UNIVERSITY COLLEGE LONDON

MENG MECHANICAL ENGINEERING

MECH0071 ELECTRICAL POWER SYSTEMS AND ELECTRICAL PROPULSION

PSCAD COURSEWORK

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1 Diode bridge circuit

1.1 Circuit diagram

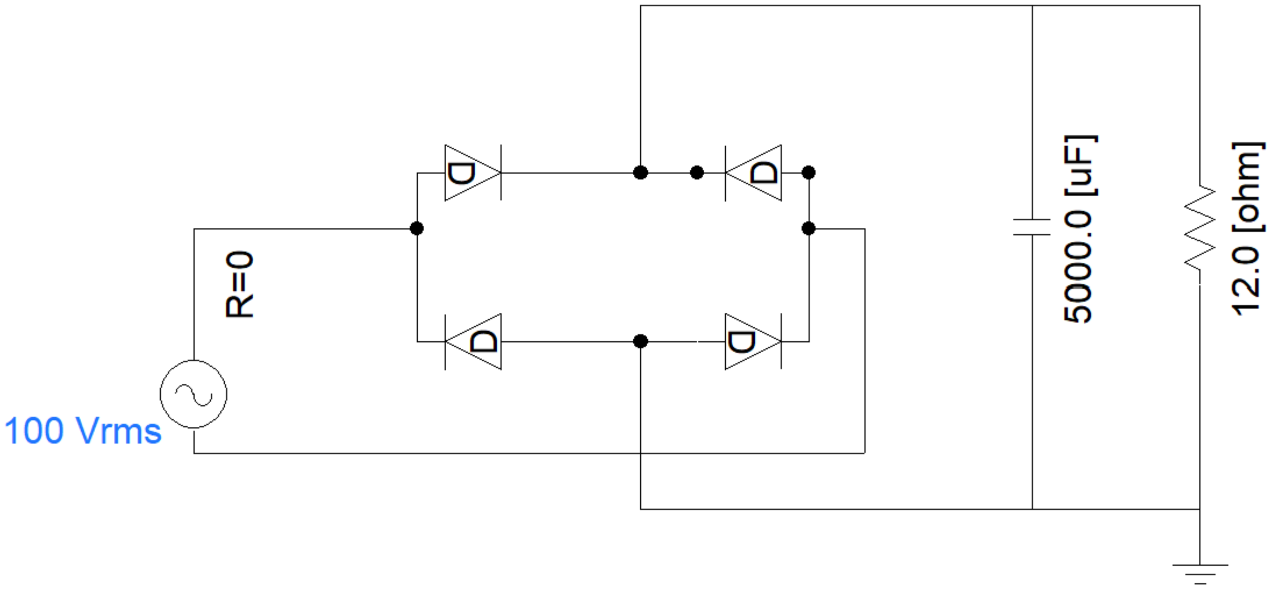

Figure 1: Circuit diagram to show diode bridge circuit.

1.2 Instantaneous voltages

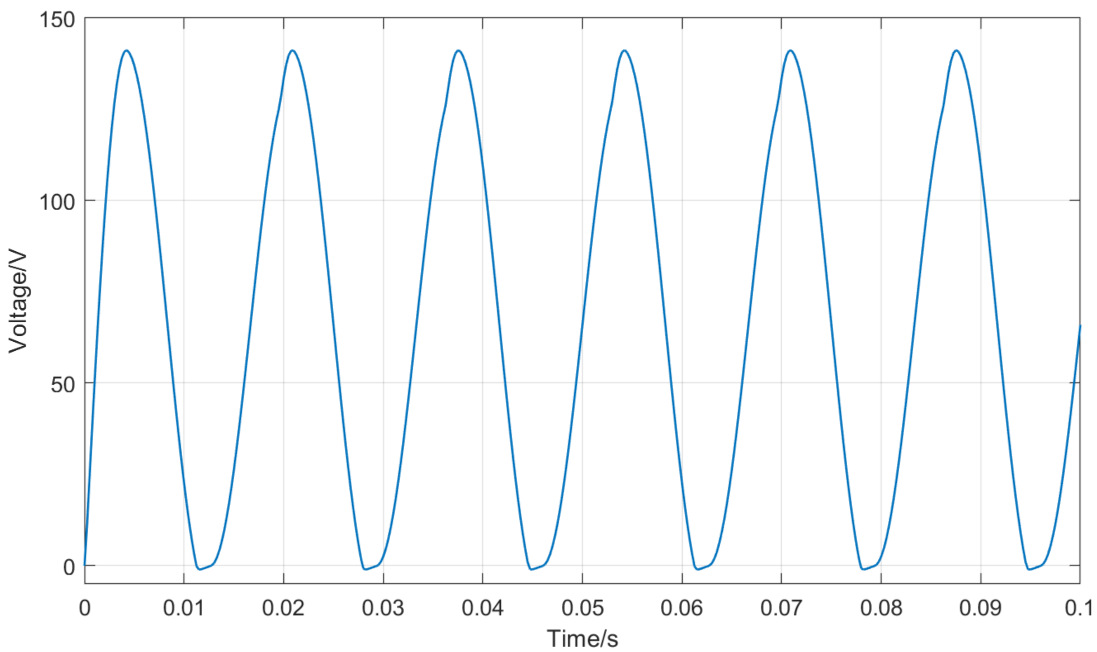

Figure 2: Graph to show instantaneous input voltage across the voltage source.

