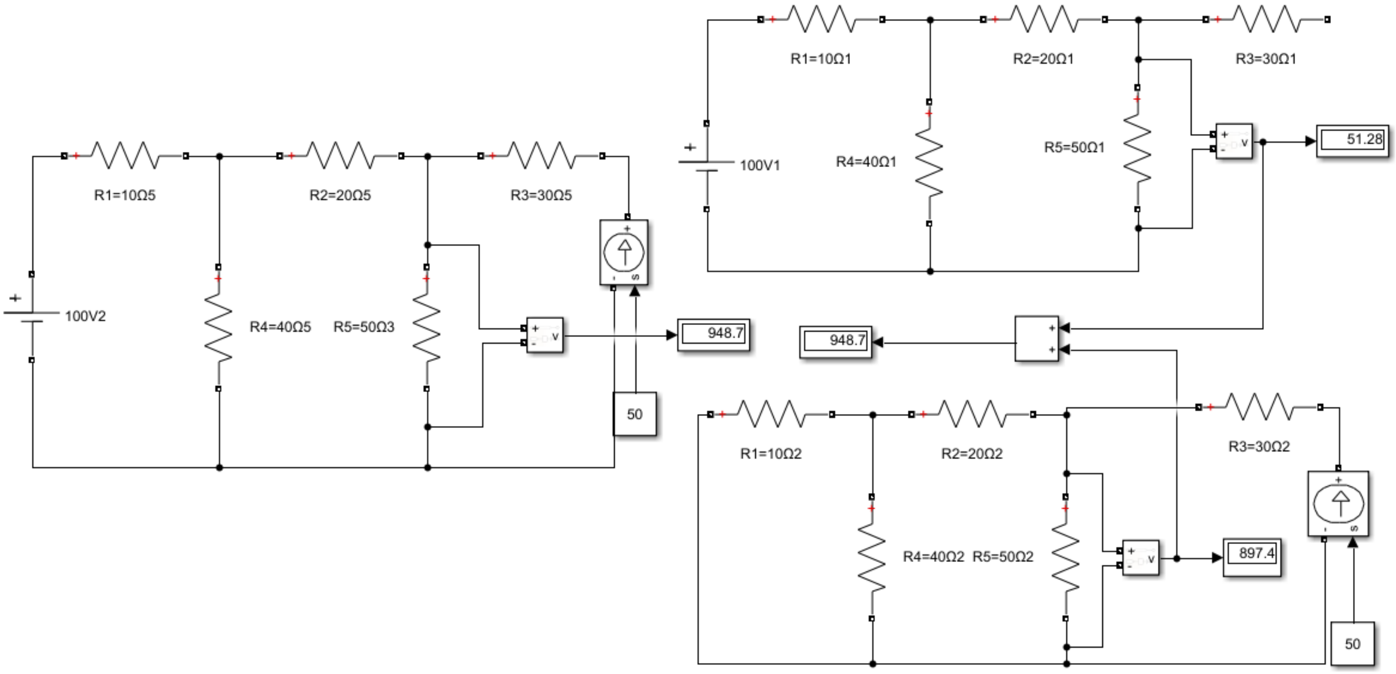


Fig3a: Circuit connections in Simulink for Superposition theorem

Observation No.	Applied Forcing Function		Load Voltage (volts) (V_L) due to all forcing Function		Load Voltage (volts) (V_{LV}) due to V only		Load Voltage (volts) (V_{LI}) due to I only		V_{LV} + V_{LI} (volts)	
	Applied Voltage (V) in volts	Applied Current (I) in A	Theoretical	Simulated	Theoretical	Simulated	Theoretical	Simulated	Theoretical	Simulated
1	100	50	948.72	948.7	51.28	51.28	897.44	897.4	948.72	948.68
2	100	100	1846.15	1846	51.28	51.28	1794.87	1795	1846.15	1846.28
3	50	100	1820.51	1821	25.64	25.64	1794.87	1795	1820.51	1820.64
4	50	50	923.08	923.1	25.64	25.64	897.44	897.4	923.08	923.04

Table3.1: Observation table for superposition theorem

➢ Thevenin's And Norton's Theorem:

Circuit Diagram:

