Military Institute of Science & Technology

Power System 1 Laboratory

Course code: EECE-306

Project name: Load Flow Analysis of 5-bus power system

Submitted To

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Objectives

1. To determine the voltage magnitude and phase angle at each bus in the power system .
2. To determine load flow analysis calculation for real and reactive power flow through transmission lines and buses.
3. To determine power flows and power losses in transmission lines of a multi-bus system.
4. To create undervoltage event in buses and subsequent techniques to overcome undervoltage.
5. To Implement methods for reducing power flow through transmission lines.

Theoretical Background

Load flow analysis, also referred to as power flow analysis or steady-state power flow analysis, is an essential method employed in electrical power systems to examine the distribution of electrical power and voltage levels across the network. It is a computational technique utilized to determine the stable operating conditions of the power system under normal circumstances.

The primary goal of load flow analysis is to calculate the voltage magnitude and phase angle at each bus, as well as the real and reactive power flow through transmission lines, generators, and loads. This analysis ensures that the power system adheres to various constraints, including power balance, voltage limits, and equipment operating limits. By conducting load flow analysis, engineers can evaluate voltage stability, power losses, and the overall performance of the power system.

Load flow analysis relies on certain assumptions, including steady-state conditions, a balanced three-phase system, and the application of Kirchhoff's laws to model power system behavior. The analysis involves solving a set of nonlinear algebraic equations derived from the power flow equations. Various methods, such as Gauss-Seidel, Newton-Raphson, and Fast Decoupled, are employed to solve these equations iteratively until convergence is achieved.

Input data required for load flow analysis includes system topology, generation data, and load data. The results of load flow analysis provide valuable information about the operating state of the power system, including voltage profiles, power flows, and equipment loading.

Load flow analysis finds practical applications in power system engineering, such as optimizing voltage profiles, compensating for reactive power, planning power system expansions, and identifying necessary network reinforcements.

Load flow analysis has several practical applications in power system engineering, such as:

1. Voltage profile optimization: By analyzing the load flow, engineers can identify voltage drop issues and take corrective measures to maintain acceptable voltage levels throughout the network.
2. Reactive power compensation: Load flow analysis helps in determining the required amount of reactive power compensation devices (such as capacitors and reactors) to regulate voltage levels and minimize power losses.
3. Power system planning: Load flow analysis aids in planning future expansion or modification of power systems by assessing the impact of new generation or load additions.
4. Network reinforcement: Load flow analysis helps identify overloaded components, such as transmission lines or transformers, allowing engineers to determine the necessary reinforcements to maintain system reliability.

Methods

The computations used in load flow analysis may be thought of as defining the steady-state operational parameters of an energy system. In the modern era, we can perform this load flow analysis using a variety of software programs such as PSAT, PSAF, CYME, PSCAD, and others. But we have done the analysis in our study using PowerWorld simulator and verified the results of our analysis with MATLAB.

Data and Results

1. Perform load flow studies of the power system of Fig. 1 to identify slack bus (Bus no. 1) power and bus voltages (Bus no. 2 to Bus no. 3). Compute line flows and line losses also. [Use any simulation software]

Firstly, the network was drawn and the given data were input.

