Islamic University of Technology

Name : Shazzad Ahmed

Student ID : 220021108

Section : A-2

Course Code : EEE-4402

Course Name : Power System II Lab

Experiment No : 04

Experiment Name : Load Flow ~~and~~ Analysis Using MATLAB

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Theory:

Load flow analysis is a systemaic study of a power system operating under steady-state conditions. Because power networks are highly complex, their behavior cannot be accurately determined using basic circuit analysis alone.

Instead a mathematical model is developed to represent the network in matrix form, and calculations are performed iteratively on this model. This approach forms the basic of load flow analysis, which provides both formation and extension of power system studies.

In this method, load buses are treated as demand points, consuming specified amounts of real and reactive power, while generator buses are modeled as supply points, delivering real power at a fixed voltage magnitude. To ensure balance in the overall power flow, one bus is designated as the reference bus. This bus has a fixed voltage phasor and serves as a benchmark for the entire calculation.

Additionally, the reference bus plays another critical role - it absorbs or supplies the mismatch in real power caused by system losses and imbalances within the network. Since exact power values cannot always be predetermined, the reference bus ensures system stability by compensating for these variations.

The slack bus compensates for mismatches in the network's power flow, ensuring balance in the system. This feature not only allows the network to meet varying requirements but also helps account for line losses and supports fault analysis.

However, load-flow equations are inherently nonlinear. Each bus in the system is associated with four variables, out of which two are fixed initially. Because of this, the equations become complex, with interdependent terms that make direct solutions difficult.

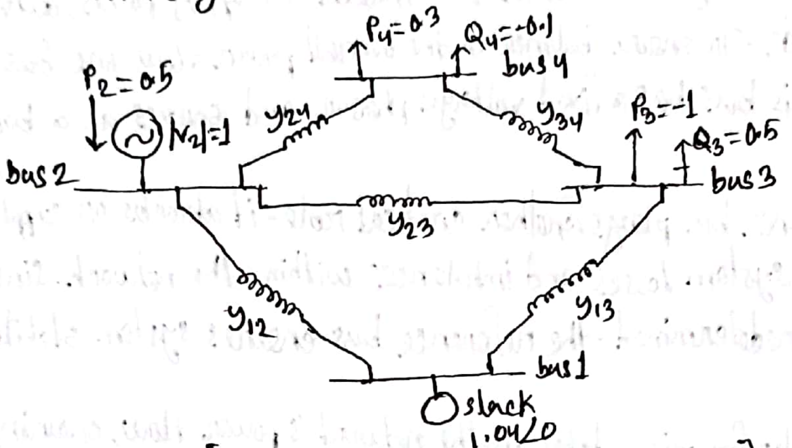
To overcome this challange, iterative methods are employed. One widely used technique is the Gauss-seidel method, where the voltage at load buses is initially assumed to be 1 p.u. Iterations are then performed repeatedly until the successive changes in results fall below a defined tolerance level. This point, known as the convergence criterion, indicates that a stable solution has been reached. Finally, the slack bus values are determined to ensure overall balance of the system's net power flow.

Theoretical calculation:

Table. data:

Line	Z (Pu)	Y (Pu)	Ybus element
1-2	0.05+j0.05	2-6j	y_{12}
1-3	0.1+j0.3	1-3j	y_{13}
2-3	0.15+j0.45	0.6666-2j	y_{23}
2-4	0.1+j0.3	1-3j	y_{24}
3-4	0.05+j0.15	2-6j	y_{34}

Approximate diagram:



$$Y_{bus}=\begin{bmatrix} 3-9j & -2+6j & -1+3j & 0 \\ -2+6j & 3.666-11j & -0.666+2j & -1+3j \\ -1+3j & -0.666+2j & 3.666-11j & -2+6j \\ 0 & -1+3j & -2+6j & 3-9j \end{bmatrix}$$

Known data:

Bus 1 (slack): $V_1=1.04\angle 0^\circ$

Bus 2 (PV): $P_2=0.5$; $|V_2|=1$

Bus 3 (PQ): $P_3=-1$; $Q_3=0.5$

Bus 4 (PQ): $P_4=0.3$; $Q_4=-0.1$

Initial Assumption: $V_2^{(0)}=V_3^{(0)}=V_4^{(0)}=1+j0$

Iteration 1:

Bus 2 (PV Bus).