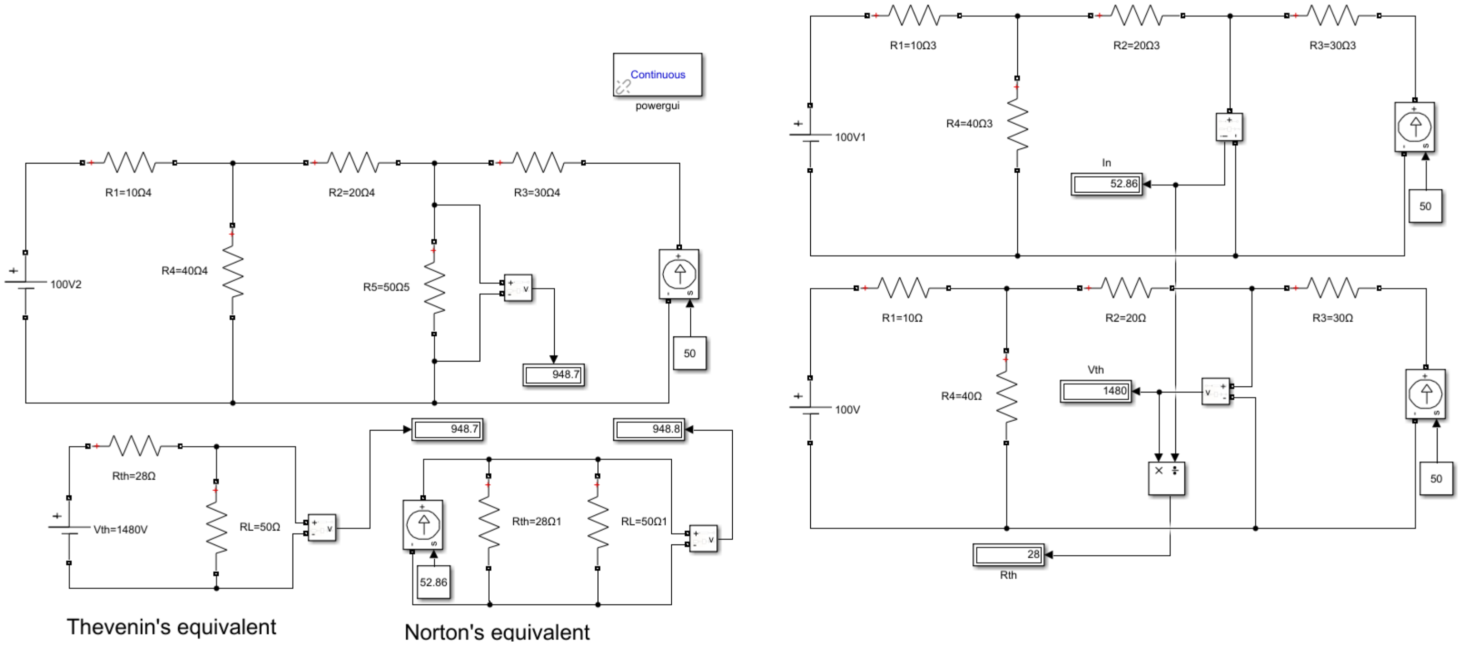


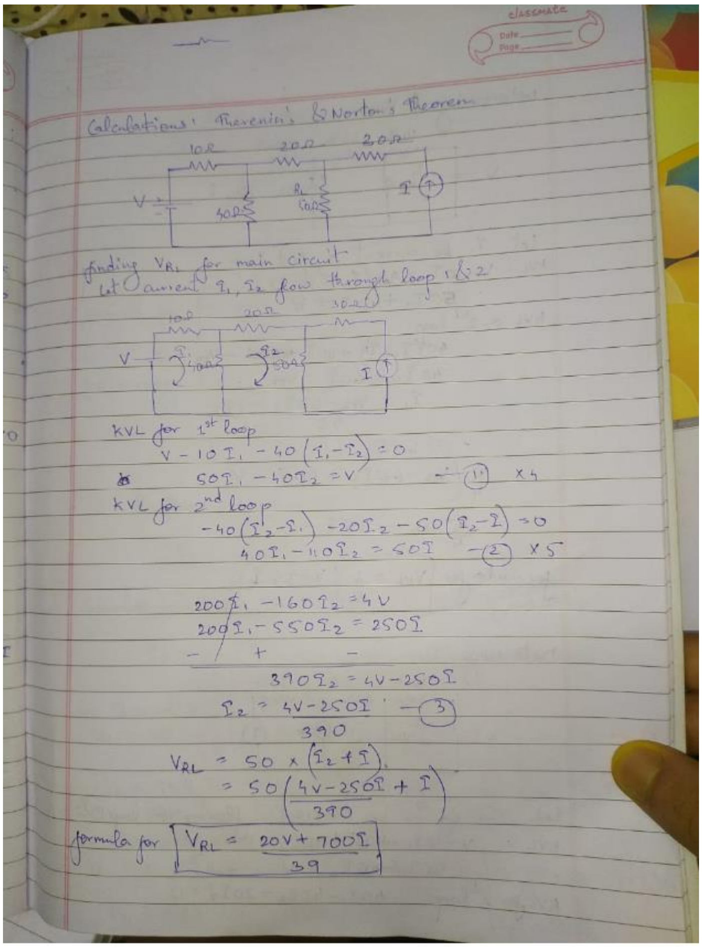
Fig3b: Circuit connections in Simulink for Thevenin's Theorem And Norton's Theorem

Observation Table:

Obs No.	Applied Forcing function		Voltage across Load R_L in main circuit (Volts)		V_{TH} (Volts)		I_N (Amperes)		$R_{TH}=V_{TH}/I_N$ ohms		Voltage across Load R_L in Thevenin's equivalent		Voltage across Load R_L in Norton's equivalent	
	Applied Voltage V (Volts)	Applied current I (Amps)	Theoretical	Simulated	Theoretical	Simulated	Theoretical	Simulated	Theoretical	Simulated	Theoretical	Simulated	Theoretical	Simulated
1	100	50	948.7	948.7	1480	1480	52.86	52.86	28	28	948.7	948.7	948.7	948.7
2	50	50	923.1	923.1	1440	1440	51.43	51.43	28	28	923.1	923.1	923.1	923.1
3	50	100	1821	1821	2840	2840	101.4	101.4	28	28	1821	1821	1821	1821
4	150	200	3667	3667	5720	5720	204.3	204.3	28	28	3667	3667	3667	3667

Table2.2: Observation table for Thevenin's theorem and Norton's theorem

Theoretical Calculations:



Calculations: Thevenin's & Norton's Theorem

finding V_{RL} for main circuit
Let current I_1, I_2 flow through loop 1 & 2

KVL for 1st loop
$V - 10I_1 - 40(I_1 - I_2) = 0$
$50I_1 - 40I_2 = V \quad \text{---} (1) \quad \times 4$

KVL for 2nd loop
$-40(I_2 - I_1) - 20I_2 - 50(I_2 - I) = 0$
$40I_1 - 110I_2 = 50I \quad \text{---} (2) \quad \times 5$

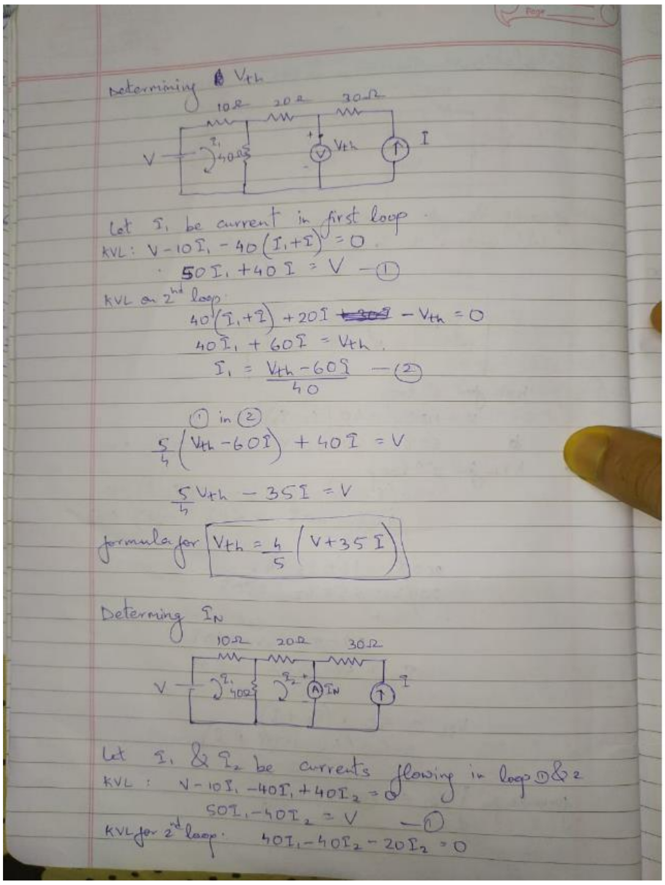
$200I_1 - 160I_2 = 4V$
$200I_1 - 550I_2 = 250I$

$390I_2 = 4V - 250I$

$I_2 = \frac{4V - 250I}{390} \quad \text{---} (3)$

$V_{RL} = 50 \times (I_2 + I)$
$= 50\left(\frac{4V - 250I}{390} + I\right)$

formula for $\boxed{V_{RL} = \frac{20V + 700I}{39}}$



Determining V_{th}

Let I_1 be current in first loop
KVL: $V - 10I_1 - 40(I_1 + I) = 0$
$50I_1 + 40I = V \quad \text{---} (1)$

KVL on 2nd loop
$40(I_1 + I) + 20I - V_{th} = 0$
$40I_1 + 60I = V_{th}$
$I_1 = \frac{V_{th} - 60I}{40} \quad \text{---} (2)$

(1) in (2)
$\frac{5}{4}(V_{th} - 60I) + 40I = V$

$\frac{5}{4}V_{th} - 35I = V$

formula for $\boxed{V_{th} = \frac{4}{5}(V + 35I)}$

Determing I_N

Let I_1 & I_2 be currents flowing in loop (1) & 2
KVL: $V - 10I_1 - 40I_1 + 40I_2 = 0$
$50I_1 - 40I_2 = V \quad \text{---} (1)$
KVL for 2nd loop: $40I_1 - 40I_2 - 20I_2 = 0$

$40I_1 = 60I_2$ — (2)

(2) in (1)

$50\left(\frac{3}{2}I_2\right) - 40I_2 = V$

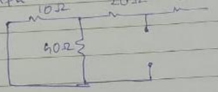
$75I_2 - 40I_2 = V$

$35I_2 = V$

$I_N = I_2 + I$

formula for $\boxed{I_N = \frac{V}{35} + I}$

Determing R_{th}



$R_{th} = \frac{40(10)}{50} + 20$

$\boxed{R_{th} = 28\Omega}$

~~Calculate~~ Formulas $V_{RL} = \frac{20V + 700I}{39}$, $V_{th} = \frac{4}{5}(V + 35I)$