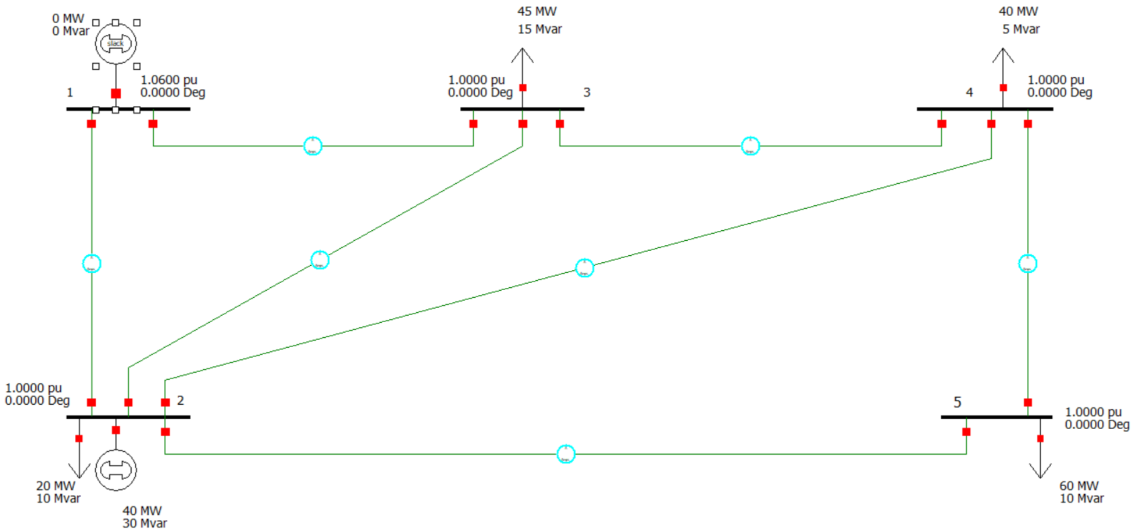

Fig 1: Simulation diagram of power system

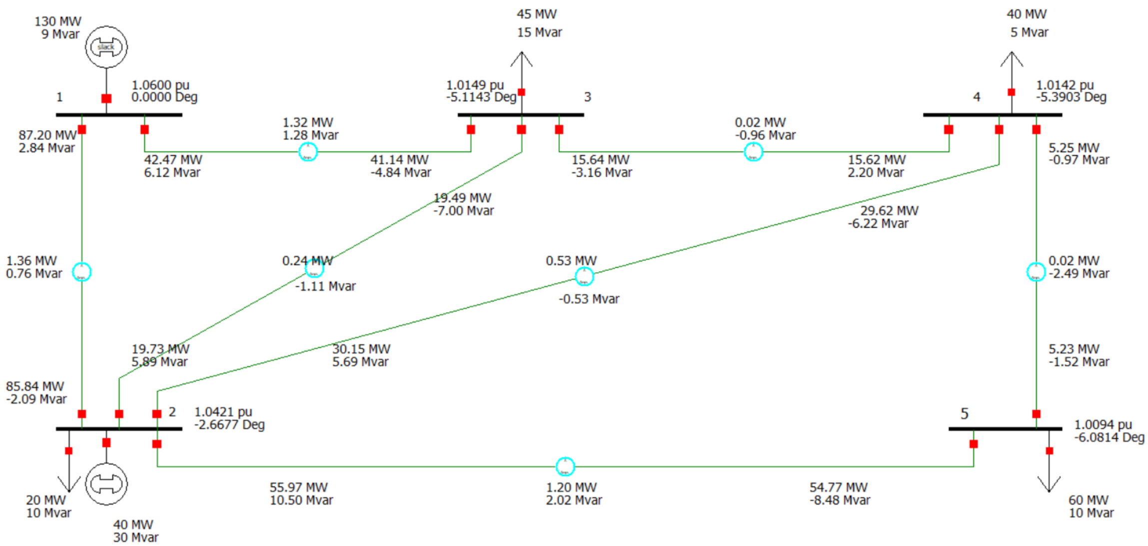

Fig 2: The power system after being run

Table 1: Bus data after running simulation

			Generation		Load	
Bus No.	**Voltage (pu)**	**Phase (deg)**	**P (MW)**	**Q (MVAR)**	**P (MW)**	**Q (MVAR)**
1	1.0600	0.0000	130	9	0	0
2	1.0421	-2.6677	40	30	20	10
3	1.0149	-5.1143	0	0	45	15
4	1.0142	-5.3903	0	0	40	5
5	1.0094	-6.0814	0	0	60	10

The above table shows all the data related to the bus information. The slack bus voltage and phase remains same whereas the other buses changed. The power data of the slack bus is also found.

