ECEN 667 HW2 Solutions

Solution 1:

Given:

f = 60 Hz

GMR of phase conductor = 0.0507 ft.

Resistance of phase conductor = 0.0622 ohm/mile

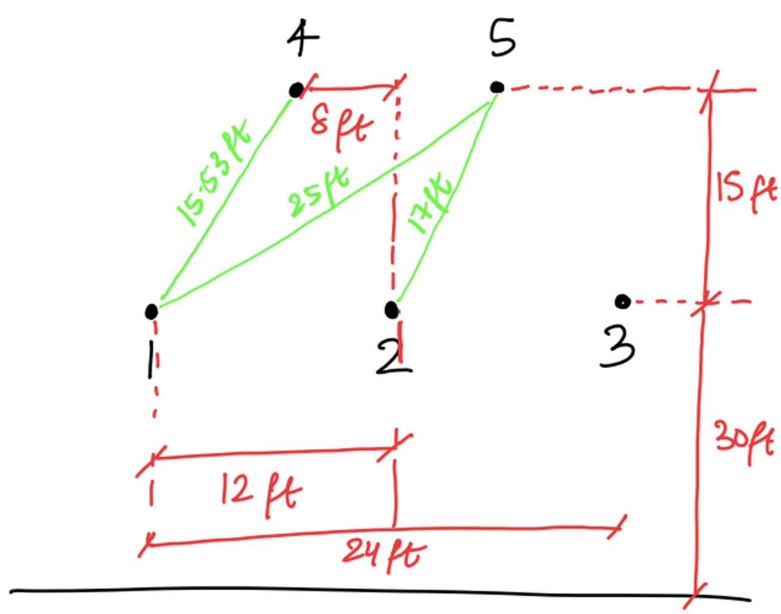
GMR of ground conductor = 0.0217 ft.

Resistance of ground conductor = 0.350 ohm/mile

Ground resistivity = 80 ohm-m

Assumption: Since $D_{kk'}$ is large, so $D_{km'}$ = $D_{kk'}$ for the inductance calculation.

Conductor positions are as indicated below:



Distances between the conductors are listed below:

D_{11} = D_{22} = D_{32} = GMR of phase conductor = 0.0507 ft.

D_{44} = D_{55} = GMR of ground conductor = 0.0217 ft.

D_{12} = 12 ft.	D_{21} = 12 ft.	D_{31} = 24 ft.	D_{41} =15.53 ft.	D_{51} =25 ft.
D_{13} = 24 ft.	D_{23} = 12 ft.	D_{32} = 12 ft.	D_{42} =17 ft.	D_{52} =17 ft.
D_{14} = 15.53 ft.	D_{24} = 17 ft.	D_{34} = 25 ft.	D_{43} =25 ft.	D_{53} =15.53 ft.
D_{15} = 25 ft.	D_{25} = 17 ft.	D_{35} = 15.53 ft.	D_{45} =16 ft.	D_{54} =16 ft.