$$Q_2^{(1)}=-\operatorname{Img}\left\{V_2^*(0)\sum_{k=1}^{4}Y_{2k}V_k\right\}$$

$$\sum_{k=1}^{4}Y_{2k}V_k=Y_{21}V_1+Y_{22}V_2+Y_{23}V_3+Y_{24}V_4$$

$$=-0.08+0.24j$$

$\therefore Q_2^{(1)}=-0.24$

$S_2^{*(1)}=P_2-jQ_2^{(1)}=0.5+j0.24$

$$Y_{2e}^{(1)} = \left[\frac{S_2^{*}(1)}{V_2^{*}(1)} - \sum_{\substack{k=1\\k\neq 2}}^{4} Y_{2k}V_k\right]\frac{1}{Y_{22}}$$

$$= 1.015817 + 0.0474547j$$

as; $|V_2| = 1$; only retaining the imaginary part

$$e_2^{(1)} = \sqrt{|V_2|^2 - (f_2^{(1)})^2} = \sqrt{1^2 - (0.0474547)^2}$$

$$= 0.998873A$$

$$\therefore V_2^{(1)} = 0.998873 + 0.0474547j$$

Bus 3 (PQ Bus):

$$\sum_{\substack{k=1\\k\neq 3}}^{4} Y_{3k}V_k = Y_{31}V_1 + Y_{32}V_2^{(1)} + V_{34}V_4^{(1)}$$

$$= -3.690493 + 11.048255j$$

$$V_3^{(2)} = \left[\frac{P_3 - jQ_3}{V_3^{*}(1)} - \sum_{\substack{k=1\\k\neq 3}} Y_{3k}V_k\right]\frac{1}{Y_{33}}$$

$$= 1.000947 - 0.094008j$$

Bus 4 (PQ Bus):

$$\sum_{\substack{k=1\\k\neq 4}}^{4} Y_{4k}V_k = Y_{41}V_1 + Y_{42}V_2^{(2)} + Y_{43}V_3^{(2)}$$

$$= -2.544498 + 9.2166778j$$

$$V_4^{(2)} = \left[\frac{P_4 - jQ_4}{V_4^{*}(1)} - \sum_{\substack{k=1\\k\neq 4}}^{4} Y_{4k}V_k\right]\frac{1}{Y_{44}}$$

$$= 1.006198 - 0.019725j$$

Iteration-3:

Bus 2 (PQ Bus):

$$\sum_{k=1}^{4} Y_{2k}V_k = Y_{21}V_1 + Y_{22}V_2^{(2)} + Y_{23}V_3^{(2)} + Y_{24}V_4^{(2)}$$

$$= 0.559432 + 0.234627j$$

$$\sum_{\substack{k=1\\k\neq 2}}^{4} Y_{2k}V_k = \sum_{k=1}^{4} Y_{2k}V_k - Y_{22}V_2^{(2)}$$

$$= -3.432235 + 11.120881j$$

$$Q_2^{(3)} = -\mathrm{Imag}\left\{V_2^{*}(2) \sum_{k=1}^{4} Y_{2k}V_k\right\}$$

$$Q_2^{(3)} = -0.2179$$

$$\therefore V_{23}^{(3)} = \left[\frac{P_2 - jQ_2^{(3)}}{V_2^{*}(2)} - \sum_{\substack{k=1\\k\neq 2}}^{4} Y_{2k}V_k\right]\frac{1}{Y_{22}}$$

$$= 0.9979169 + 0.02423468j$$

$$|V_2| = 1;\quad e_2^{(3)} = \sqrt{1^2 - (0.02423468)^2}$$

$$= 0.999706$$

$$\therefore V_2^{(3)} = 0.99706 + 0.02423468j$$

Bus 3 (PQ Bus):

$$\sum_{\substack{k=1\\k\neq 3}}^{k=4} Y_{3k}V_k = Y_{31}V_1 + Y_{32}V_2^{(1)} + V_{34}V_4^{(0)}$$

$$= -3.7608 + j10.9661$$

$$V_3^{(1)} = \left[\frac{P_3 - jQ_3}{V_3^{*}(0)} - \sum_{\substack{k=1\\k\neq 3}}^{4} Y_{3k}V_k\right]\frac{1}{Y_{33}}$$

$$= 1.013433 + (-0.086824j)$$

Bus 4 (PQ Bus):

$$\sum_{\substack{k=1\\k\neq 4}}^{4} Y_{4k}V_k = Y_{41}V_1 + Y_{42}V_2^{(1)} + Y_{43}V_3^{(1)}$$