Table 2: Transmission line data after running simulation

Tx line	Line flow at from bus		Line flow at to bus		Line losses	
	P(MW)	Q(MVAR)	P(MW)	Q(MVAR)	P(MW)	Q(MVAR)
1-2	87.20	2.84	85.64	2.07	1.357	0.757
1-3	42.70	6.12	41.14	4.84	1.325	1.281
2-3	19.73	5.87	19.49	7.00	0.242	-1.108
2-4	30.15	5.69	29.62	6.22	0.528	-0.532
2-5	55.97	10.50	54.77	8.48	1.201	2.024
3-4	15.64	-3.16	15.62	-2.20	0.024	-0.956
4-5	5.25	-0.97	5.23	1.52	0.022	-2.495

The above table shows the power flowing from the bus and to the bus which are connected by the transmission line. The losses are also computed. The total real power loss is P = 4.699 MW and the total reactive power loss is Q = -0.849 MVAR.

2. Verify the results obtained in Task no. 1 by writing a MATLAB code adopting any load flow analysis method.

We used Gauss-Seidel analysis method to compute the load flow data. The MATLAB code is given below:

```
%% This program is for inputting our data
% 202116095 , 202116089 , 202116160
clc
clear all
close all

basemva = 100;  accuracy = 0.0001; maxiter = 100;

%        Bus Bus  Voltage Angle   ---Load---- -------Generator----- Static Mvar
%        No  code Mag.    Degree  MW     Mvar  MW   Mvar  Qmin Qmax    +Qc/-Ql
busdata=[1   1    1.06    0.0     0.0    0.0   0.0   0.0   0    0        0
         2   0    1.0     0.0     20.0   10.0  40.0  30    0    0        0
         3   0    1.0     0.0     45.0   15.0  0.0   0.0   0    0        0
         4   0    1.0     0.0     40.0   5.0   0.0   0.0   0    0        0
         5   0    1.0     0.0     60.0   10.0  0.0   0.0   0    0        0];

%                                           Line code
%         Bus   bus R      X      charge   = 1 for lines
%         from  to  p.u.   p.u.   p.u.     > 1 or < 1 tr. tap at bus nl
linedata=[1     2   0.02   0.06   0.015         1
          1     3   0.08   0.24   0.0125        1
          2     3   0.06   0.25   0.01          1
          2     4   0.06   0.18   0.01          1
          2     5   0.04   0.12   0.0075        1
          3     4   0.01   0.03   0.005         1
          4     5   0.08   0.24   0.0125        1];


%% This program obtains the Bus Admittance Matrix for power flow solution

    j=sqrt(-1); i = sqrt(-1);
    nl = linedata(:,1); nr = linedata(:,2); R = linedata(:,3);
    X = linedata(:,4); Bc = j*linedata(:,5); a = linedata(:, 6);
    nbr=length(linedata(:,1)); nbus = max(max(nl), max(nr));
    Z = R + j*X; y= ones(nbr,1)./Z;        %branch admittance
    for n = 1:nbr
    if a(n) <= 0  a(n) = 1; else end
    Ybus=zeros(nbus,nbus);     % initialize Ybus to zero
                 % formation of the off diagonal elements
    for k=1:nbr;
         Ybus(nl(k),nr(k))=Ybus(nl(k),nr(k))-y(k)/a(k);
        Ybus(nr(k),nl(k))=Ybus(nl(k),nr(k));
    end
    end
              % formation of the diagonal elements
    for  n=1:nbus
        for k=1:nbr
             if nl(k)==n
            Ybus(n,n) = Ybus(n,n)+y(k)/(a(k)^2) + Bc(k);
            elseif nr(k)==n
            Ybus(n,n) = Ybus(n,n)+y(k) +Bc(k);
            else, end
