Contents


```
clc;
close all;
clear all;
%linedata - not used
%            FB   TB      R           X       G      B     Qlim
linedata = [1,    5,   0.00150,     0.02,     0,     0,    6;
            2,    4,   0.009,       0.1,      0,  1.72,    12;
            2,    5,   0.0045,      0.05,     0,  0.44,    12;
            3,    4,   0.00075,     0.01,     0,     0,    10;
            4,    5,   0.00225,     0.025,    0,  0.44,    12]


%        Bus No.  V    Ang,   Pg    Qg    Pl    Ql   Type:
busdata = [1,      1,    0,    0,    0,    0,    0,    1;
           2,      1,    0,    0,    0,    8,   2.8,   2;
           3,    1.05,   0,   5.2,   0,   0.8,  0.4,   3;
           4,      1,    0,    0,    0,    0,    0,    2;
           5,      1,    0,    0,    0,    0,    0,    2]
%Bus types 1:SLACK, 2:PQ -LOAD  3:CONSTANT VOLTAGE
%initial voltages are considered as generator set point values = 1 angle 0

%susceptance = linedata(:,6)/2;

%listing and defining variables - defining ybus from powerworld
ybus = sparse(5);
ybus(    1,    1) =      3.7290+ 1i*(  -49.7203);
ybus(    1,    5) =     -3.7290+ 1i*(   49.7203);
ybus(    2,    2) =      2.6783+ 1i*(  -28.4590);
ybus(    2,    4) =     -0.8928+ 1i*(    9.9197);
ybus(    2,    5) =     -1.7855+ 1i*(   19.8393);
ybus(    3,    3) =      7.4580+ 1i*(  -99.4406);
ybus(    3,    4) =     -7.4580+ 1i*(   99.4406);
ybus(    4,    2) =     -0.8928+ 1i*(    9.9197);
ybus(    4,    3) =     -7.4580+ 1i*(   99.4406);
ybus(    4,    4) =     11.9219+ 1i*( -147.9589);
ybus(    4,    5) =     -3.5711+ 1i*(   39.6786);
ybus(    5,    1) =     -3.7290+ 1i*(   49.7203);
ybus(    5,    2) =     -1.7855+ 1i*(   19.8393);
ybus(    5,    4) =     -3.5711+ 1i*(   39.6786);
ybus(    5,    5) =      9.0856+ 1i*( -108.5782);

%known_variables = [delta1 V1 V3]
PQ_buses = 3;
PV_buses = 1;
totalbuses = 5;

jacobianmatrix = sparse(2*totalbuses - PV_buses - 2); % will be a 7*7 matrix
tic;
%separating ybus into G and B
G = zeros(5,5); %real(ybus);% real part of Ybus values
B = imag(ybus);% imaginary part of Ybus values

%listing and defining variables - unknown variables
V=busdata(:,2); % initial voltage
Theta=busdata(:,3); % initial angles
P = zeros(5,1);
Q = zeros(5,1);
bustype=busdata(:,8);
pq = [2; 4; 5]; %load buses
npv = 2     % No. of PV buses..
npq = 3     % No. of PQ buses..
```

```matlab
% Actual power from busdata(Generation - Load)
Pact=busdata(:,4)-busdata(:,6);
Qact=busdata(:,5)-busdata(:,7);

error=1;
%convergence = 1e-5; %convergence limit
iter=0;
while(error>0.0001)
    P = zeros(5,1);
    Q = zeros(5,1);
    %calculate power flow
    for i=1:5
        for k=1:5
            P(i) = P(i) + V(i)*V(k)*( G(i,k)*cos(Theta(i)-Theta(k)) + B(i,k)*sin(Theta(i)-Theta(k)));
            Q(i) = Q(i) + V(i)*V(k)*( G(i,k)*sin(Theta(i)-Theta(k)) - B(i,k)*cos(Theta(i)-Theta(k)));
        end
    end
    %calculate power difference
    deltaP = Pact-P;
    deltaQ = Qact-Q;
    temp = 1;

    dQ = zeros(npq,1);
    for i = 1:5
        if bustype(i) == 2 %valid for PQ bus
            dQ(temp,1) = deltaQ(i);
            temp = temp+1;
        end
    end
    dP = deltaP(2:5);
    M = [dP; dQ];


%calculate Jacobian
      %derivative of P wrt theta - J11
      J1 = zeros(5-1,5-1);
      for i = 1:(5-1)
          m = i+1;
          for k = 1:(5-1)
              n = k+1;
              if n == m %for diagonal elements - need to subtract the Vm squared term
                  for n = 1:5
                      J1(i,k) = J1(i,k) + V(m)* V(n)*(-G(m,n)*sin(Theta(m)-Theta(n)) + B(m,n)*cos(Theta(m)-Theta(n)));
                  end
                  J1(i,k) = J1(i,k) - V(m)^2*B(m,m);
              else
                  J1(i,k) = V(m)* V(n)*(G(m,n)*sin(Theta(m)-Theta(n)) - B(m,n)*cos(Theta(m)-Theta(n)));
              end
          end
      end
      %derivative of P wrt Voltage - J12
      J2 = zeros(5-1,npq);
      for i = 1:(5-1)
        m = i+1;
        for k = 1:npq
            n = pq(k);
            if n == m