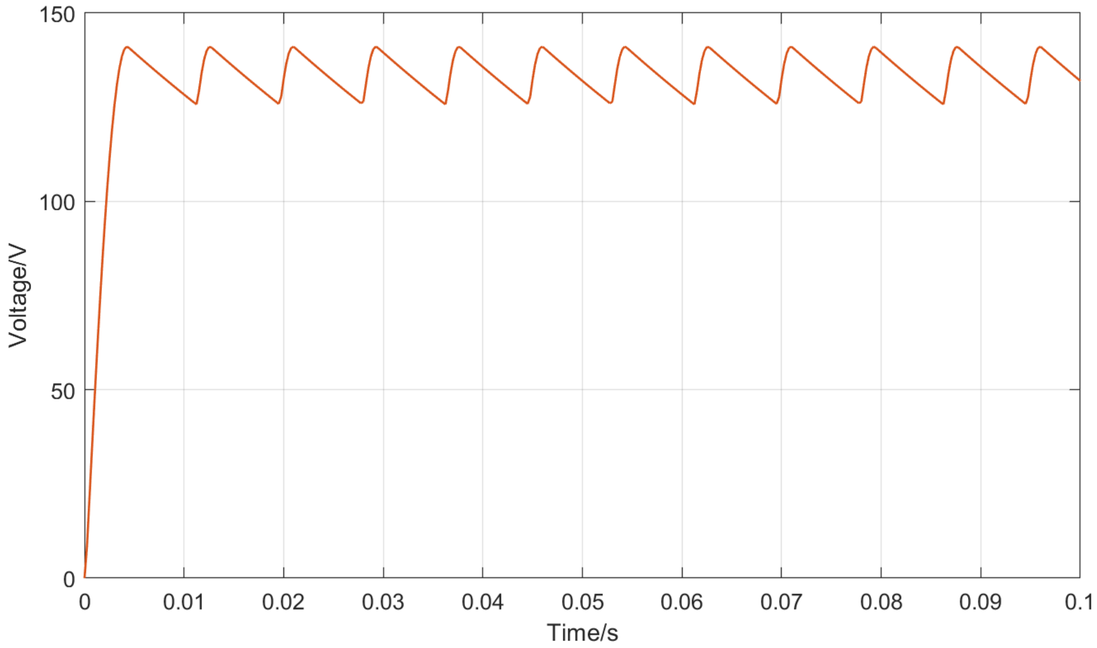

Figure 3: Graph to show instantaneous output voltage across the resistive load.

1.3 Effect of increasing capacitcance to $25\,\mu\mathrm{F}$

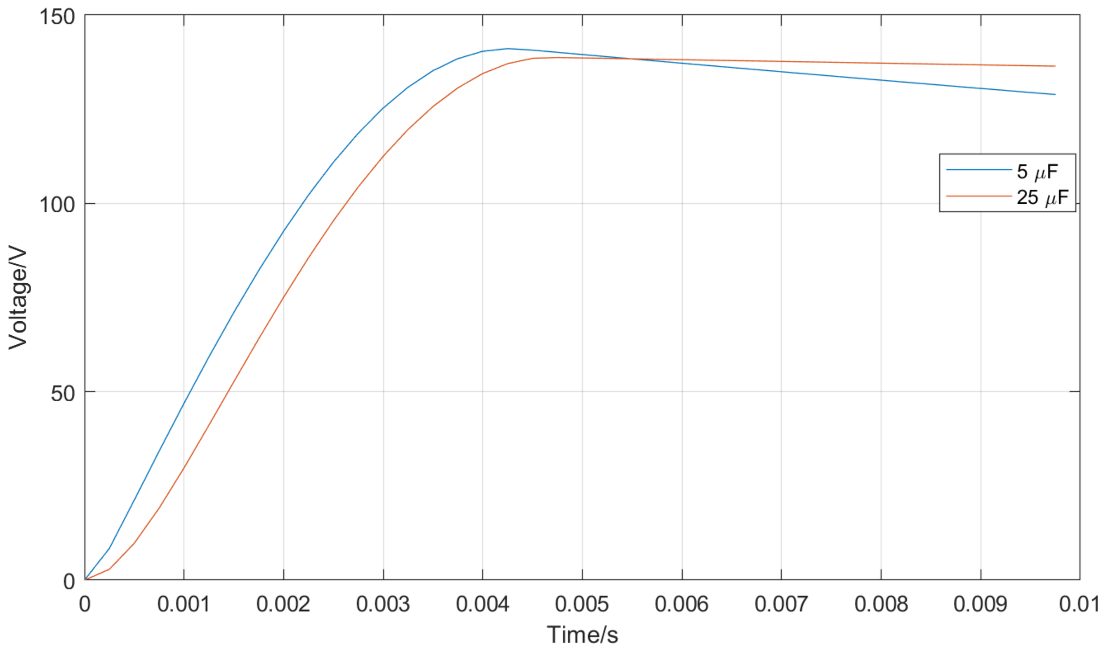

Figure 4: Graph to show comparison between instantaneous output voltage across the resistive load for different capacitance values.

The purpose of the capacitor in this diode bridge circuit is to filter/reduce the amount of voltage ripple, inherent to bridge diode circuits. We can see in Figure 3 that our voltage drop is approximately $25\,\mathrm{V}$ between pulses ($5\,\mu\mathrm{F}$). By increasing the capacitance, our voltage drop reduces (from data: voltage drop with $25\,\mu\mathrm{F} \approx 4\,\mathrm{V}$.) This is desirable as this achieves a more stable DC output. However, increasing the capacitance also increases the rise time and reduces the peak voltage of the output, shown in Figure 4.

2 Equivalent transformer

2.1 Circuit diagram

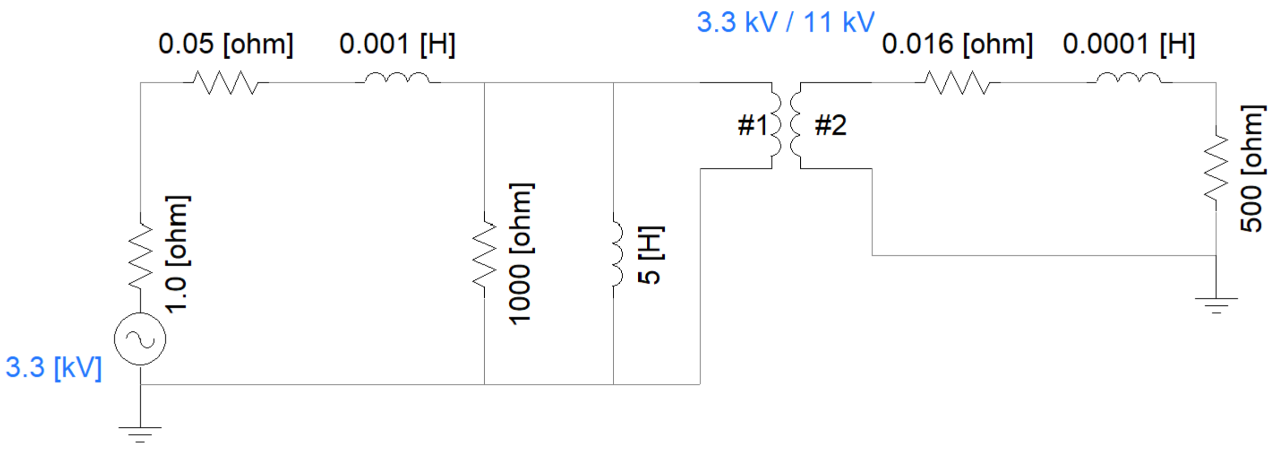

Figure 5: Circuit diagram to show equivalent transformer.