        end
    end
    clear Pgg
```

```matlab
%% Load flow solution by Gauss-Seidel method

Vm=0; delta=0; yload=0; deltad =0;
nbus = length(busdata(:,1));
for k=1:nbus
n=busdata(k,1);
kb(n)=busdata(k,2); Vm(n)=busdata(k,3); delta(n)=busdata(k, 4);
Pd(n)=busdata(k,5); Qd(n)=busdata(k,6); Pg(n)=busdata(k,7); Qg(n) = busdata(k,8);
Qmin(n)=busdata(k, 9); Qmax(n)=busdata(k, 10);
Qsh(n)=busdata(k, 11);
    if Vm(n) <= 0  Vm(n) = 1.0; V(n) = 1 + j*0;
    else delta(n) = pi/180*delta(n);
         V(n) = Vm(n)*(cos(delta(n)) + j*sin(delta(n)));
         P(n)=(Pg(n)-Pd(n))/basemva;
         Q(n)=(Qg(n)-Qd(n)+ Qsh(n))/basemva;
         S(n) = P(n) + j*Q(n);
    end
DV(n)=0;
end
num = 0; AcurBus = 0; converge = 1;
Vc = zeros(nbus,1)+j*zeros(nbus,1); Sc = zeros(nbus,1)+j*zeros(nbus,1);

while exist('accel')~=1
   accel = 1.3;
end
while exist('accuracy')~=1
   accuracy = 0.001;
end
while exist('basemva')~=1
   basemva= 100;
end
while exist('maxiter')~=1
   maxiter = 100;
end
iter=0;
maxerror=10;
while maxerror >= accuracy & iter <= maxiter
iter=iter+1;
  for n = 1:nbus;
  YV = 0+j*0;
    for L = 1:nbr;
            if nl(L) == n, k=nr(L);
            YV = YV + Ybus(n,k)*V(k);
            elseif nr(L) == n, k=nl(L);
            YV = YV + Ybus(n,k)*V(k);
            end
    end
       Sc = conj(V(n))*(Ybus(n,n)*V(n) + YV) ;
       Sc = conj(Sc);
       DP(n) = P(n) - real(Sc);
       DQ(n) = Q(n) - imag(Sc);
         if kb(n) == 1
         S(n) =Sc; P(n) = real(Sc); Q(n) = imag(Sc); DP(n) =0; DQ(n)=0;
         Vc(n) = V(n);
         elseif kb(n) == 2
         Q(n) = imag(Sc); S(n) = P(n) + j*Q(n);

           if Qmax(n) ~= 0
             Qgc = Q(n)*basemva + Qd(n) - Qsh(n);
             if abs(DQ(n)) <= .005 & iter >= 10 % After 10 iterations
               if DV(n) <= 0.045                 % the Mvar of generator buses are
                  if Qgc < Qmin(n),              % tested. If not within limits Vm(n)
                  Vm(n) = Vm(n) + 0.005;         % is changed in steps of 0.005 pu
```

```
                    DV(n) = DV(n)+.005;           % up to .05  pu in order to bring
                    elseif Qgc > Qmax(n),          % the generator Mvar within the
                    Vm(n) = Vm(n) - 0.005;         % specified limits.
                    DV(n)=DV(n)+.005; end
                 else, end
               else,end
             else,end
           end
         if kb(n) ~= 1
         Vc(n) = (conj(S(n))/conj(V(n)) - YV )/ Ybus(n,n);
         else, end
            if kb(n) == 0
            V(n) = V(n) + accel*(Vc(n)-V(n));
            elseif kb(n) == 2
            VcI = imag(Vc(n));
            VcR = sqrt(Vm(n)^2 - VcI^2);
            Vc(n) = VcR + j*VcI;
             V(n) = V(n) + accel*(Vc(n) -V(n));
            end
   end
  maxerror=max( max(abs(real(DP))), max(abs(imag(DQ))) );
   if iter == maxiter & maxerror > accuracy
   fprintf('\nWARNING: Iterative solution did not converged after ')
   fprintf('%g', iter), fprintf(' iterations.\n\n')
   fprintf('Press Enter to terminate the iterations and print the results \n')