Remaining calculations and answers are in MATLAB on next page.

```
clc;

clear all;

rho = 80; %resistivity of earth
f = 60; %frequency

rphase = 0.0622; %resistance of phase conductor - from question
rground = 0.350; %resistance of ground conductor - from question

%building the distance matrix from figure indicated on previous page using
%Pythagoras theorem and values given in question

%All the values of D are in ft. !!
D = [0.0507,    12,     24,     15.53,      25;
         12,  0.0507,   12,       17,       17;
         24,    12,   0.0507,     25,    15.53;
      15.53,    17,     25,    0.0217,      16;
         25,    17,    15.53,     16,   0.0217];
%display(D);

%defining all the matrices used in the program
L = zeros(5,5);
R = zeros(5,5);
Z = zeros(5,5);
Za = zeros(3,3);
Zb = zeros(3,2);
Zc = zeros(2,3);
Zd = zeros(2,2);
Zabc = zeros(3,3); %phase imp. matrix
Zs = zeros(3,3); %seq imp. matrix


%calculating Dkk'
Dk = 658.6 * sqrt(rho/f);
%converting to ft
Dk = Dk *  3.2808;

%calculating self and mutual inductance
for i=1:5
    for j=1:5
            L(i,j) = 2*(10^-7)*log(Dk/D(i,j)); %calculating in H/meter
            L(i,j) = L(i,j) / 0.00062137; %converting to H/mile
    end
end

% calculating resistance of the equivalent conductors Rk'
Rk=((9.869*10^-7)*f)/(0.000621); %this value is in ohm/miles

%calculating resistance
for i=1:5
    for j=1:5
        if i==j
            if (i==4||i==5) && (j==4||j==5)
                R(i,j) = Rk + rground; %calculated in ohm/mile
            else
                R(i,j) = Rk + rphase; %calculated in ohm/mile
            end
        else
            R(i,j) = Rk;%calculated in ohm/mile
        end
    end
end

%display(R);

%calculating Z matrix which is simply R + jwL
for i=1:5
    for j=1:5
            Z(i,j) = R(i,j) + 1i*(2*pi*f)*L(i,j);
    end
end

%display(Z);
```

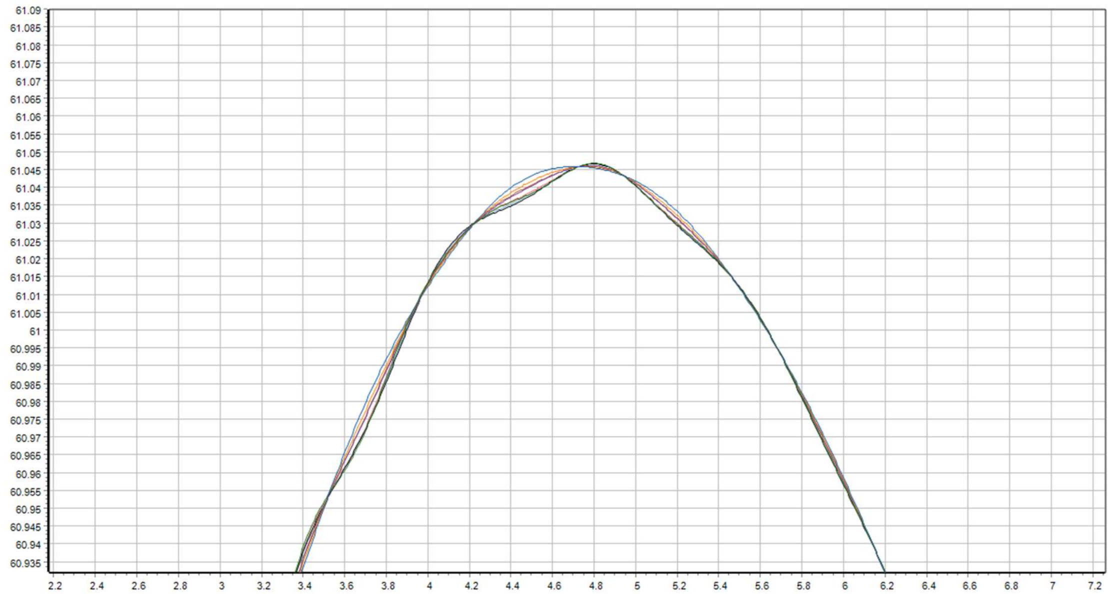
```
%Calculating Za, Zb, Zc and Zd
for i=1:5
    for j=1:5
        if i<=3 && j<=3