2.2 Resistive load

MATLAB code for this section of the assignment can be viewed in Appendix A.2.

2.2.1 RMS Voltage

The RMS voltage can be calculated using (1).

$$V_{RMS} = \sqrt{\frac{\sum_{i=1}^{n} x_i^2}{n}} \tag{1}$$

- Simulation time: $0.5\,\mathrm{s}$
- Number of data points (n): 2002

Using MATLAB, the RMS voltage over the time period is:

$$V_{RMS,r} = 10.14\,\mathrm{kV} \tag{2}$$

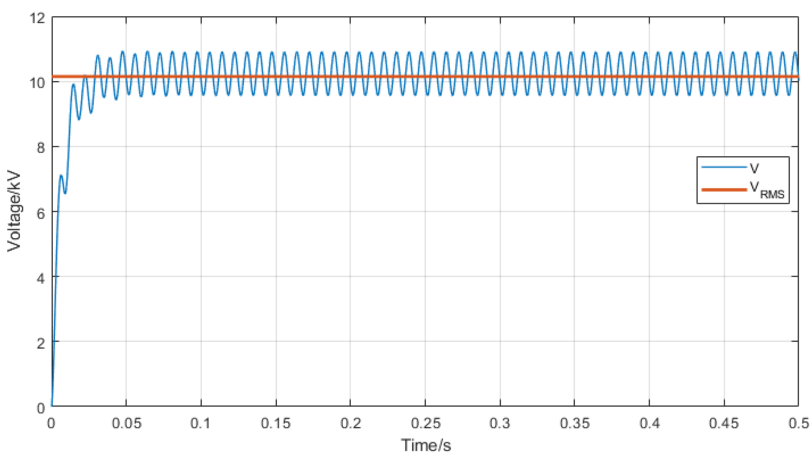

Figure 6: Voltage across load over time and value of $V_{RMS,r}$ for the time period.

2.2.2 Power factor

The power factor can be calculated using the following equation:

$$PF = \cos\phi \tag{3}$$

Using MATLAB, the converged value of the power factor was found by averaging the final values in the dataset.

$$PF_r = 0.995 \tag{4}$$

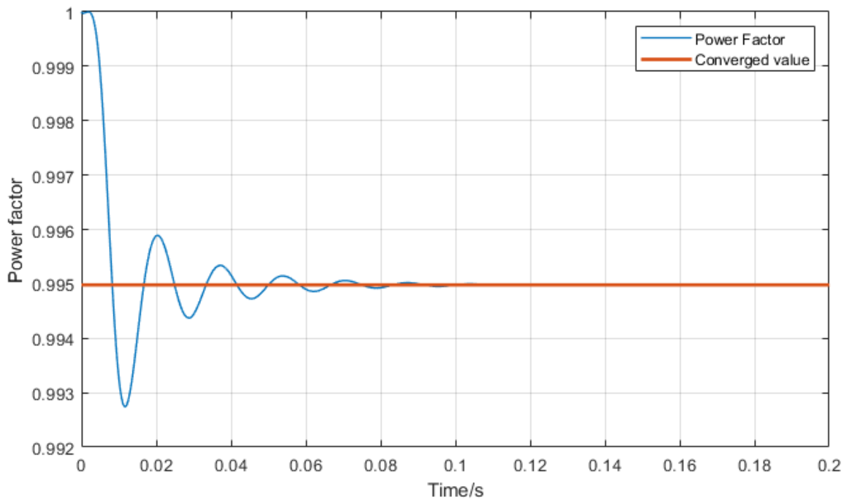

Figure 7: Power factor over time (resistor).

2.3 Inductive load

2.3.1 RMS Voltage

Using MATLAB, the RMS voltage over the time period is:

$$V_{RMS,i} = 2.79\,\text{kV} \tag{5}$$

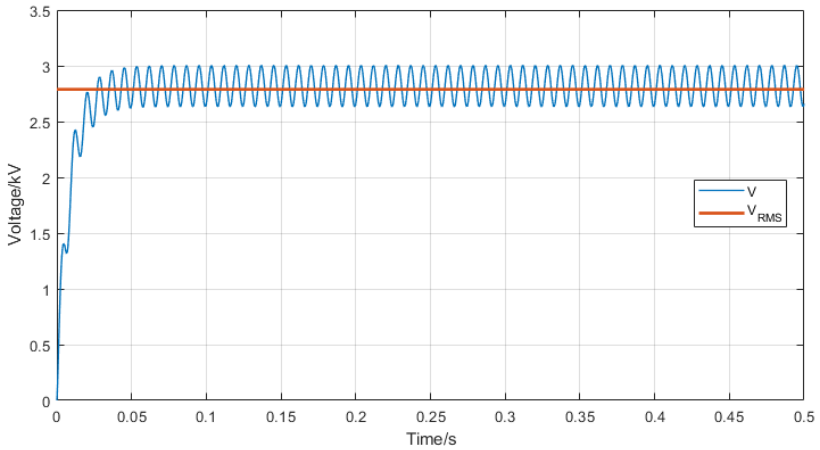

Figure 8: Voltage across load over time and value of $V_{RMS,i}$ for the time period.

2.3.2 Power factor

Using MATLAB:

$$PF_i = 0.563 \tag{6}$$

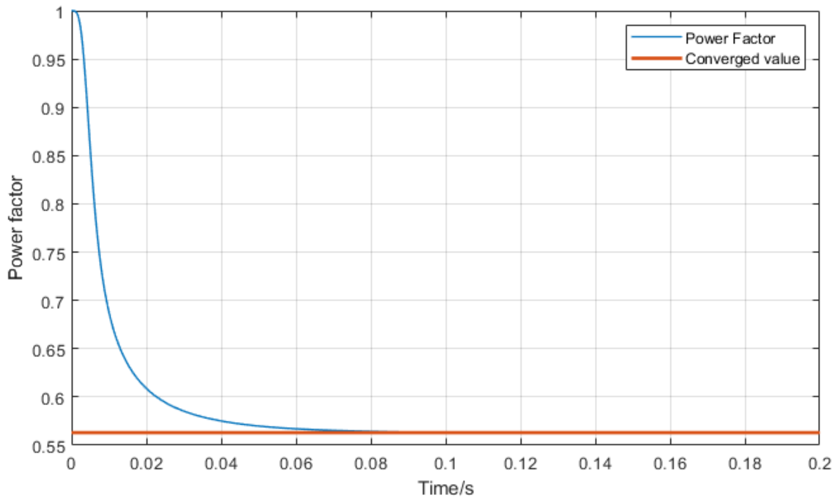

Figure 9: Power factor over time (inductor).