   converge = 0; pause, else, end

end
k=0;
for n = 1:nbus
  Vm(n) = abs(V(n)); deltad(n) = angle(V(n))*180/pi;
     if kb(n) == 1
     S(n)=P(n)+j*Q(n);
     Pg(n) = P(n)*basemva + Pd(n);
     Qg(n) = Q(n)*basemva + Qd(n) - Qsh(n);
     k=k+1;
     Pgg(k)=Pg(n);
     elseif  kb(n) ==2
     k=k+1;
     Pgg(k)=Pg(n);
     S(n)=P(n)+j*Q(n);
     Qg(n) = Q(n)*basemva + Qd(n) - Qsh(n);
     end
yload(n) = (Pd(n)- j*Qd(n)+j*Qsh(n))/(basemva*Vm(n)^2);
end
Pgt = sum(Pg);  Qgt = sum(Qg); Pdt = sum(Pd); Qdt = sum(Qd); Qsht = sum(Qsh);
busdata(:,3)=Vm'; busdata(:,4)=deltad';
clear  AcurBus  DP  DQ  DV  L Sc Vc VcI VcR YV converge delta


%% Prints the power flow solution on the screen

head =['    Bus  Voltage  Angle    ------Load------    ---Generation---   Injected'
       '    No.  Mag.     Degree     MW       Mvar       MW       Mvar       Mvar '
       '                                                                          '];
disp(head)
for n=1:nbus
     fprintf(' %5g', n), fprintf(' %7.3f', Vm(n)),
     fprintf(' %8.3f', deltad(n)), fprintf(' %9.3f', Pd(n)),
     fprintf(' %9.3f', Qd(n)),  fprintf(' %9.3f', Pg(n)),
     fprintf(' %9.3f ', Qg(n)), fprintf(' %8.3f\n', Qsh(n))
end
    fprintf('      \n'), fprintf('    Total              ')
    fprintf(' %9.3f', Pdt), fprintf(' %9.3f', Qdt),
```

```
    fprintf(' %9.3f', Pgt), fprintf(' %9.3f', Qgt), fprintf(' %9.3f\n\n', Qsht)


%% Computes and displays the line flow and losses

SLT = 0;
fprintf('\n')
fprintf('     --Line--  Power at bus & line flow    --Line loss--  Transformer\n')
fprintf('     from  to    MW      Mvar     MVA       MW      Mvar      tap\n')

for n = 1:nbus
busprt = 0;
   for L = 1:nbr;
       if busprt == 0
       fprintf('   \n'), fprintf('%6g', n), fprintf('      %9.3f', P(n)*basemva)
       fprintf('%9.3f', Q(n)*basemva), fprintf('%9.3f\n', abs(S(n)*basemva))

       busprt = 1;
       else, end
       if nl(L)==n      k = nr(L);
       In = (V(n) - a(L)*V(k))*y(L)/a(L)^2 + Bc(L)/a(L)^2*V(n);
       Ik = (V(k) - V(n)/a(L))*y(L) + Bc(L)*V(k);
       Snk = V(n)*conj(In)*basemva;
       Skn = V(k)*conj(Ik)*basemva;
       SL  = Snk + Skn;
       SLT = SLT + SL;
       elseif nr(L)==n  k = nl(L);
       In = (V(n) - V(k)/a(L))*y(L) + Bc(L)*V(n);
       Ik = (V(k) - a(L)*V(n))*y(L)/a(L)^2 + Bc(L)/a(L)^2*V(k);
       Snk = V(n)*conj(In)*basemva;
       Skn = V(k)*conj(Ik)*basemva;
       SL  = Snk + Skn;
       SLT = SLT + SL;
       else, end
         if nl(L)==n | nr(L)==n
         fprintf('%12g', k),
         fprintf('%9.3f', real(Snk)), fprintf('%9.3f', imag(Snk))
         fprintf('%9.3f', abs(Snk)),
         fprintf('%9.3f', real(SL)),
             if nl(L) ==n & a(L) ~= 1
             fprintf('%9.3f', imag(SL)), fprintf('%9.3f\n', a(L))
             else, fprintf('%9.3f\n', imag(SL))
             end
         else, end
  end
end
SLT = SLT/2;
fprintf('   \n'), fprintf('    Total loss                         ')
fprintf('%9.3f', real(SLT)), fprintf('%9.3f\n', imag(SLT))
clear Ik In SL SLT Skn Snk
```