$$= -2.64718 + 9.2034j$$

$$V_4^{(1)} = \left[\frac{P_4 - jQ_4}{V_4^{*}(0)} - \sum_{\substack{k=1\\k\neq 4}}^{4} Y_{4k}V_k\right]\frac{1}{Y_{44}}$$

$$= 1.008579 - j0.008728j$$

Iteration-2

Bus 2 (PV Bus):

$$\sum_{\substack{k=1\\k\neq 2}}^{4} Y_{2k}V_k = Y_{21}V_1 + Y_{23}V_3^{(1)} + Y_{24}V_4^{(1)}$$

$$= -3.484309 + 11.119205j$$

$$\sum_{k=1}^{4} Y_{2k}V_k = 0.7001 + 0.30559j$$

$$Q_2^{(2)} = -\mathrm{Imag}\left\{V_2^{*}(1) \sum_{k=1}^{4} Y_{2k}V_k\right\}$$

$$= -0.2720249$$

$$V_{2e}^{(2)} = \left[\frac{P_2 - jQ_2^{(2)}}{V_2^{*}(1)} - \sum_{\substack{k=1\\k\neq 4}}^{4} Y_{2k}V_k\right]\frac{1}{Y_{22}}$$

$$= 0.99387749 + 0.02969869j$$

$$|V_2| = 1;\quad e_2^{(2)} = \sqrt{1^2 - (0.02969869)^2}$$

$$= 0.9995588$$

$$\therefore V_2^{(2)} = 0.9995588 + 0.02969869j$$

BUS 3 (PQ BUS):

$$\sum_{\substack{k=1\\k\neq 3}}^{4} Y_{3k}V_k = Y_{31}V_1 + Y_{32}V_2^{(3)} + Y_{34}V_4^{(2)}$$

$$= -3.6089 + 11.059899j$$

$$V_3^{(3)} = \left[\frac{P_3 - jQ_3}{V_3^{*(2)}} - \sum_{\substack{k=1\\k\neq 3}}^{4} Y_{3k}V_k\right]\frac{1}{Y_{33}}$$

$$= 1.007992 - 0.1013017j$$

BUS 4:

$$\sum_{\substack{k=1\\k\neq 4}}^{4} Y_{4k}V_k = Y_{41}V_1 + Y_{42}V_2^{(3)} + Y_{43}V_3^{(3)}$$

$$= -2.480587\ 9.225441j$$

$$V_4^{(3)} = \left[\frac{P_4 - jQ_4}{V_4^{*(2)}} - \sum_{\substack{k=1\\k\neq 4}}^{4} Y_{4k}V_k\right]\frac{1}{Y_{44}}$$

$$V_4^{(3)} = 1.005879 - 0.026341j$$

After 3 iterations:

Bus-1:

$$I_1^{(3)} = Y_{11}V_1 + Y_{12}V_2^{(3)} + Y_{13}V_3^{(3)}$$

$$= 0.2410923 - 0.1949 53j$$

$$S_1^{(3)} = V_1 \cdot I_1^{*(3)} = 0.250736 - 0.20275j$$

Upon closer observation; the valuer don't match exactly with the simulated results that are done in the next page of matlab code. but are close enough; and all of them belong to close proximily range.

__Discussion:__

This lab focused on load flow analysis, highlighting how it provides valuable insight into the operation of a power network while also allowing for the evaluation of system losses.

In this experiment, the Gauss-seidel iterative method was applied, with calculations repeated up to three iterations for both theoretical analysis and MATLAB implementation. Although the numerical results from both approaches did not match exactly, they were close in range and accuracy, which is sufficient to validate the method. The minor variations observed are likely due to rounding errors and limited decimal precision during computation.