$I_N = \frac{V}{35} + I$ $R_{th} = 28\Omega$

for Observation (1) $V = 100V$ $I = 50A$

$V_{RL} = \frac{20(100) + 700(50)}{39}$ | $V_{th} = \frac{4}{5}(100 + 35(50))$ | $I_N = \frac{100}{35} + 50$

$V_{RL} = 948.7V$ | $V_{th} = 1480V$ | $I_N = 52.86A$

$R_{th} = 28\Omega$

for Observation (2) $V = 50V$ $I = 50A$

$V_{RL} = \frac{20(50) + 700(50)}{39}$ | $V_{th} = \frac{4}{5}(50 + 35(50))$ | $I_N = \frac{50}{35} + 50 = 51.43A$

$V_{RL} = 923.1V$ | $V_{th} = 1440V$ | $R_{th} = 28\Omega$

for observation (3) $V = 50V$ $I = 100A$

$V_{RL} = \frac{20(50) + 700(100)}{39}$ | $V_{th} = \frac{4}{5}(V + 35I)$ | $I_N = \frac{50}{35} + 100$

$= \frac{4}{5}(50 + 35(100))$ | $I_N = 101.4A$

$V_{RL} = 1821V$ | $V_{th} = 2840V$

$R_{th} = 28\Omega$

for observation (4) $V = 150V$ $I = 200A$

$V_{RL} = \frac{20(150) + 700(200)}{39}$ | $V_{th} = \frac{4}{5}(150 + 35(200))$ | $I_N = \frac{150}{35} + 200$

$V_{RL} = 3667V$ | $V_{th} = 5720V$ | $I_N = 204.3A$

$R_{th} = 28\Omega$

Assignment:

1. Replace constant voltage source by variable voltage source (sinusoidal source with the same magnitude, ramp input with slope 1) in Fig. 3.a, do all the simulation again.

➢ Superposition Theorem

- **Constant sources replaced with Sinusoidal sources**

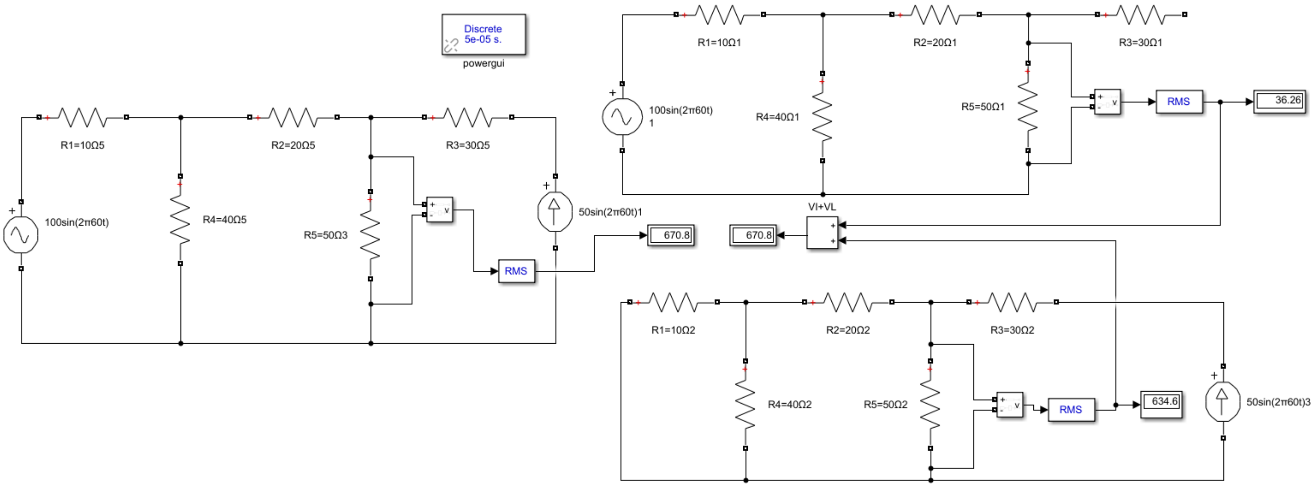
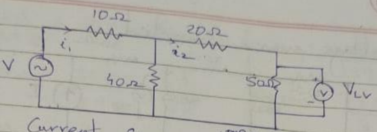


Fig3c: Circuit connections in Simulink for Superposition theorem using sinusoidal sources

Observation No.	Applied Forcing Function		Load Voltage (volts) (V_L) due to all forcing Function		Load Voltage (volts) (V_{LV}) due to V only		Load Voltage (volts) (V_{LI}) due to I only		$V_{LV}+V_{LI}$ (volts)	
	Applied Voltage (V) in volts	Applied Current (I) in A	Theoretical	Simulated	Theoretical	Simulated	Theoretical	Simulated	Theoretical	Simulated
1	100sin(2π60t)	50sin(2π60t)	670.86	670.86	36.26	36.26	634.6	634.6	670.86	670.86

Table3.3: Observation table for Superposition theorem using sinusoidal input



Current Source ~~short~~ open circuited.

$\cancel{R_{eq} = 10 + \frac{40 \times 70}{40+70}}$

$\cancel{= 10 + \frac{2800}{110}}$

$\cancel{R_{eq} = \frac{390}{11}\ \Omega}$

$\cancel{i_2 = \frac{40}{110} i_1}$

$\cancel{= \frac{40}{110} \frac{V}{390} \times 11}$

$\cancel{=}$

$R_{eq} = 10 + \frac{40 \times 70}{40+70}$

$= 10 + \frac{2800}{110}$

$R_{eq} = \frac{390}{11}\ \Omega$

$i_2 = \frac{40}{110} i_1$

$= \frac{4}{11} \times \frac{V}{390/11}$

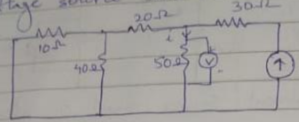
$i_2 = \frac{4V}{390}$

$V_{LV} = 50 \times i_2$

$= \frac{50 \times 4}{390} V$

$\boxed{V_{LV} = \frac{20V}{39}}$

Voltage source shorted



$i = \frac{\left(\frac{40 \times 10}{50} + 20\right)}{70 + \frac{40 \times 10}{50}} \times I$