            Za(i,j) = Z(i,j); %Zij
        elseif (j==4||j==5) && (i==4||i==5)
            Zd(i-3,j-3) = Z(i,j); %Znn
        elseif i<=3 && (j==4||j==5)
            Zb(i,j-3) = Z(i,j); %Zin
        elseif j<=3 && (i==4||i==5)
            Zc(i-3,j) = Z(i,j); %Znj
        end
    end
end

%calculating phase impedance matrix using Kron reduction
temp = (Zb * inv(Zd)* Zc);
Zabc = Za - temp;

%defining matrix A
a= -0.5 + 1i*(0.5*sqrt(3));
a = [1, 1, 1;
     1, a^2, a;
     1, a, a^2];

 Zs = inv(a) * Zabc * a;

 display(Zs);

 %The units of all impedance matrices displayed is ohm/mile.

 fprintf('The Phase Impedance Matrix in ohm/mile is as below');
 display(Zabc);

 fprintf('Zij is as below');
 display(Za);
 fprintf('Zin is as below');
 display(Zb);
 fprintf('Znj is as below');
 display(Zc);
 fprintf('Znn is as below');
 display(Zd);

 fprintf('The Sequence Impedance Matrix in ohm/mile is as below');
 display(Zs);
```

```
The Phase Impedance Matrix in ohm/mile is as below
Zabc =

   0.1377 + 0.9721i   0.0757 + 0.3004i   0.0740 + 0.2282i
   0.0757 + 0.3004i   0.1390 + 0.9534i   0.0757 + 0.3004i
   0.0740 + 0.2282i   0.0757 + 0.3004i   0.1377 + 0.9721i

Zij is as below
Za =

   0.1576 + 1.3110i   0.0954 + 0.6476i   0.0954 + 0.5635i
   0.0954 + 0.6476i   0.1576 + 1.3110i   0.0954 + 0.6476i
   0.0954 + 0.5635i   0.0954 + 0.6476i   0.1576 + 1.3110i

Zin is as below
Zb =

   0.0954 + 0.6163i   0.0954 + 0.5586i
   0.0954 + 0.6054i   0.0954 + 0.6054i
   0.0954 + 0.5586i   0.0954 + 0.6163i

Znj is as below
Zc =

   0.0954 + 0.6163i   0.0954 + 0.6054i   0.0954 + 0.5586i
   0.0954 + 0.5586i   0.0954 + 0.6054i   0.0954 + 0.6163i
```

```
Znn is as below
Zd =

   0.4454 + 1.4139i   0.0954 + 0.6127i
   0.0954 + 0.6127i   0.4454 + 1.4139i

The Sequence Impedance Matrix in ohm/mile is as below
Zs =

   0.2884 + 1.5186i   0.0149 - 0.0098i  -0.0160 - 0.0080i
  -0.0160 - 0.0080i   0.0630 + 0.6895i  -0.0468 + 0.0278i
   0.0149 - 0.0098i   0.0475 + 0.0266i   0.0630 + 0.6895i
```