2.4 Capacitive load

2.4.1 RMS Voltage

Using MATLAB, the RMS voltage over the time period is:

$$V_{RMS,c} = 0.262\,\text{kV} \tag{7}$$

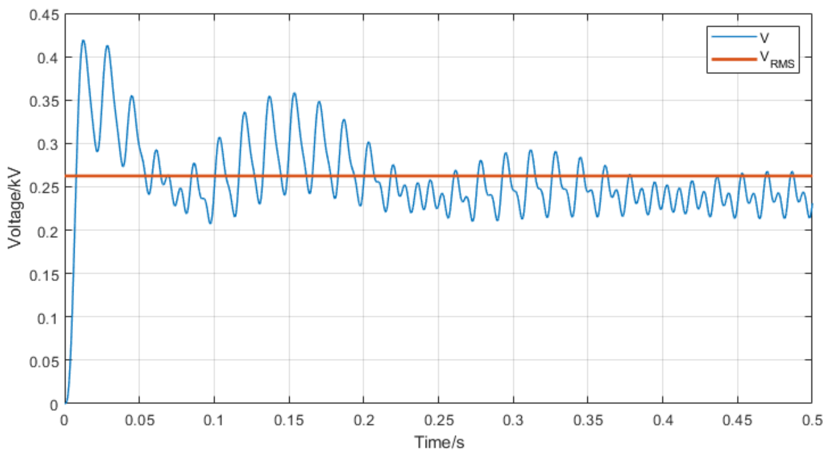

Figure 10: Voltage across load over time and value of $V_{RMS,c}$ for the time period.

2.4.2 Power factor

Using MATLAB:

$$PF_c = -0.328 \tag{8}$$

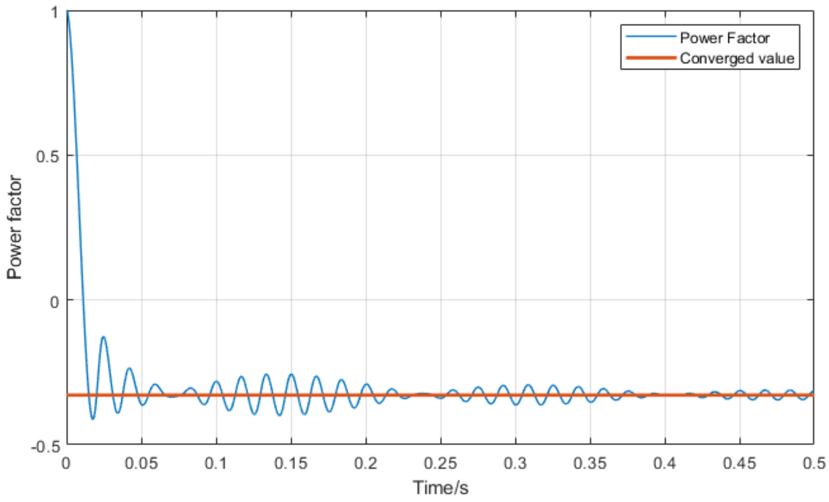

Figure 11: Power factor over time (capacitor).

3 Faulted 3-phase network (1)

3.1 Circuit diagram

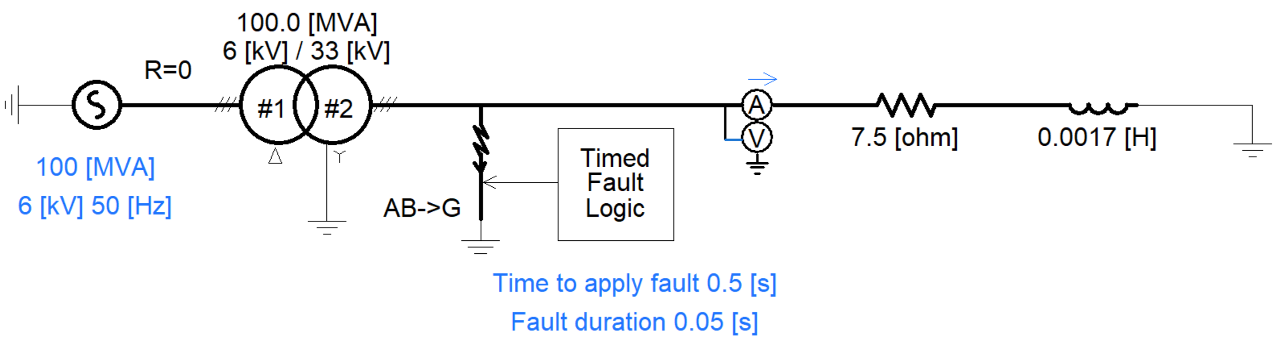

Figure 12: Circuit diagram to show distribution network.

3.2 Voltage and current waveforms

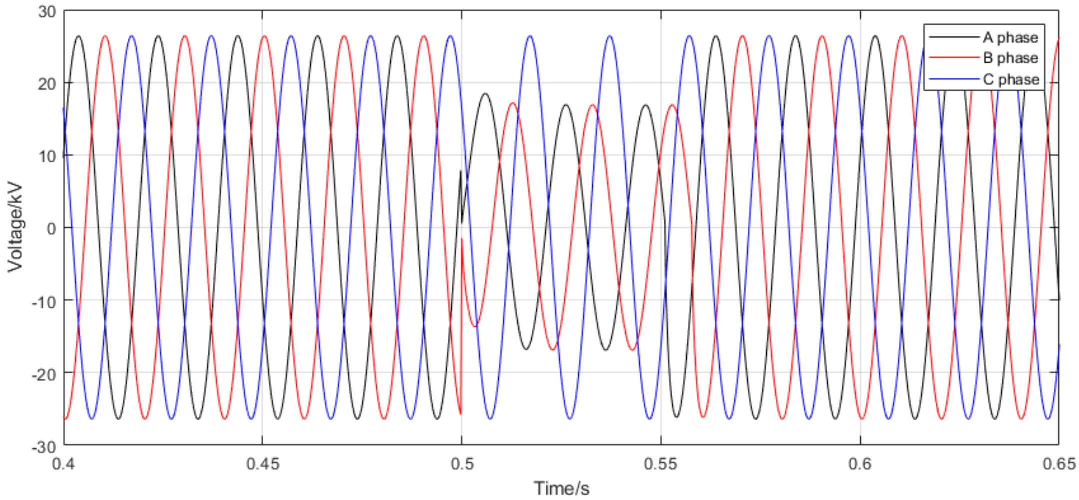

Figure 13: Faulted phase voltages over time from 0.4 s to 0.65 s.