$i = \frac{28 I}{78}$

$V_{LI} = 50 i$

$V_{LI} = \frac{700}{39} i$

~~for obsv No. 1~~

formulas: $V_{RL} = \frac{20V + 700I}{39}$ $V_{LV} = \frac{20V}{39}$ $V_{LI} = \frac{700i}{39}$

for obsv No. 1

$V = 100\sin(2\pi 60t)$ $I = 50\sin(2\pi 60t)$

$V_{RL} = \frac{20(100\sin 2\pi 60t) + 700(50\sin 2\pi 60t)}{39}$

$= \cancel{\frac{2000}{39}} +$

$V_{RL} = \frac{37000}{39} \sin(2\pi 60t)$

$V_{RL\,rms} = \frac{37000}{39} \times \frac{1}{\sqrt{2}}$

$V_{RL\,rms} = 670.8\ V$

$V_{LV} = \frac{20}{39} \times 100\sin(2\pi 60t)$

$V_{LV}\,rms = \frac{2000}{39} \times \frac{1}{\sqrt{2}}$

$V_{LV}\,rms = 36.26\ V$

$V_{LI} = \frac{700}{39} \times 50\sin(2\pi 60t)$

$V_{LI}\,rms = \frac{35000}{39} \times \frac{1}{\sqrt{2}}$

$V_{LI}\,rms = 634.6\ V$

$V_{LV} + V_{LI} = 634.6 + 36.26$

$V_{LV} + V_{LI} = 670.86\ V$

for obsv No. 2

$V = 50\sin(2\pi 60t) \quad I = 50\sin(2\pi 60t)$

$V_{RL} = \frac{20 \times 50\sin(2\pi 60t) + 700(50\sin 2\pi 60t)}{39}$

$V_{RL} = \frac{36000}{39}\sin(2\pi 60t)$

$V_{RL}\,rms = \frac{36000}{39} \times \frac{1}{\sqrt{2}}$

$V_{RL}\,rms = 652.7\ V$

$V_{LV} = \frac{20 \times 50}{39}\sin(2\pi 60t)$

$V_{LV}\,rms = \frac{1000}{39} \times \frac{1}{\sqrt{2}}$

$V_{LV}\,rms = 18.13\ V$

$V_{LI} = \frac{700}{39} \times 50\sin(2\pi 60t)$

$V_{LI}\,rms = \frac{700 \times 50}{39} \times \frac{1}{\sqrt{2}}$

$V_{LI}\,rms = 634.57\ V$

$V_{LV} + V_{LI} = 18.13 + 634.57$

$V_{LV} + V_{LI} = 652.7\ V$

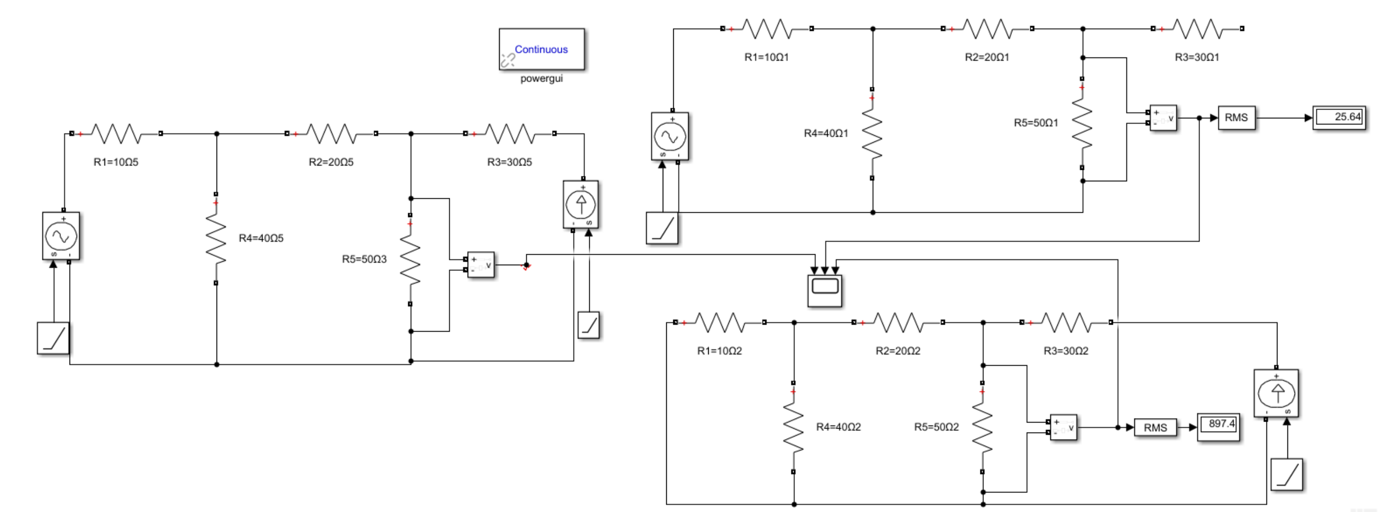


Fig3d: Circuit connections in Simulink for Superposition theorem using variable sources with ramp

Observation No.	Applied Forcing Function		Load Voltage (volts) (V_L) due to all forcing Function (RMS)		Load Voltage (volts) (V_{LV}) due to V only (RMS)		Load Voltage (volts) (V_{LI}) due to I only (RMS)		$V_{LV}+V_{LI}$ (volts) (RMS)	
	Applied Voltage (V) in volts Ramp slope:1	Applied Current (I) in A Ramp slope:1	Theoretical	Simulated	Theoretical	Simulated	Theoretical	Simulated	Theoretical	Simulated
1	0 - 50	0 - 50	532.93	533	14.8	14.8	518.1	518.2	532.9	533

Table3.4: Observation table for Superposition theorem for variable sources using ramp

- Thevenin and Norton's Theorem

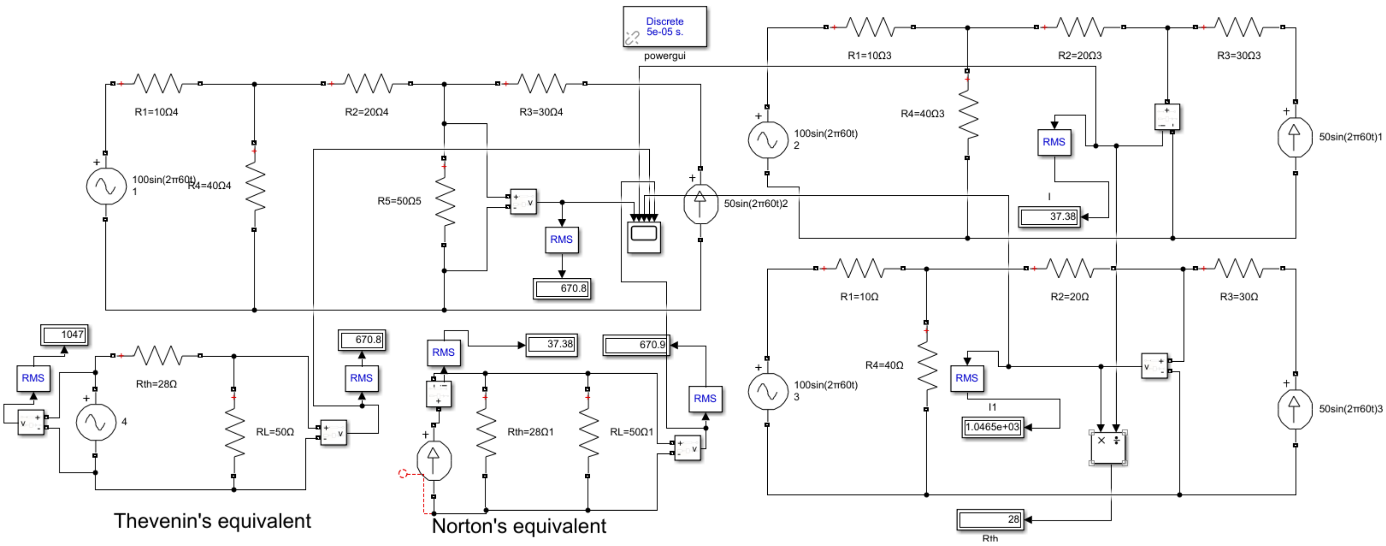
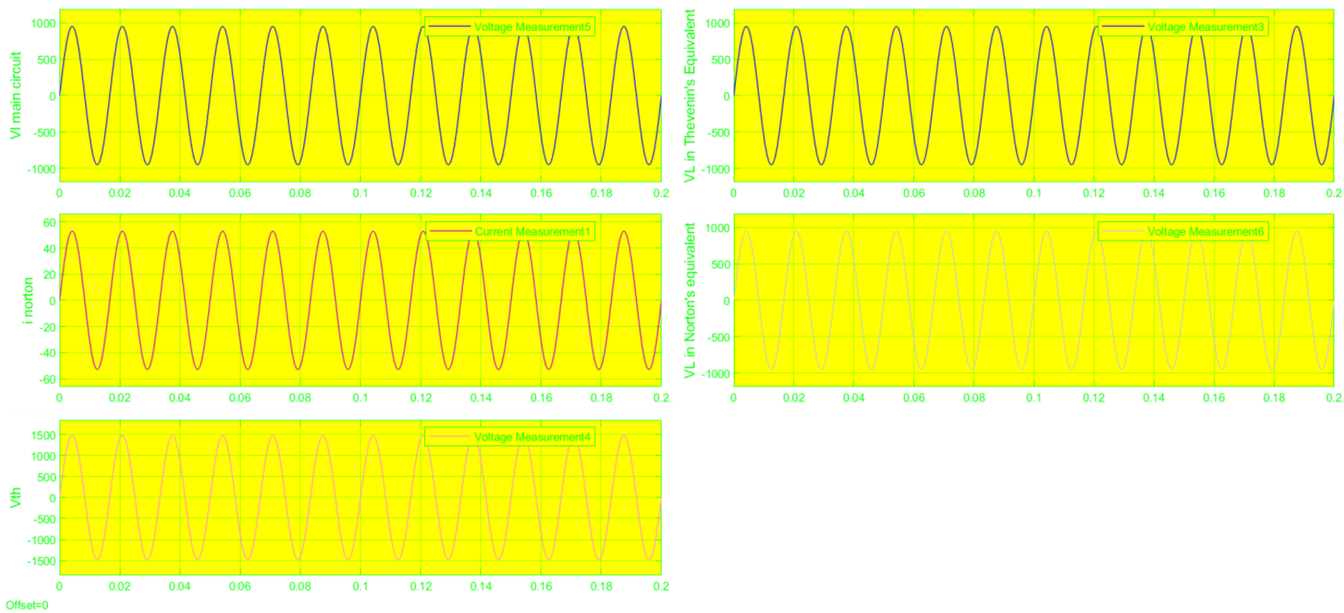


