Mini-project

Write a **MATLAB m-code** to perform the complete fault analysis and thus find the

i. Fault current
ii. During fault voltage
iii. Line flows

for a 3-phase symmetrical fault.

Submitted by,

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Initial Calculations:

Consider an N bus power system, with a 3-phase symmetrical fault occurring at bus 'k'

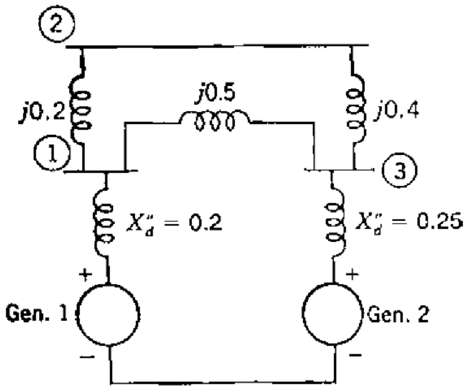

Figure 1

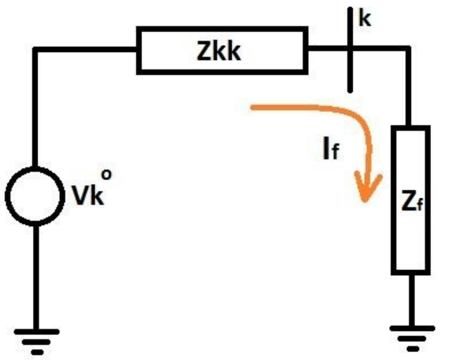

Figure 2

Thevenin equivalent of the system looking into it from the kth bus would be as shown in Figure 2. The fault current I_f at the kth bus can be found from this equation:

$$I_f = \frac{{V_k}^0}{Z_{kk} + Z_f}$$

Now, compute the difference matrix, by multiplying the Z_{bus} matrix with the injected fault current matrix as shown by this equation:

$$\begin{bmatrix} \Delta V_1 \\ \Delta V_2 \\ \vdots \\ \Delta V_k \\ \vdots \\ \Delta V_N \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} & \cdots & Z_{1k} & \cdots & Z_{1N} \\ Z_{21} & Z_{22} & \cdots & Z_{2k} & \cdots & Z_{2N} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ Z_{k1} & Z_{k2} & \cdots & Z_{kk} & \cdots & Z_{kN} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ Z_{N1} & Z_{N2} & \cdots & Z_{Nk} & \cdots & Z_{NN} \end{bmatrix} \times \begin{bmatrix} 0 \\ 0 \\ \vdots \\ -I_f \\ \vdots \\ 0 \end{bmatrix}$$

Thus the during-fault voltages at the kth bus can be found as:

$${V_k}^f = {V_k}^0 + \Delta V_k$$

$${V_k}^f = {V_k}^0 - Z_{kk} I_f$$

Line flows:

$${I_{mn}}^f = \frac{{V_m}^f - {V_n}^f}{z_{mn}}$$

➔ z_{mn} being the physical impedance connected between bus 'm' and 'n'

Flowchart:

Y_{bus}
- Accept the physical impedances between buses of the power system network from the user
- Formulate the Y_{bus} matrix from the physical admittances

Z_{bus}
- Invert the Y_{bus} matrix to obtain the Z_{bus} matrix of the given network

Type of Fault
- Accept from the user, the bus at which the 3-phase fault is to be simulated
- Also ask if it is a bolted fault or a fault through an impedance

I_f
- Compute the fault current at the bus with the 3-phase fault
- Assume the pre-fault voltages at all buses are 1 p.u.

V_f
- Compute the difference matrix, by multiplying the Z_{bus} with the injected fault current matrix
- Add the pre-fault voltages to the difference matrix to get the during-fault voltages

Line flows
- From the knowledge of during-fault voltages at the buses and the physical impedances between them, the line flows can be calculated