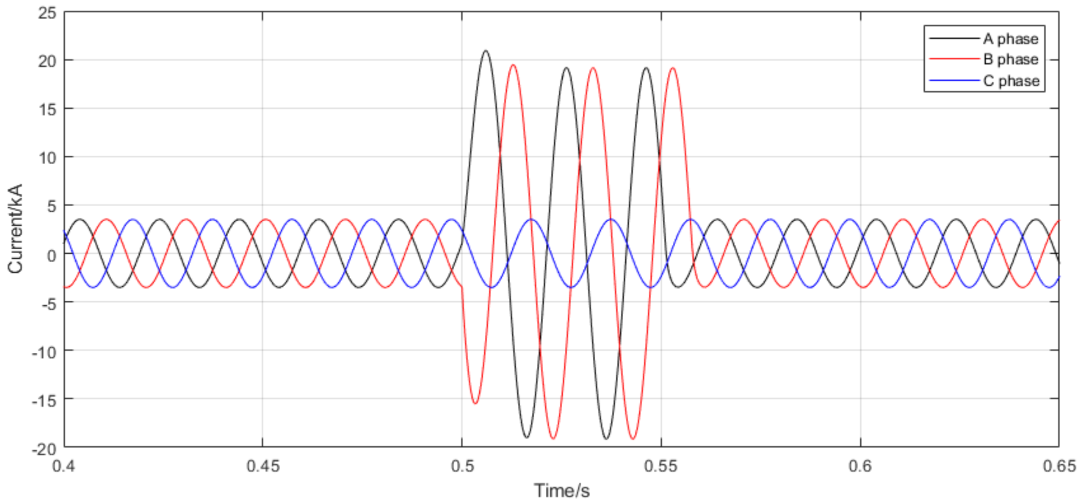

Figure 14: Faulted phase currents over time from 0.4 s to 0.65 s.

3.3 Discussion

From Figure 13, a collapse in the voltages of the faulted phases (A and B) is observed. There is no significant effect on the voltage of phase C. Phase angle is disrupted; phase A and C are 180° out of phase with respect to one another during the fault, whilst phase B is 120° out of phase with respect to phase A.

From Figure 14, the faulted phases see a considerable increase in current magnitude due to the sudden increase in ground current flow. However, all phases remain at 120° phase angle with respect to the other phases. Unfaulted phase remains unaffected.

4 Faulted 3-phase network (2)

4.1 Type of fault

From the waveforms presented in the assignment sheet, we see that as the fault occurs, the phase A and B voltages collapse, whilst the phase C voltage remains unaffected. The phase angle of A and B becomes the same and is 180° out of phase with respect to C. In terms of the current, we see that there is a significant increase in current magnitude in phase A and B. They are also 180° out of phase with each other. The unfaulted phase remains as is. We also see that there is no significant ground current in the faulted phases.

In terms of the standard fault sequence connections, the above can be summarised as:

$$V_a = V_b \tag{9}$$

$$\therefore V_1 = V_2 \tag{10}$$

$$I_a = -I_b \tag{11}$$

$$I_c \ll I_a \tag{12}$$

$$I_0 = 0 \tag{13}$$

$$\therefore I_c = I_1 + I_2 \tag{14}$$

where subscript a, b, c represents phase and subscript 1, 2, 0 represents positive, negative and zero sequence. Hence, the analysis is indicative of a line-to-line fault, occurring on phases A and B.

4.2 Breaker circuit

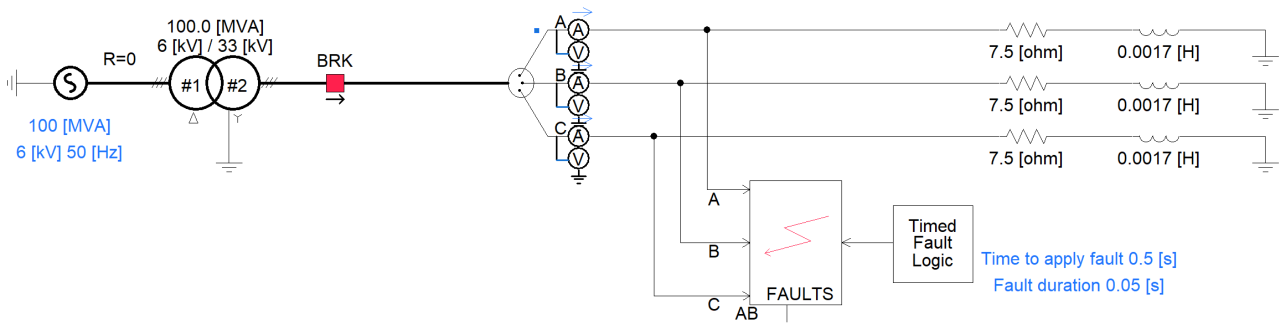

Figure 15: Circuit diagram to show distribution network with circuit breaker.