Fig3e: Circuit connections in Simulink for Thevenin and Norton's theorem using sinusoidal sources

Obs No.	Applied Forcing function		Voltage across Load R_L in main circuit (Volts)		V_{TH} (Volts)		I_N (Amperes)		$R_{TH}=V_{TH}/I_N$ ohms		Voltage across Load R_L in Thevenin's equivalent		Voltage across Load R_L in Norton's equivalent	
	Applied Voltage V (Volts)	Applied current I (Amps)	Theoretical	Simulated	Theoretical	Simulated	Theoretical	Simulated	Theoretical	Simulated	Theoretical	Simulated	Theoretical	Simulated
1	100sin(2π60t)	50sin(2π60t)	670.84	670.7	1046.51	1046.348	37.37	37.37	28	28	670.84	670.7	670.74	670.7

Table3.5: Observation table for Thevenin and Norton's theorem for variable sources using sinusoidal

Graphical Results:



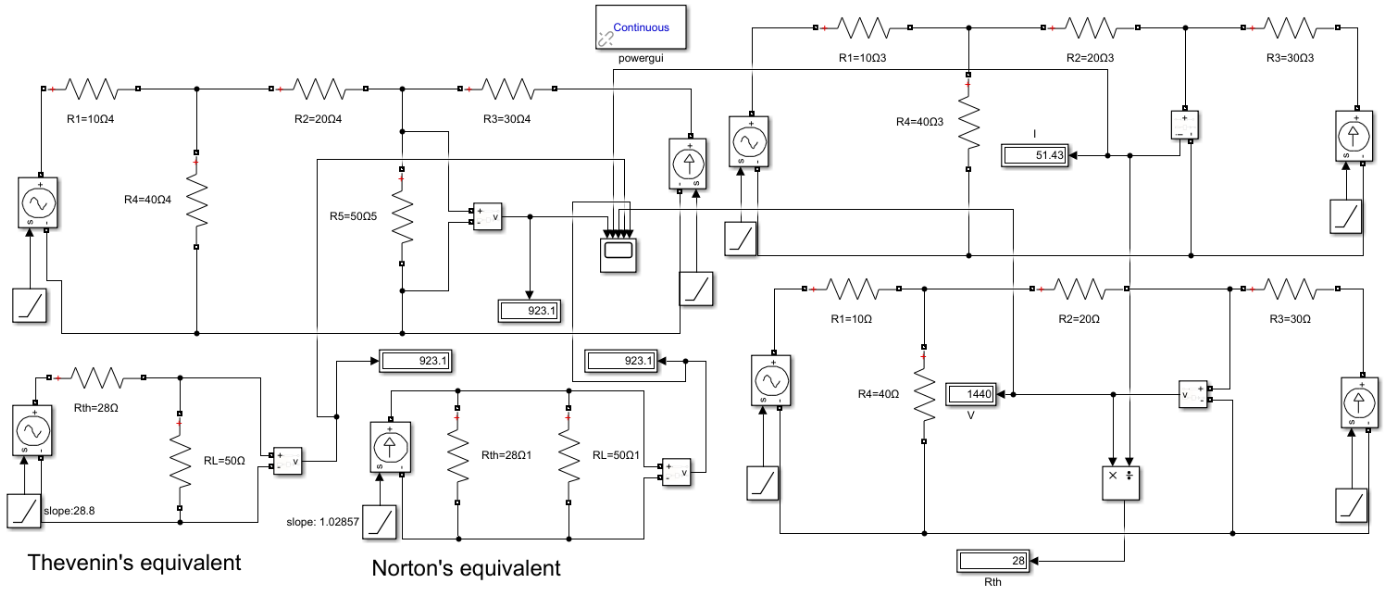


Fig3f: Circuit connections in Simulink for Thevenin and Norton's theorem using variable sources with ramp

Graphical Results:

Obs No.	Applied Forcing function		Voltage across Load R_L in main circuit (Volts)		V_{TH} (Volts)		I_N (Amperes)		$R_{TH}=V_{TH}/I_N$ ohms		Voltage across Load R_L in Thevenin's equivalent		Voltage across Load R_L in Norton's equivalent	
	Applied Voltage V (Volts) Ramp slope: 1	Applied current I (Amps) Ramp slope : 1	Theoretical	Simulated	Theoretical	Simulated	Theoretical	Simulated	Theoretical	Simulated	Theoretical	Simulated	Theoretical	Simulated
1	50	50	923.08	923.1	1440	1440	51.43	51.43	28	28	923.08	930.1	930.08	930.1

Table3.5: Observation table for Thevenin and Norton's theorem for variable sources with ram

for obsv ①

V = 0 - 50V ramp slope 1

I = 0 - 50V ramp slope 1

$V(t) = t \quad 0<t<50$

$I(t) = t \quad 0<t<50$

$V_{RMS} = \sqrt{\dfrac{\int_0^{50} (V(t))^2 dt}{T}}$

$= \sqrt{\dfrac{\int_0^{50} t^2 dt}{50}}$

$= \sqrt{\dfrac{\frac{t^3}{3}\Big|_0^{50}}{50}}$

$V_{RMS} = \dfrac{50}{\sqrt{3}}$ similarly $I_{RMS} = \dfrac{50}{\sqrt{3}}$

formula: $V_{RL} = \dfrac{20V + 700I}{39}$; $V_{LV} = \dfrac{20V}{39}$; $V_{LI} = \dfrac{700I}{39}$