Bus No.	Voltage Mag.	Angle Degree	------Load------ MW	Mvar	---Generation--- MW	Mvar	Injected Mvar
1	1.060	0.000	0.000	0.000	129.692	8.970	0.000
2	1.042	-2.668	20.000	10.000	40.000	30.000	0.000
3	1.015	-5.115	45.000	15.000	0.000	0.000	0.000
4	1.014	-5.391	40.000	5.000	0.000	0.000	0.000
5	1.009	-6.082	60.000	10.000	0.000	0.000	0.000
Total			165.000	40.000	169.692	38.970	0.000

Fig 3: MATLAB output of bus data

--Line-- from	to	Power at bus & line flow MW	Mvar	MVA	--Line loss-- MW	Mvar
1		129.692	8.970	130.002		
	2	87.219	2.847	87.265	1.358	0.759
	3	42.476	6.127	42.916	1.325	1.283
2		20.000	20.000	28.284		
	1	-85.861	-2.088	85.886	1.358	0.759
	3	19.736	5.891	20.597	0.242	-1.107
	4	30.153	5.693	30.686	0.528	-0.531
	5	55.974	10.505	56.951	1.201	2.025
3		-45.000	-15.000	47.434		
	1	-41.151	-4.844	41.435	1.325	1.283
	2	-19.494	-6.998	20.712	0.242	-1.107
	4	15.650	-3.155	15.964	0.024	-0.956
4		-40.000	-5.000	40.311		
	2	-29.625	-6.225	30.272	0.528	-0.531
	3	-15.625	2.199	15.779	0.024	-0.956
	5	5.249	-0.975	5.339	0.022	-2.495
5		-60.000	-10.000	60.828		
	2	-54.773	-8.480	55.425	1.201	2.025
	4	-5.228	-1.520	5.444	0.022	-2.495
Total loss					4.700	-1.023

Fig 4: MATLAB output of Transmission line data

From the above data, we can see that the MATLAB data matches with the PowerWorld data.

3. Make an undervoltage event in Bus-4 and apply any technique to overcome the undervoltage problem of the system. (Consider, below 90% to be undervoltage for any bus)

There are many factors which can lead to undervoltage in a bus system. It can be due to an increase in load in the system. Also, it can occur due to the loss if an incoming transformer. Undervoltage may occur from faulty transformer earthing or overloading of the transformer. We have caused an undervoltage event in bus 4 by adding an additional load.

Undervoltage problem can be solved by using either capacitors or transformers. Capacitors supply reactive power and raise voltage whereas transformers raise voltage by reducing current flow.