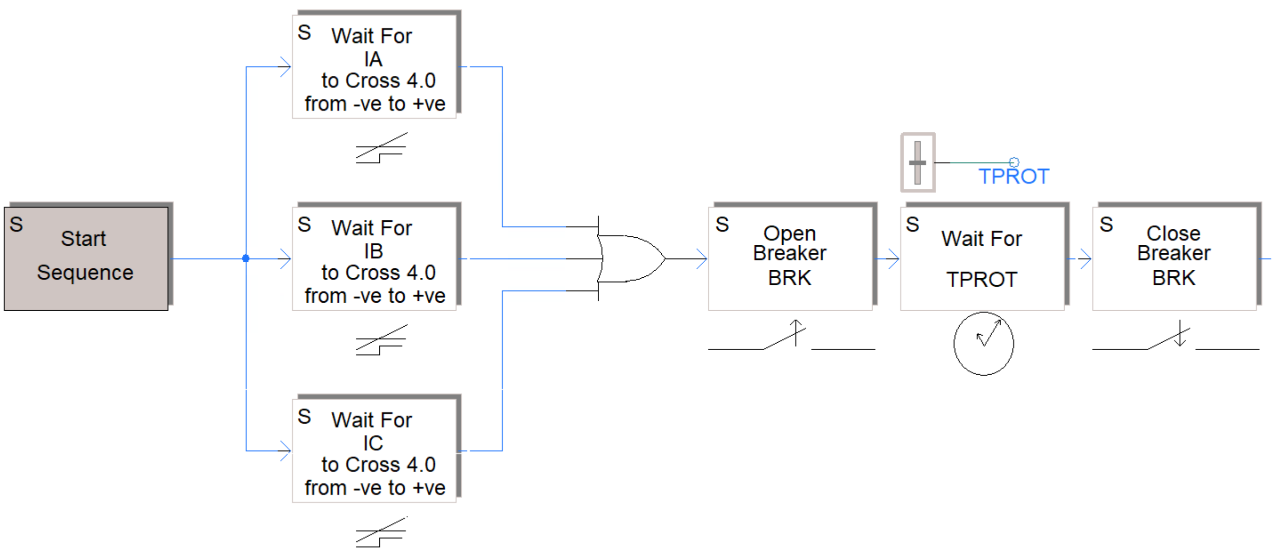

Figure 16: Sequencer diagram to show breaker activation logic.

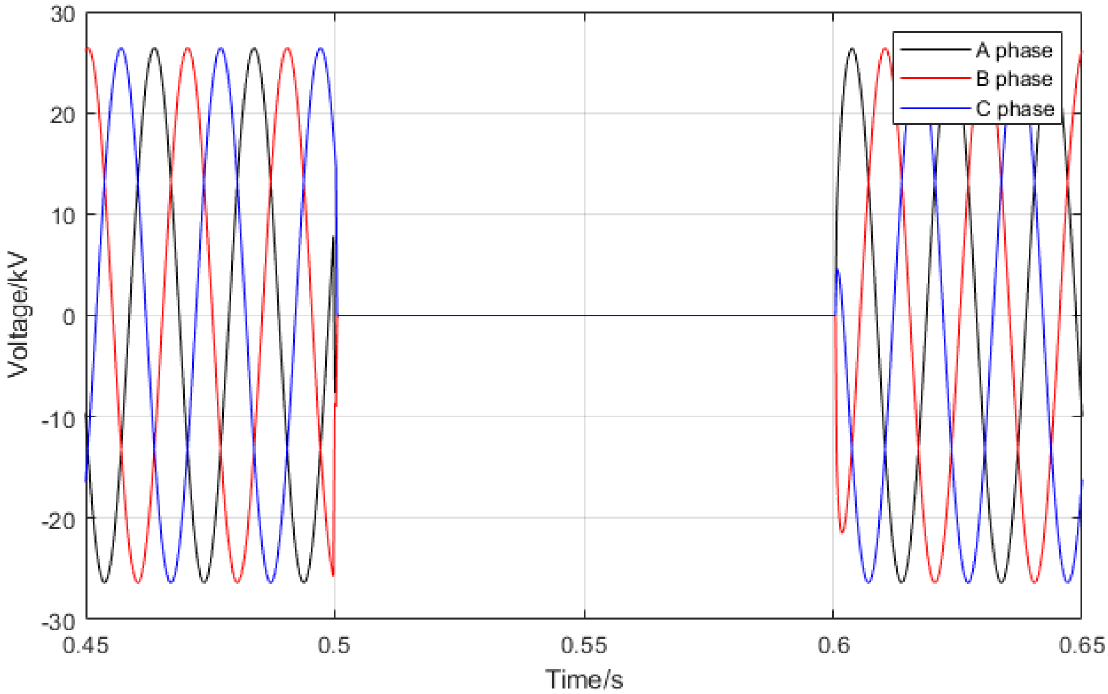

Figure 17: Faulted phase voltages over time from 0.45 s to 0.65 s with breaker circuit.

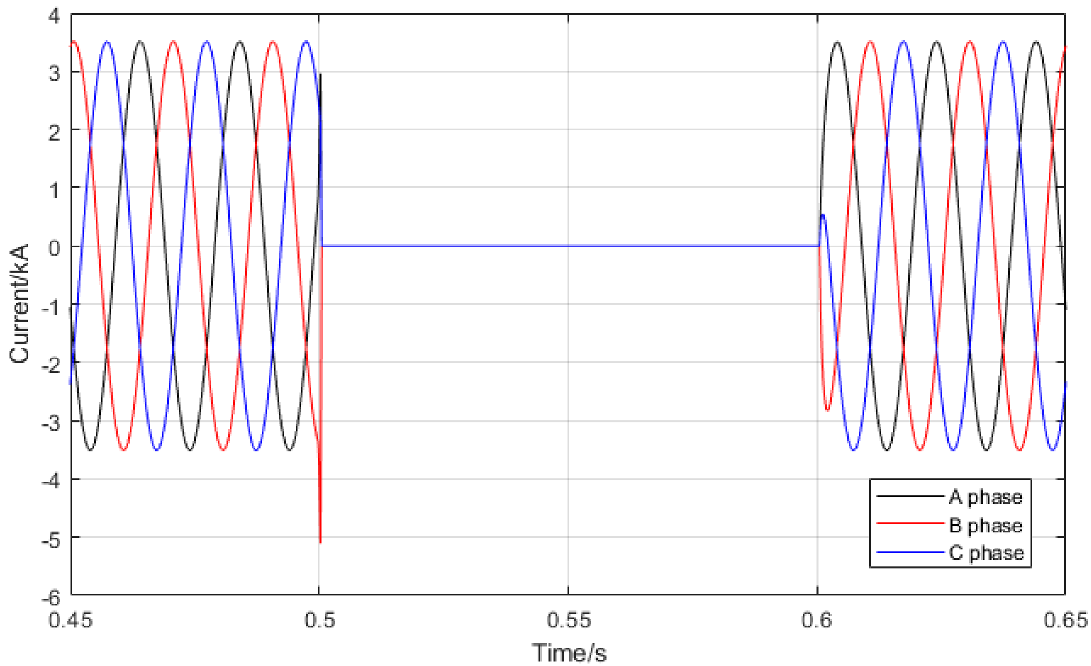

Figure 18: Faulted phase currents over time from 0.45 s to 0.65 s with breaker circuit.

Using sequencer blocks within PSCAD, an approach where the breaker is tripped by measuring the fault current was chosen. A START SEQUENCE block is first, which then leads to three current measurement blocks. These operate on boolean principles, taking an initial value of 0 and flipping to a 1 when the programmed event occurs. In this case, the trip event is if the phase current exceeds the fault current. Note that in this design, the fault current can be changed to any value dependent on system requirements. A value of 4 kA was chosen for testing purposes. The outputs of these blocks is inputted into an OR gate. A positive ('1') output from the OR gate triggers an `Open Breaker` block. The purpose of the OR gate is to activate the breaker in the case that any 1 phase displays fault current behaviour.