$V_{RL\ rms} = \dfrac{20 V_{RMS} + 700 I_{RMS}}{39}$

$= \dfrac{20\left(\frac{50}{\sqrt{3}}\right) + 700\left(\frac{50}{\sqrt{3}}\right)}{39}$

$V_{RL\ RMS} = 532.93$ Volts

$V_{LV} = \dfrac{20V}{39}$	$V_{LI} = \dfrac{700I}{39}$	$(V_{LV} + V_{LI})(rms) = 14.8 + 518.1$
$V_{LV\ RMS} = \dfrac{20 V_{RMS}}{39}$	$V_{LI\ rms} = \dfrac{700 I_{RMS}}{39}$	$= 532.9V$
$= \dfrac{20}{39} \times \dfrac{50}{\sqrt{3}}$	$= \dfrac{700}{39} \times \dfrac{50}{\sqrt{3}}$	
$V_{LV\ RMS} = 14.8$ Volts	$V_{LI\ rms} = 518.1$ Volts	

formulas: $V_{th} = \dfrac{4}{5}(V + 35I)$ $\quad V_{RL} = \dfrac{20V + 700I}{39}$

$I_N = \dfrac{V}{35} + I \quad R_{th} = 28\ \Omega$

for obsv ①

$V = 100\sin(2\pi 60t) \quad I = 50\sin(2\pi 60t)$

$V_{RL} = \dfrac{20V + 700I}{39}$

$= \dfrac{20(100\sin 2\pi 60t) + 700(50\sin 2\pi 60t)}{39}$

$V_{RL} = \dfrac{37000\sin(2\pi 60t)}{39}$

$V_{RL\ rms} = \dfrac{37000}{39} \times \dfrac{1}{\sqrt{2}}$

$V_{RL\ rms} = 670.84\ V$

$V_{th} = \dfrac{4}{5}(V + 35I)$	$I_N = \dfrac{V}{35} + I$
$= \dfrac{4}{5}\left(100\sin 2\pi 60t + 35(50\sin 2\pi 60t)\right)$	$I_N = \dfrac{100\sin 2\pi 60t}{35} + 50\sin 2\pi 60t$
$= \dfrac{4}{5}(1850\sin 2\pi 60t)$	$I_N = \dfrac{370}{7}\sin 2\pi 60t$
$V_{th} = 1480\sin 2\pi 60t$	$I_{N\ rms} = \dfrac{370}{7} \times \dfrac{1}{\sqrt{2}}$
$V_{th\ rms} = \dfrac{1480}{\sqrt{2}}$	
$V_{th\ rms} = 1046.51V$	$I_{N\ rms} = 37.37\ A$

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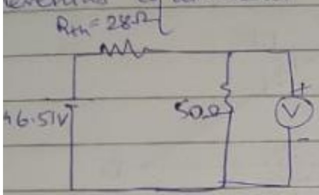
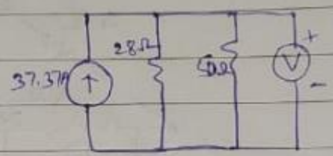
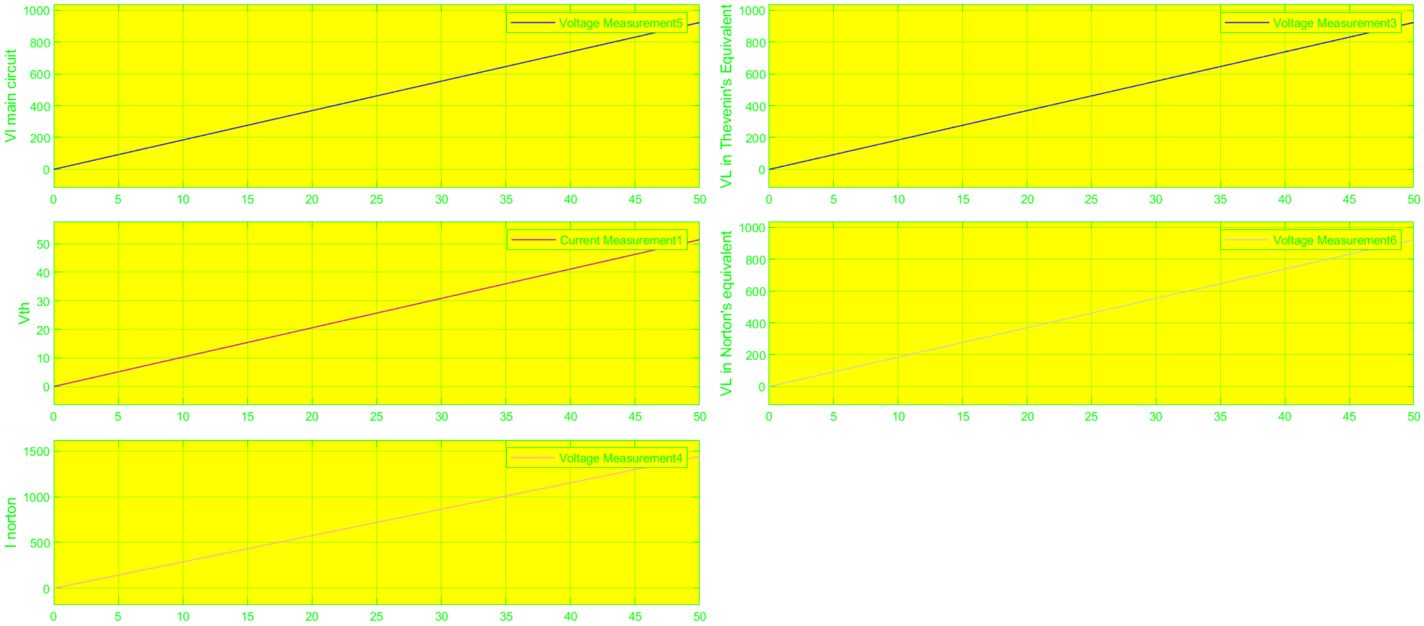
evenin's Equivalent	Norton's Equivalent
	
$V_{LT} = \dfrac{50}{50+28} \times 1046.51$	$V_{LN} = \dfrac{28}{28+50} \times 37.37 \times 50$
$V_{LT} = 670.84V$	$V_{LN} = 670.74V$

Graphical Results:


Vl main circuit
Voltage Measurement5
VL in Thevenin's Equivalent
Voltage Measurement3
Vth
Current Measurement1
VL in Norton's equivalent
Voltage Measurement6
I norton
Voltage Measurement4