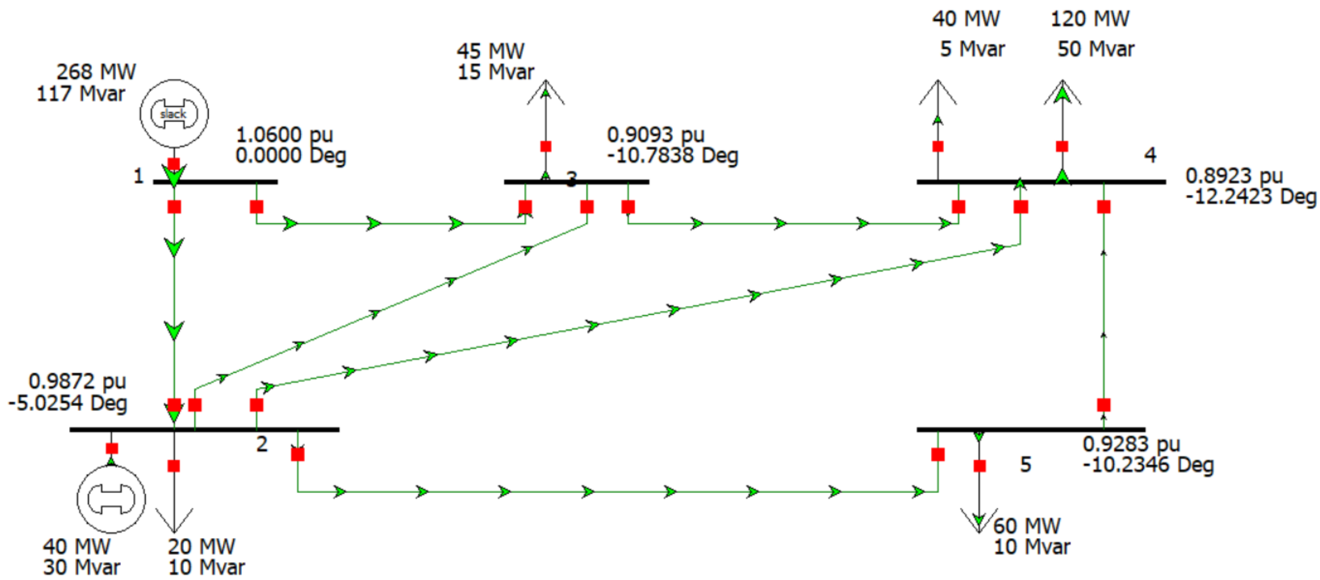

Fig 5: Undervoltage event in bus-4

Here in the above diagram, we can see that voltage in bus 4 is less than 0.9 pu which is considered as undervoltage. Due to the event at bus-4, the other buses have also gotten quite close to undervoltage. In order to again get the bus voltages to acceptable levels, a transformer has been connected in line 2-3.

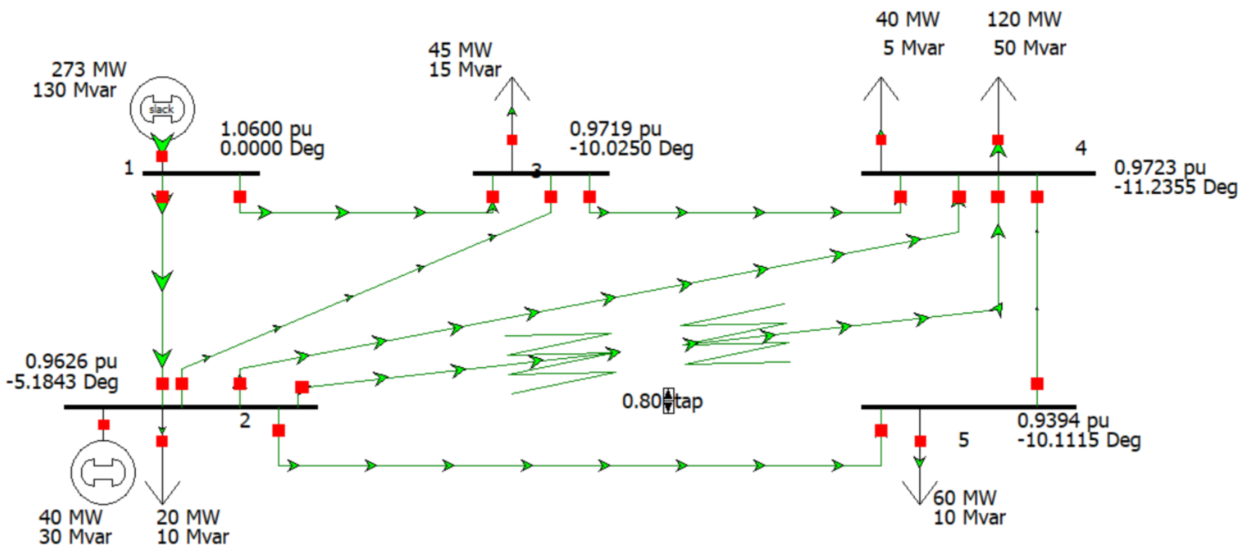

Fig 6: Addition of transformer to raise bus voltage

The transformer tap setting was selected at 0.8 to compromise between bus 2 and bus 4. At this tap setting, all bus voltages in the system were raised to more than 0.9 pu. These voltage levels are much more acceptable.

4. If the power flow through the transmission line (2-5) is to be made 75% of the normal condition, what should be the steps that can be adopted to do it? Implement any of them to do this job.

We know that real power flow in a transmission line is given by the formula:

$$P = \frac{|V_S| \; |V_R|}{X_L} \sin \delta$$

Where, P = real power
V_S = Sender bus voltage
V_R = Receiver bus voltage
δ = Load angle
X_L = Reactance of transmission line

From the above relation, power flow in a transmission line can be altered by changing the voltages of the buses or the load angle or changing the reactance of the line. In practice, the reactance cannot be changed so we are left with voltage or load angle. Both of these can be altered by either changing a load on the buses connecting the line or by using a buck-boost or phase-shift transformer. In our simulation, we chose a phase shift transformer to reduce the power flow in line 2-5.