The function of `TPROT` is to simulate a manual delay of the breaker reactivation. In reality, fixing faults and reactivation of the circuit is a complex process. However, for the purposes of this simulation, a user can choose how long they would like their breaker to be open. Figure 18 shows that the sequencer successfully trips the breaker when there is fault current (`TPROT` = 1 s).

MATLAB code may be viewed in Appendix A.4

5 Faulted 3-phase network (3)

Selecting Base values from generator specification

$$\text{Base\_S} = 12.5\,\text{MVA} \tag{15}$$
$$\text{Base\_V} = 13.3\,\text{kV} \tag{16}$$
$$\text{Base\_I} = \frac{12.6 \times 10^6}{\sqrt{3} \times 13.3 \times 10^3} = 542.6\,\text{A} \tag{17}$$
$$\text{Base\_Z} = \frac{13.3 \times 10^3}{542.6} = 24.512\,\Omega \tag{18}$$

Per unit values:

$$12.5\,\text{MVA} = 1\,\text{pu, S} \tag{19}$$
$$13.3\,\text{kV} = 1\,\text{pu, V} \tag{20}$$
$$542.6\,\text{A} = 1\,\text{pu, A} \tag{21}$$
$$24.512\,\Omega = 1\,\text{pu, Z} \tag{22}$$

Per unit conversions. For the motor:

$$\frac{10}{12.5} = 0.8\,\text{pu, S} \tag{23}$$
$$\frac{3.3}{13.3} = 0.248\,\text{pu, V} \tag{24}$$
$$0.28 \cdot \frac{12.5}{10} = 0.35\,\text{pu, reactance} \tag{25}$$

For the transformer:

$$\frac{0.75}{12.5} = 0.06\,\text{pu, S} \tag{26}$$
$$0.021 \cdot \frac{12.5}{0.75} = 0.35\,\text{pu, resistance} \tag{27}$$
$$0.013 \cdot \frac{12.5}{0.75} = 0.2167\,\text{pu, reactance} \tag{28}$$

For Line 1:

$$\frac{0.2}{24.512} = 0.0137\,\text{pu, resistance} \tag{29}$$
$$\frac{0.45}{24.512} = 0.031\,\text{pu, reactance} \tag{30}$$

For Line 2:

$$\frac{1.2}{24.512} = 0.0827\,\text{pu, resistance} \tag{31}$$
$$\frac{2.2}{24.512} = 0.1516\,\text{pu, reactance} \tag{32}$$

At location A, we can write out the impedance values.

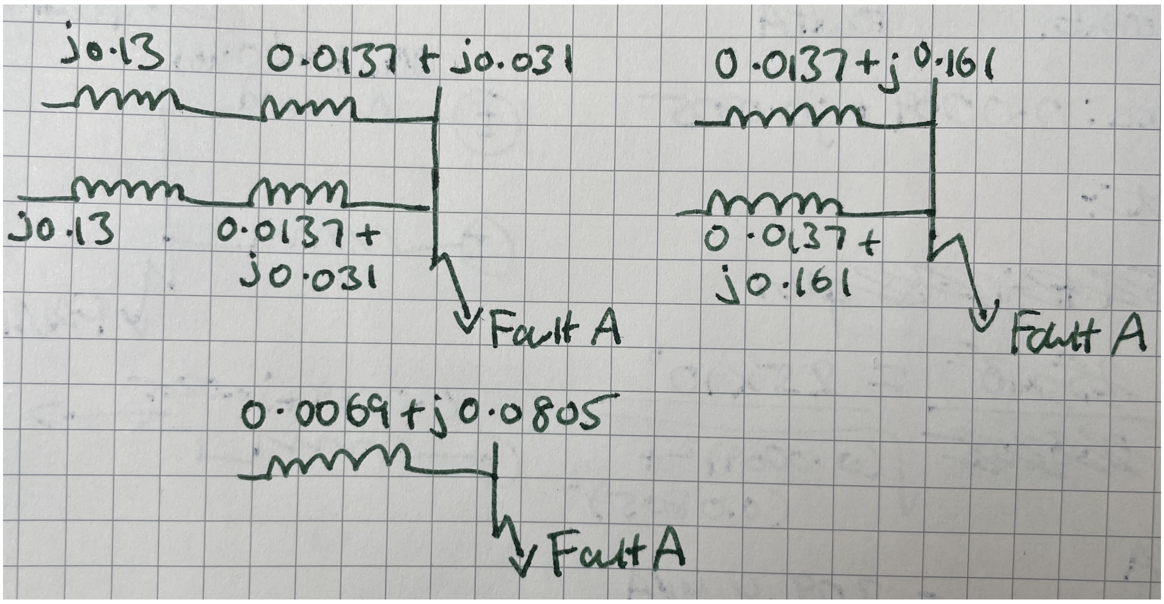

Figure 19: Impedance values for fault A.

$$\text{MVA Fault level} = \frac{25}{\sqrt{0.0069^2 + 0.0805^2}} = 309.4\,\text{MVA} \tag{33}$$

$$\text{Fault current} = \frac{0.5426}{\sqrt{0.0069^2 + 0.0805^2}} = 6.715\,\text{kA} \tag{34}$$

At location B, we can write out the impedance values.

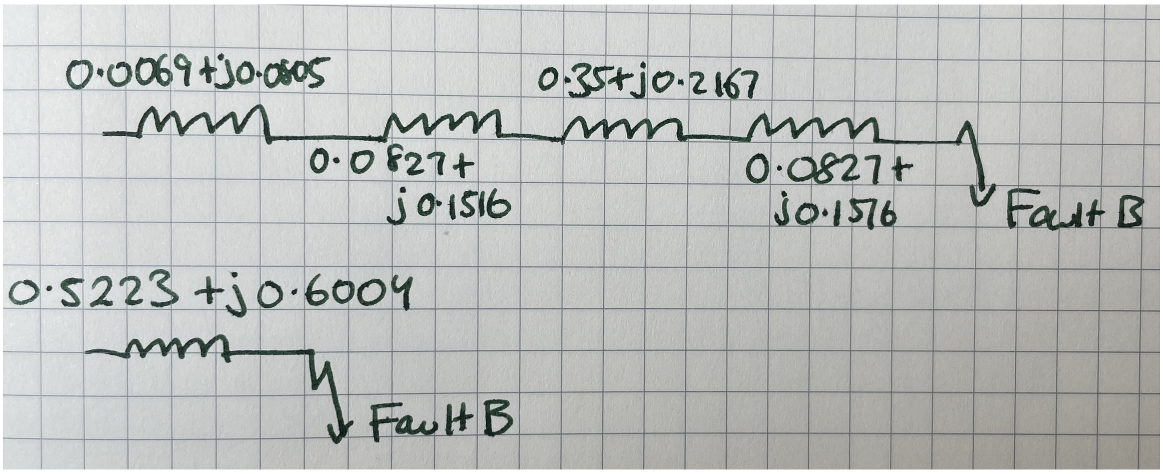

Figure 20: Impedance values for fault B.