2. Using circuit shown in Fig. 3.b, do the experiments again. Consider, the load resistance mentioned in red colour.

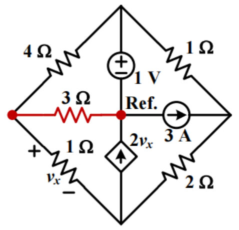


Fig. 3.b

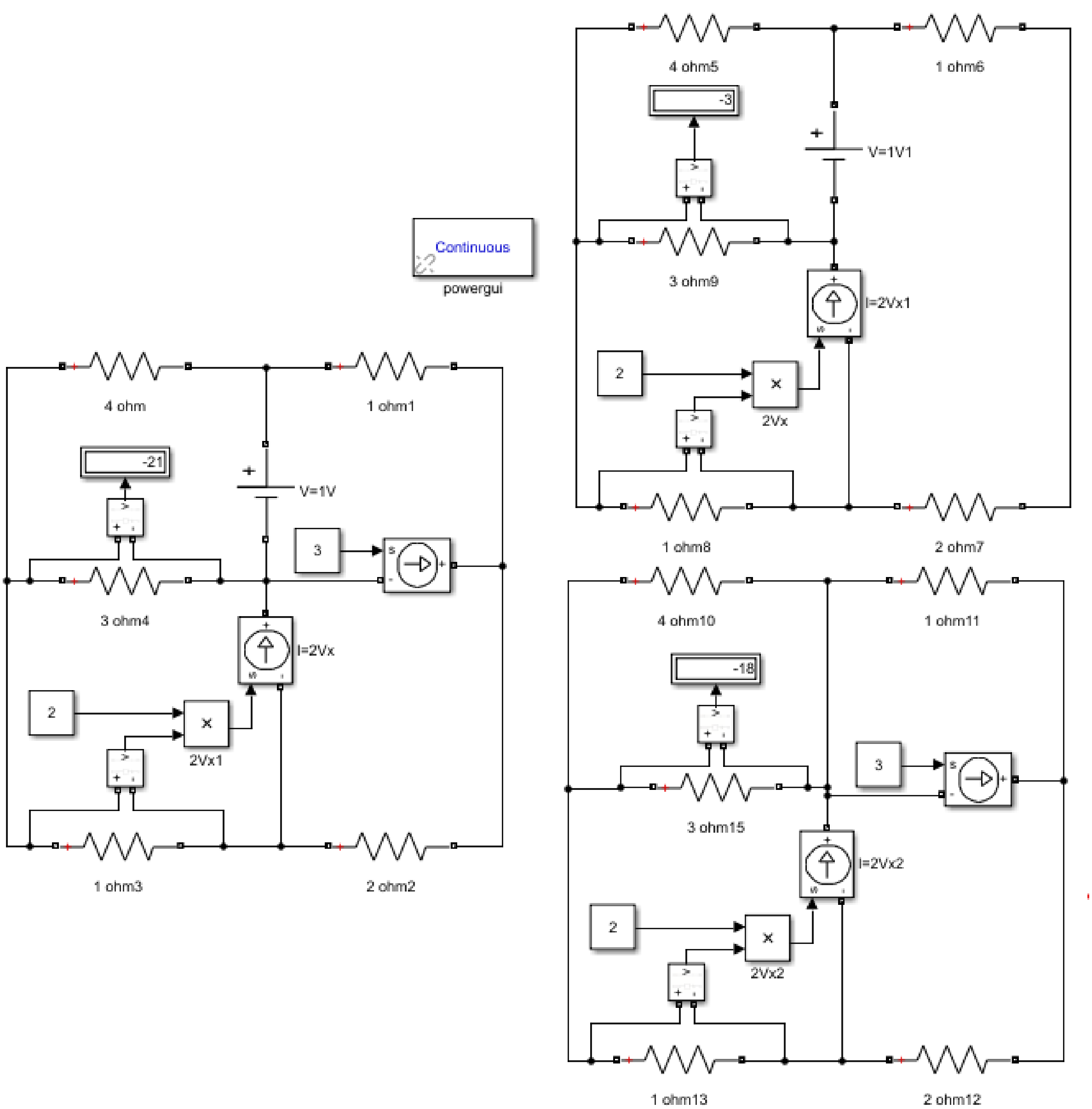


Fig3g: Circuit connections in Simulink for Superposition theorem for ckt 3b

Observation No.	Applied Forcing Function		Load Voltage (volts) (V_L) due to all forcing Function		Load Voltage (volts) (V_{LV}) due to V only		Load Voltage (volts) (V_{LI}) due to I only		$V_{LV}+V_{LI}$ (volts)	
	Applied Voltage (V) in volts	Applied Current (I) in A	Theoretical	Simulated	Theoretical	Simulated	Theoretical	Simulated	Theoretical	Simulated
1	1	3	-21	-21	-3	-3	-18	-18	-21	-21
2	3	3	-27	-27	-9	-9	-18	-18	-27	-27
3	3	1	-15	-15	-9	-9	-6	-6	-15	-15
4	2	5	-36	-36	-6	-6	-30	-30	-36	-36

Table3.6: Observation table for Superposition theorem for ckt 3b

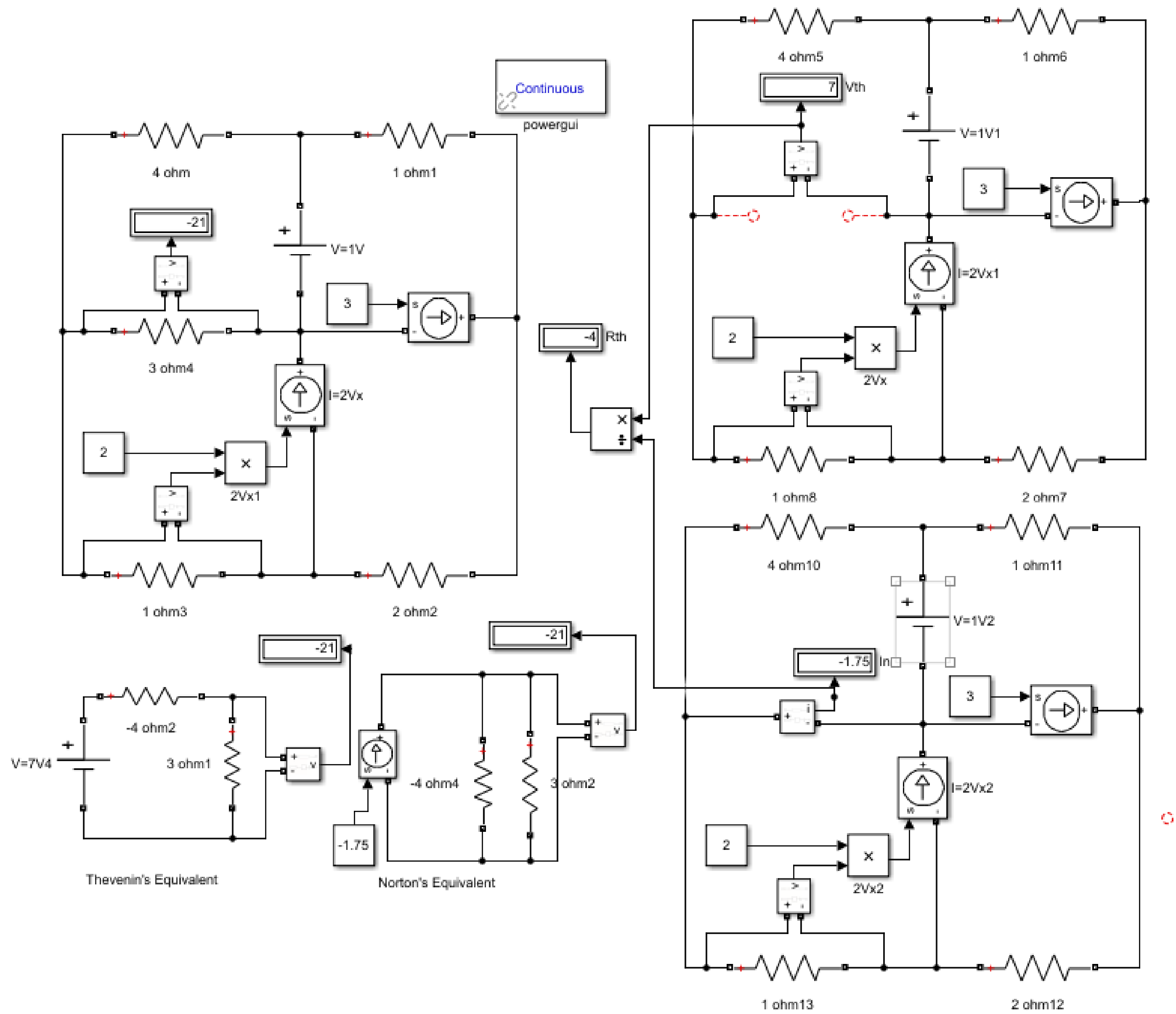
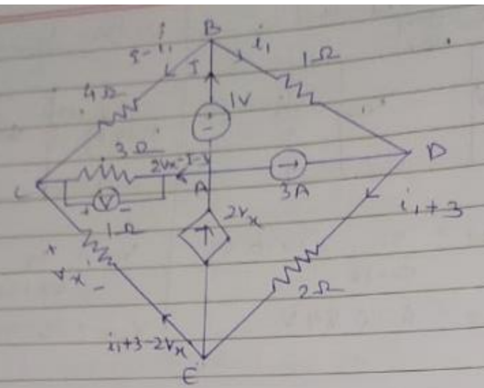