M-code:

```
% ---------------------------------------------------------%
% Power System Simulation Laboratory  --  Mini-project %
% ---------------------------------------------------------%
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% ---------------------------------------------------------%

clc;
clear all;
close all;

fprintf('3-phase symmetrical fault analysis\n\n');

N = input('Enter the number of buses in the existing power system (excluding
reference bus): ');

fprintf('\nAssume\n1. Reference bus is denoted by "0"\n2. If there is no impedance
between two buses, enter NaN\n\n');

% Formulation of Zbus, by forming Ybus followed by inversion
disp('Enter the physical impedances between buses:');
for m = 1:1:N
    % Case 1: Impedance between two buses
    for n = m+1:1:N
        % These are the physical impedances between buses, and not the Zbus
        % elements
        z(m,n) = input(sprintf('Enter the z(%d,%d) (e.g. 2j): ',m,n));
        % Check if two buses are not at all connected (infinite impedance)
        % i.e. NaN - Not a Number
        if isnan(z(m,n))
            % If yes, then the admittance would be zero
            y(m,n) = 0;
        else
            y(m,n) = 1/z(m,n);
        end
        y(n,m)=y(m,n);
    end

    % Case 2: Impedance between a bus and the reference bus
    z(m,m) = input(sprintf('Enter the z(%d,0) (e.g. 2j): ',m));
    if isnan(z(m,m))
            y(m,m) = 0;
        else
            y(m,m) = 1/z(m,m);
    end
end

rowsum = sum(y,2);
for m = 1:1:N
    for n = 1:1:N
        if m == n
            % Diagonal elements of Ybus (Ymm) = sum of all admittances connected
            % to the mth bus
            Y(m,n) = rowsum(m);
        else
            % Off diagonal elements of Ybus (Ymn) = negative of the admittance
            % connected between m and n
            Y(m,n) = -y(m,n);
        end
    end
end
```

```
Z = inv(Y);

fprintf('\nThe Zbus of the given power system is:\n');
disp(Z);

% Finding which buses are generator buses and which are load buses
for m = 1:1:N
    g(m) = input(sprintf('\nFor bus %d:\n 1 -> Generator bus\n 2 -> Load
bus\nChoose: ',m));
end

while 1
k = input(sprintf('\nEnter the bus index at which a 3-phase fault is to be
simulated: '));
if k >=1 && k <= N
    break
else
    fprintf('\nError!! Please enter a value between 1 and %d!\n',N);
end
end

Zf = input(sprintf('\nEnter the fault impedance (zero in case of bolted fault):
'));

V = ones(N,1);          % Pre-fault voltages are assumed to be 1 p.u.
I = zeros(N,1);

I_f = 1/(Z(k,k)+Zf);    % Fault current at bus 'k'
fprintf('\nPer-unit fault current out of bus %d:\n',k);
disp(I_f);
I(k,1) = -I_f;
del_V = Z*I;            % Difference in voltage vector
Vf = V + del_V;         % During-fault voltage vector at buses

fprintf('During-fault voltages (p.u.):\n');
for m = 1:1:N
    fprintf('Vf_%d = ',m);
    disp(Vf(m));
end

fprintf('During-fault currents (p.u.):\n');
for m = 1:1:N
    for n = m+1:1:N
        if isnan(z(m,n))
        If(m,n) = 0;
        else
        If(m,n) = (Vf(m,1)-Vf(n,1))/z(m,n);
        end
        fprintf('If_%d%d = ',m,n);
        disp(If(m,n));
    end
end
% Fault current from generator terminals
for m = 1:1:N
    if g(m) == 1
        If(m,m) = (1-Vf(m,1))/z(m,m);
        fprintf('If_g%d = ',m);
        disp(If(m,m));
    end
end
```

Terminal Display:

```
3-phase symmetrical fault analysis

Enter the number of buses in the existing power system (excluding reference bus): 3

Assume
1. Reference bus is denoted by "0"
2. If there is no impedance between two buses, enter NaN

Enter the physical impedances between buses:
Enter the z(1,2) (e.g. 2j): 0.2j
Enter the z(1,3) (e.g. 2j): 0.5j
Enter the z(1,0) (e.g. 2j): 0.2j
Enter the z(2,3) (e.g. 2j): 0.4j
Enter the z(2,0) (e.g. 2j): NaN
Enter the z(3,0) (e.g. 2j): 0.25j

The Zbus of the given power system is:
        0 + 0.1447i        0 + 0.1195i        0 + 0.0692i
        0 + 0.1195i        0 + 0.2465i        0 + 0.1006i
        0 + 0.0692i        0 + 0.1006i        0 + 0.1635i

For bus 1:
 1 -> Generator bus
 2 -> Load bus
Choose: 1

For bus 2:
 1 -> Generator bus
 2 -> Load bus
Choose: 2

For bus 3:
 1 -> Generator bus
 2 -> Load bus
Choose: 1

Enter the bus index at which a 3-phase fault is to be simulated: 4
Error!! Please enter a value between 1 and 3!
Enter the bus index at which a 3-phase fault is to be simulated: 2
Enter the fault impedance (zero in case of bolted fault): 0

Per-unit fault current out of bus 2:
        0 - 4.0561i

During-fault voltages (p.u.):
Vf_1 =     0.5153
Vf_2 =      0
Vf_3 =     0.5918

During-fault currents (p.u.):
If_12 =        0 - 2.5765i
If_13 =        0 + 0.1531i
If_23 =        0 + 1.4796i
If_g1 =        0 - 2.4235i
If_g3 =        0 - 1.6327i
```

Results and Discussion:

i. The equations required to perform the 3-phase symmetrical fault analysis are derived for an N-bus system, to support any generic system
ii. The N-bus system is treated as an N-port network and hence its Thevenin circuit is used to obtain the fault current
iii. A MATLAB code is written to simulate the fault at any specified bus, in a given power system network
iv. The fault current and during fault voltages are computed, from which, the line flows are calculated and displayed
v. By repeatedly simulating the fault analysis at different buses in a network, the rating of the circuit breaker can be determined from the maximum of line current during each of these simulations