$$\text{MVA Fault level} = \frac{25}{\sqrt{0.5223^2 + 0.06004^2}} = 31.3\,\text{MVA} \tag{35}$$

$$\text{Fault current} = \frac{542.6}{\sqrt{0.5223^2 + 0.6004^2}} = 682\,\text{A} \tag{36}$$

A MATLAB code

A.1 Question 1

```
%HD
clc
clear

%import data
data = readmatrix('dataimport.xlsx','Sheet','q1');

%datasets
VSource = cat(2,data(:,5),data(:,6));
VResistor = cat(2,data(:,7),data(:,8));
VResistor2 = cat(2,data(:,9),data(:,10));

%graph plots
%plot(VResistor2(:,1),VResistor2(:,2),'LineWidth',1,'color',[0.4940 0.1840
    0.5560])
plot(VResistor(1:40,1),VResistor(1:40,2),VResistor2(1:40,1),VResistor2(1:40,2))
grid on
axis 'auto xy'
xlim([0,0.01])
ylim([0,150])
xlabel('Time/s')
ylabel('Voltage/V')
legend('5 {\mu}F','25 {\mu}F')

%'color',[0.4940 0.1840 0.5560]
```

A.2 Question 2

```
%HD
clc
clear

%import data
data = readmatrix('dataImport.xlsx','Sheet','table2');
data2 = readmatrix('dataImport.xlsx','Sheet','table2.2');

%datasets
VResistor = cat(2,data(:,1),data(:,2));
PhaseResistor = cat(2,data(:,3),data(:,4));
VInductor = cat(2,data2(:,1),data2(:,2));
PhaseInductor = cat(2,data2(:,3),data2(:,4));
VCapacitor = cat(2,data2(:,5),data2(:,6));
PhaseCapacitor = cat(2,data2(:,7),data2(:,8));

%VRMS
VSq1 = VResistor(:,2).^2;
VRMSResistor = sqrt(sum(VSq1)/numel(VSq1));

VSq2 = VInductor(:,2).^2;
VRMSInductor = sqrt(sum(VSq2)/numel(VSq2));

VSq3 = VCapacitor(:,2).^2;
VRMSCapacitor = sqrt(sum(VSq3)/numel(VSq3));

%PF
```

```
averagePFResistor =
    cos(mean(PhaseResistor(0.8*numel(PhaseResistor(:,1)):end,2)));
PFResistor = cos(PhaseResistor(:,2));

averagePFInductor =
    cos(mean(PhaseInductor(0.8*numel(PhaseInductor(:,1)):end,2)));
PFInductor = cos(PhaseInductor(:,2));

averagePFCapacitor =
    cos(mean(PhaseCapacitor(0.8*numel(PhaseCapacitor(:,1)):end,2)));
PFCapacitor = cos(PhaseCapacitor(:,2));

%graph plotting
%{
plot(VCapacitor(:,1),VCapacitor(:,2),...
   VCapacitor(:,1),linspace(VRMSCapacitor,VRMSCapacitor,numel(VCapacitor(:,1))))
grid on
axis 'auto xy'
xlim([0,0.5])
xlabel('Time/s')
ylabel('Voltage/kV')
legend('V','V_{RMS}')
%}

plot(PhaseResistor(:,1),PFResistor,PhaseResistor(:,1),...
   linspace(averagePFResistor,averagePFResistor,numel(PhaseResistor(:,1))))
grid on
axis 'auto xy'
xlim([0,0.2])
xlabel('Time/s')
ylabel('Power factor')
legend('Power Factor','Converged value')
```

A.3 Question 3

```
%HD
clc
clear

%import data
data = readmatrix('data4');

%split data
%line voltages
V_A = cat(2,data(:,1),data(:,2));
V_B = cat(2,data(:,1),data(:,4));
V_C = cat(2,data(:,1),data(:,6));

%line currents
I_A = cat(2,data(:,1),data(:,3));
I_B = cat(2,data(:,1),data(:,5));
I_C = cat(2,data(:,1),data(:,7));

%graph plotting

plot(V_A(:,1),V_A(:,2),'black',...
   V_B(:,1),V_B(:,2),'red',...
   V_C(:,1),V_C(:,2),'blue')
xlim([0.4,0.65])
```

```
grid on
xlabel('Time/s')
ylabel('Voltage/kV')
legend('A phase','B phase','C phase')

%{
plot(I_A(:,1),I_A(:,2),'black',...
   I_B(:,1),I_B(:,2),'red',...
   I_C(:,1),I_C(:,2),'blue')
xlim([0.4,0.65])
grid on
xlabel('Time/s')
ylabel('Current/kA')
legend('A phase','B phase','C phase')
%}
```

A.4 Question 4

```
%HD
clc
clear

%import data
data = readmatrix('data5');

%split data
%line voltages
V_A = cat(2,data(:,1),data(:,2));
V_B = cat(2,data(:,1),data(:,4));
V_C = cat(2,data(:,1),data(:,6));

%line currents
I_A = cat(2,data(:,1),data(:,3));
I_B = cat(2,data(:,1),data(:,5));
I_C = cat(2,data(:,1),data(:,7));

%graph plotting
%{
plot(V_A(:,1),V_A(:,2),'black',...
   V_B(:,1),V_B(:,2),'red',...
   V_C(:,1),V_C(:,2),'blue')
xlim([0.45,0.65])
grid on
xlabel('Time/s')
ylabel('Voltage/kV')
legend('A phase','B phase','C phase')
%}

plot(I_A(:,1),I_A(:,2),'black',...
   I_B(:,1),I_B(:,2),'red',...
   I_C(:,1),I_C(:,2),'blue')
xlim([0.45,0.65])
grid on
xlabel('Time/s')
ylabel('Current/kA')
legend('A phase','B phase','C phase')
```