Solution 3:

Upon opening load on Bus 6 at 1.0 seconds it is observed that over the course of the 20 second simulation **the highest bus frequency is 61.047 Hz** (observed at bus 3) at time 4.8 second. This is indicated in graph shown below:



Frequency vs Simulation Time plot

The final bus frequency at 20 second is 60.296 Hz. This can be seen in the Results from RAM tab in the transient stability dialog box.

Solution 4:

Part a:

Fault created on bus 31 on line 28 and 31, as indicated in snapshot from Power World below:

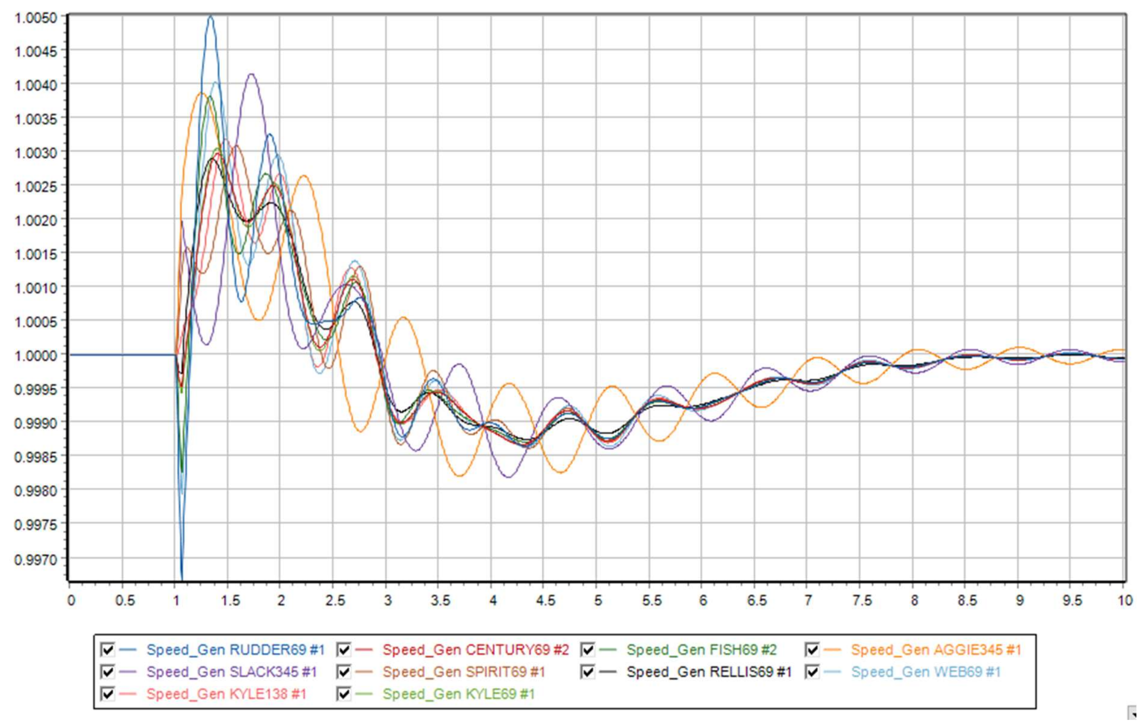
SCont	WhoAmI:2	TimeInCycle	Time (1)	Object (2)	Action (3)
1	Line SLACK345 TO AGGIE345 CKT 1	60.0	1.000000	Branch '31' '28' '1'	FAULT 0 3PB SOLID
2	Line SLACK345 TO AGGIE345 CKT 1	63.2	1.053000	Branch '31' '28' '1'	OPEN BOTH

Generator speed here is the electrical speed. Since system frequency under stable conditions is 60Hz, the value of 60.3Hz in per unit will be 1.005pu.

As generator speed should not exceed 60.3Hz, the speed in per unit value should not exceed 1.005pu.

When the fault is applied at 1.0s and is cleared at 1.053s (as indicated in above figure), it is observed that the maximum speed is limited within 1.005pu. If fault duration is increased, the speed exceeds 1.005pu. The maximum speed is observed for RUDDER69 generator.

Duration: 0.053 s



Generator electrical speed vs Time

<u>Solution 4:</u>

<u>Part b:</u>

Fault created on bus 31 on line 28 and 31, as indicated in snapshot from Power World below:

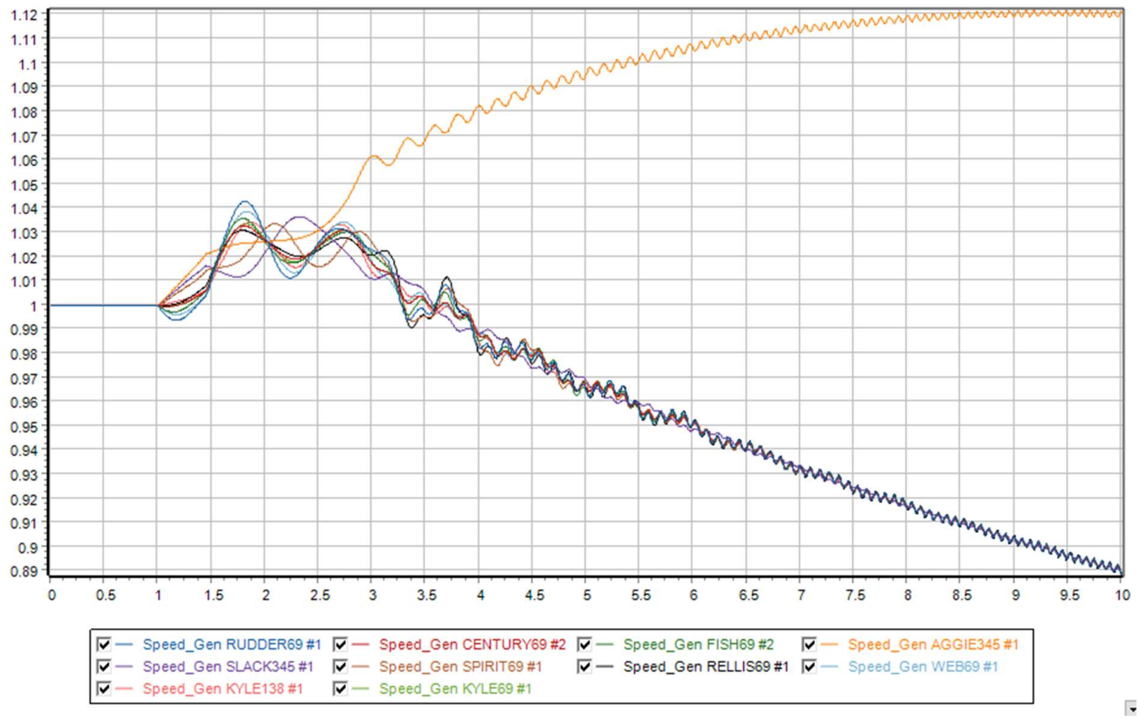
Cont	WhoAmI:2	TimeInCycle	Time (1)	Object (2)	Action (3)	C
1	Line SLACK345 TO AGGIE345 CKT 1	60.0	1.000000	Branch '31' '28' '1'	FAULT 0 3PB SOLID	C
2	Line SLACK345 TO AGGIE345 CKT 1	78.0	1.300000	Branch '31' '28' '1'	OPEN BOTH	C

The generator rotor angles under above condition have still not lost synchronism and settle to new values at around 10seconds.

Instead, when fault is cleared at 1.4499s, the generators lose synchronism. Refer below simulation conditions and graph:

Cont	WhoAmI:2	TimeInCycle	Time (1)	Object (2)	Action (3)
1	Line SLACK345 TO AGGIE345 CKT 1	60.0	1.000000	Branch '31' '28' '1'	FAULT 0 3PB SOLID
2	Line SLACK345 TO AGGIE345 CKT 1	87.0	1.449900	Branch '31' '28' '1'	OPEN BOTH

Duration: 0.4499s



<u>Solution 5:</u>

<u>Part a:</u>

This part is repeated for solution 4, with fault created in the middle of the line from bus 28 to bus 31.

In this case when the fault is applied at 1.0s and is cleared at 1.072s (as indicated in above figure), it is observed that the maximum speed is limited within 1.005pu. If fault duration is increased, the speed exceeds 1.005pu. The maximum speed is observed for RUDDER69 generator.

Since the fault is in the middle of the line, the impedance observed by the fault has increased and thus, the duration of fault to sustain speed within 1.005pu has increased to 1.072s instead of 1.053s as observed in previous case.

Duration: 0.072s

<u>Part b:</u>

When fault is cleared at 1.322482s, the generators lose synchronism. Refer below simulation conditions and graph:

	Object Pretty	Time (Cycles)	Time (Seconds)	Object	Description
1	Line AGGIE345 FROM SLACK345 CKT 1	60.0	1.000000	Branch '28' '31' '1'	FAULT 50 3PB SOLID
2	Line AGGIE345 FROM SLACK345 CKT 1	79.3	1.322482	Branch '28' '31' '1'	OPEN BOTH

Duration: 0.322482s