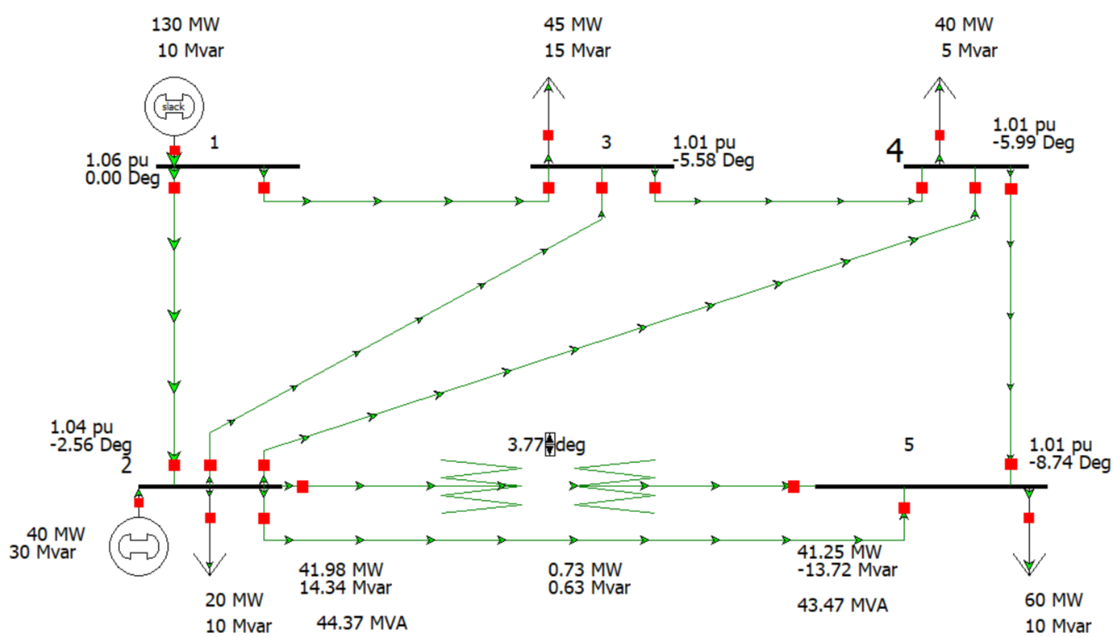

Fig 7: Altering of line power flow by using phase-shift transformer.

Initially, the real power flowing from bus-2 was 55.97 MW and 54.77 MW reached bus-5. The difference was consumed by the line. By adjusting the phase-shift of the transformer to 3.78°, we managed to reduce the power flow of the line by 25%.

$$55.97 \times 0.75 = 41.97 \text{ MW}$$

$$54.77 \times 0.75 = 41.08 \text{ MW}$$

From the diagram, our data is close to the actual calculations.

Discussion

In this project, the load flow analysis has been performed on PowerWorld Simulator software. A 5-bus study system has been taken into consideration to study the load flow. Through the load flow analysis, we were able to determine the steady-state operating conditions of the power system, including voltage magnitudes and angles, active and reactive power flows, and power losses. The load flow results provided valuable insights into the system's performance, allowing us to identify potential issues such as voltage violations, overloaded equipment, and congestion.

The load flow analysis helped in optimizing the system's operation by adjusting the generation and load settings, exploring various contingency scenarios, and assessing the impact of sudden unwanted events. The project also highlighted the importance of proper reactive power control, voltage regulation, and transmission line capacity planning to ensure efficient and reliable power delivery.

It is worth noting that due to the limitations of the PowerWorld Simulator software, some simulations could not be carried out to the desired level. For example, to overcome undervoltage, adding a synchronous capacitor to the system is the optimum method, however it was not possible for us to apply that in PowerWorld Simulator- so a transformer was used instead.

In conclusion, the load flow analysis project provided valuable insights into the steady-state behavior of the power system and its operational characteristics. By utilizing load flow analysis techniques, we were able to identify and address potential issues, optimize system performance, and make informed decisions for efficient power system operation. The project reinforced the importance of load flow analysis as an essential tool for power system planning, operation, and optimization.

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