Since the process was limited to three iterations, these small differences became noticeable but they did not undermine the validity of the results. Overall, the experiment successfully demonstrated the principles of load flow analysis, it's practical importance, and the advantages of using software tools such as MATLAB for achieving accurate and efficient power system studies.

```
n=input('Total no of bus: ');
V=ones(n,1);
delta=zeros(n,1);
P=inf(n,1);
Q=inf(n,1);
Type=zeros(n,1);

fprintf('Total buses = %d\n',n);
```

```
Total buses = 4
```

```
for i=1:n
    Type(i)=input('For slack bus press 1, for PV bus press 2, For PQ bus press 3:
');
    fprintf('for Bus%d, type=%d\n',i,Type(i));
    if Type(i)==1
        V(i)=input(['V(bus' num2str(i) '): ']);
        delta(i)=input(['Delta(bus' num2str(i) '): ']);
        fprintf('Bus%d, V=%g delta=%g\n',i,V(i),delta(i));
    elseif Type(i)==2
        P(i)=input(['P(bus' num2str(i) '): ']);
        V(i)=input(['V(bus' num2str(i) '): ']);
        fprintf('Bus%d, P=%g V=%g\n',i,P(i),V(i));
    else
        P(i)=input(['P(bus' num2str(i) '): ']);
        Q(i)=input(['Q(bus' num2str(i) '): ']);
        fprintf('Bus%d, P=%g Q=%g\n',i,P(i),Q(i));
    end
end
```

```
for Bus1, type=1
Bus1, V=1.04 delta=0
for Bus2, type=2
Bus2, P=0.5 V=1
for Bus3, type=3
Bus3, P=-1 Q=0.5
for Bus4, type=3
Bus4, P=0.3 Q=-0.1
```

```
Lines=input('Number of lines: ');
zdata=zeros(Lines,4);
fprintf('Total lines = %d\n',Lines);
```

```
Total lines = 5
```

```
for k=1:Lines
    zdata(k,1)=input('from bus: ');
    zdata(k,2)=input('to bus: ');
    zdata(k,3)=input('R: ');
    zdata(k,4)=input('X: ');
```

```
end

fprintf('\nZdata matrix:\n');
```

```
Zdata matrix:
```

```
zdata
```

```
zdata = 5×4
    1.0000    2.0000    0.0500    0.1500
    1.0000    3.0000    0.1000    0.3000
    2.0000    3.0000    0.1500    0.4500
    2.0000    4.0000    0.1000    0.3000
    3.0000    4.0000    0.0500    0.1500
```

```


itrn=input('Number of Iterations: ');
Y=ybus(zdata);
j=1i;
ang=pi/180;
Vc=V.*exp(j*delta*ang);
Vset=V;
s_bus=find(Type==1,1);

for m=1:itrn
    for i=1:n
        if Type(i)==1, continue; end
        YV=Y(i,:)*Vc - Y(i,i)*Vc(i);
        if Type(i)==3
            Vc(i)=(1/Y(i,i))*(((P(i)-j*Q(i))/conj(Vc(i)))-YV);
        else
            Qi=-imag(conj(Vc(i))*(Y(i,:)*Vc));
            Vt=(1/Y(i,i))*(((P(i)-j*Qi)/conj(Vc(i)))-YV);
            Vc(i)=Vset(i)*exp(j*angle(Vt));
            Q(i)=Qi;
        end
    end
end

P(s_bus)=real(conj(Vc(s_bus))*(Y(s_bus,:)*Vc));
Q(s_bus)=-imag(conj(Vc(s_bus))*(Y(s_bus,:)*Vc));


fprintf('\nYbus matrix:\n');
```

```
Ybus matrix:
```

```
Y
```

```
Y = 4×4 complex
   3.0000 - 9.0000i  -2.0000 + 6.0000i  -1.0000 + 3.0000i   0.0000 + 0.0000i
  -2.0000 + 6.0000i   3.6667 -11.0000i  -0.6667 + 2.0000i  -1.0000 + 3.0000i
  -1.0000 + 3.0000i  -0.6667 + 2.0000i   3.6667 -11.0000i  -2.0000 + 6.0000i
   0.0000 + 0.0000i  -1.0000 + 3.0000i  -2.0000 + 6.0000i   3.0000 - 9.0000i
```

```
for i=1:n
    fprintf('\nBus %d\n', i);
    fprintf('P = %g\n', P(i));
    fprintf('Q = %g\n', Q(i));
    fprintf('V = %g\n', abs(Vc(i)));
    fprintf('delta = %g deg\n', angle(Vc(i))*180/pi);
end
```

```
Bus 1
P = 0.241345
Q = 0.255752
V = 1.04
delta = 0 deg
Bus 2
P = 0.5
Q = -0.527797
V = 1
delta = 1.64733 deg
Bus 3
P = -1
Q = 0.5
V = 1.02897
delta = -5.71821 deg
Bus 4
P = 0.3
Q = -0.1
V = 1.01693
delta = -1.46494 deg
```

```
function Y=ybus(zdata)
n=max(max(zdata(:,1:2))); Y=zeros(n);
for k=1:size(zdata,1)
    i=zdata(k,1); j=zdata(k,2); R=zdata(k,3); X=zdata(k,4);
    y=1/(R+1i*X);
    Y(i,i)=Y(i,i)+y; Y(j,j)=Y(j,j)+y;
    Y(i,j)=Y(i,j)-y; Y(j,i)=Y(j,i)-y;
end
end
```