Fig3h: Circuit connections in Simulink for Thevenin and Norton theorem for ckt 3b

Obs No.	Applied Forcing function		Voltage across Load R_L in main circuit (Volts)		V_{TH} (Volts)		I_N (Amperes)		$R_{TH}=V_{TH}/I_N$ ohms		Voltage across Load R_L in Thevenin's equivalent		Voltage across Load R_L in Norton's equivalent	
	Applied Voltage V (Volts)	Applied current I (Amps)	Theoretical	Simulated	Theoretical	Simulated	Theoretical	Simulated	Theoretical	Simulated	Theoretical	Simulated	Theoretical	Simulated
1	1	3	-21	-21	7	7	-1.75	-1.75	-4	-4	-21	-21	-21	-21

Table3.7: Observation table for Thevenin and Norton theorem for ckt 3b



~~at $V_A = 0$~~
~~$V_B = 1V$ $V_C = V_{RL}$ $V_E = V_{RL} - V_x$~~
~~KCL at node A~~
~~$\frac{V}{3\Omega} +$~~

KVL in loop ABC
$4(I - i_1) - 1 - 3(2V_x - I - 3) = 0$
$7I - 4i_1 + 8 - 6V_x = 0$ — (1)

KVL in loop CBDE
$4(I - i_1) - i_1 - 2i_1 - 6 + V_x = 0$
$4I - 7i_1 + V_x = 6$ — (2)

$V_x = -(i_1 + 3 - 2V_x)$
$-V_x = -i_1 - 3$
$V_x = i_1 + 3$ — (3)

for (3) in (1)
$7I - 4i_1 + 8 - 6(i_1 + 3) = 0$
$7I - 10i_1 = 10$ — (4)

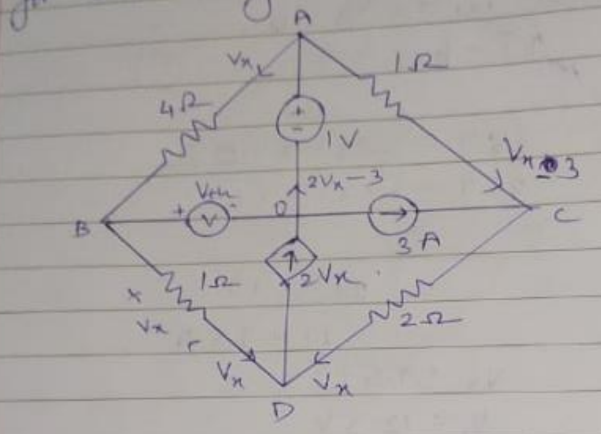
for (3) in (2)
$4I - 7i_1 + i_1 + 3 = 6$
$4I - 6i_1 = 3$ — (5)

$28I - 40i_1 = 40$
$28I - 42i_1 = 21$
$- \quad + \quad -$
$2i_1 = 19$
$i_1 = 9.5\,A$
$V_x = 9.5 + 3$
$V_x = 12.5\,V$

$I = \frac{10 + 10i_1}{7}$
$I = \frac{105}{7}$
$I = 15A$

$V_L = 3(2V_x - I - 3)$
$= 6(12.5) - 3I - 9$
$= 75 - 3(15) - 9$
$= 75 - 45 - 9$
$V_L = 21\,V$

for determining V_{th} -



KCL at junction A.

$2V_x - 3 = V_x + V_x - 3$

$0 = 0$

KVL loop BACD

$V_x + 4V_x - V_x + 3 - 2V_x$

$2V_x = -3$

$V_x = -1.5$

Let $V_0 = 0$ $V_A = 1V$ $V_B = 1 - 4V_x$

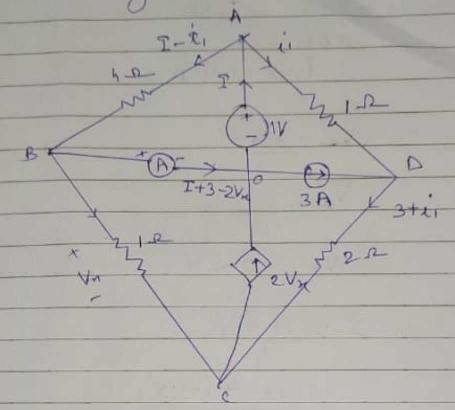
$V_{th} = 1 - 4V_x$.

$= 1 - 4(-1.5)$

$= 1 + 6$

$\boxed{V_{th} = 7\ V}$

for determining I_N



$I_{BC} = I_{ABO} - I_{BO}$

$= I - i_1 - (I + 3 - 2V_x)$

$I_{BC} = 2V_x - i_1 - 3$

KVL loop ABCD

$4(I - i_1) - i_1 - 6 - 2i_1 + V_x = 0$

$4I - 7i_1 + V_x = 6$ — (1)

$V_x = -I_{BC}$

$V_x = i_1 + 3 - 2V_x$

$3V_x = i_1 + 3$ — (2)

KVL loop AOB

$4(I - i_1) = 1$

$4I - 4i_1 = 1$ — (3)

putting (2) & (3) in (1)

$4\left(\frac{1+4i_1}{4}\right) - 7i_1 + \frac{i_1+3}{3} = 6$

$1 - 3i_1 + \frac{i_1+3}{3} = 6$

$$3 - 9i_1 + i_1 + 3 = 18$$
$$-8i_1 = 12$$
$$-2i_1 = 3$$
$$i_1 = -1.5\ A$$

$$V_x = \frac{i_1 + 3}{3}$$
$$V_x = \frac{1.5}{3}$$
$$V_x = 0.5V$$

$$I = \frac{1 + 4i_1}{4}$$
$$= \frac{1 + 4(-1.5)}{4}$$
$$I = \frac{1 - 6}{4}$$
$$I = -1.25\ A$$

$$I_N = I + 3 - 2V_x$$
$$= -1.25 + 3 - 2(0.5)$$
$$= -1.25 + 3 - 1$$
$$= 2 - 1.25$$
$$I_N = -1.75\ A$$