                for n = 1:5
                    J2(i,k) = J2(i,k) + V(n)*(G(m,n)*cos(Theta(m)-Theta(n)) + B(m,n)*sin(Theta(m)-Theta(n)));
                end
                J2(i,k) = J2(i,k) + V(m)*G(m,m);
            else
                J2(i,k) = V(m)*(G(m,n)*cos(Theta(m)-Theta(n)) + B(m,n)*sin(Theta(m)-Theta(n)));
            end
        end
      end
```

```
      %derivative of Q wrt theta - J21
      J3 = zeros(npq,5-1);
    for i = 1:npq
        m = pq(i);
        for k = 1:(5-1)
            n = k+1;
            if n == m
                for n = 1:5
                    J3(i,k) = J3(i,k) + V(m)* V(n)*(G(m,n)*cos(Theta(m)-Theta(n)) + B(m,n)*sin(Theta(m)-Theta(n)));
                end
                J3(i,k) = J3(i,k) - V(m)^2*G(m,m);
            else
                J3(i,k) = V(m)* V(n)*(-G(m,n)*cos(Theta(m)-Theta(n)) - B(m,n)*sin(Theta(m)-Theta(n)));
            end
        end
    end
      %derivative of Q wrt Voltage - J22
      J4 = zeros(npq,npq);
    for i = 1:npq
        m = pq(i);
        for k = 1:npq
            n = pq(k);
            if n == m
                for n = 1:5
                    J4(i,k) = J4(i,k) + V(n)*(G(m,n)*sin(Theta(m)-Theta(n)) - B(m,n)*cos(Theta(m)-Theta(n)));
                end
                J4(i,k) = J4(i,k) - V(m)*B(m,m);
            else
                J4(i,k) = V(m)*(G(m,n)*sin(Theta(m)-Theta(n)) - B(m,n)*cos(Theta(m)-Theta(n)));
            end
        end
    end

    J = [J1 J2; J3 J4]; %getting jacobian
    %update V and theta
    X = inv(J)*M;           % Correction Vector
    dTh = X(1:5-1);      % Change in Voltage Angle..
    dV = X(5:end);       % Change in Voltage Magnitude..

    Theta(2:5) = dTh + Theta(2:5);    % Voltage Angle..we dont need the angle for bus 1 - slack bus
    Theta_deg = Theta*180/pi;
    k = 1;
    for i = 2:5
        if bustype(i) == 2 %need values for PQ buses only
            V(i) = dV(k) + V(i); % Voltage Magnitude..
            k = k+1;
        end
    end
    %repeat
error = max(abs(M));
display(error);


%displaying V and Theta for each iteration
iter=iter+1; %keeping a count of the number of iterations
fprintf('For iteration %i :\n',iter);
for i=1:5
    fprintf('The Value of Voltage magnitude at bus %i is %.3f: with an angle of %.3f \n',i, V(i),Theta_deg(i));
end

end
```

```
linedata =

    1.0000    5.0000    0.0015    0.0200         0         0    6.0000
```

```
    2.0000    4.0000    0.0090    0.1000         0    1.7200   12.0000
    2.0000    5.0000    0.0045    0.0500         0    0.4400   12.0000
    3.0000    4.0000    0.0008    0.0100         0         0   10.0000
    4.0000    5.0000    0.0022    0.0250         0    0.4400   12.0000


busdata =

  Columns 1 through 7

    1.0000    1.0000         0         0         0         0         0
    2.0000    1.0000         0         0         0    8.0000    2.8000
    3.0000    1.0500         0    5.2000         0    0.8000    0.4000
    4.0000    1.0000         0         0         0         0         0
    5.0000    1.0000         0         0         0         0         0

  Column 8

    1.0000
    2.0000
    3.0000
    2.0000
    2.0000


npv =

     2


npq =

     3


error =

     8

For iteration 1 :
The Value of Voltage magnitude at bus 1 is 1.000: with an angle of 0.000
The Value of Voltage magnitude at bus 2 is 0.975: with an angle of -18.836
The Value of Voltage magnitude at bus 3 is 1.050: with an angle of 0.411
The Value of Voltage magnitude at bus 4 is 1.046: with an angle of -2.003
The Value of Voltage magnitude at bus 5 is 1.018: with an angle of -4.149

error =

    1.1155

For iteration 2 :
The Value of Voltage magnitude at bus 1 is 1.000: with an angle of 0.000
The Value of Voltage magnitude at bus 2 is 0.894: with an angle of -20.774
The Value of Voltage magnitude at bus 3 is 1.050: with an angle of 0.235
The Value of Voltage magnitude at bus 4 is 1.027: with an angle of -2.118
The Value of Voltage magnitude at bus 5 is 0.988: with an angle of -4.199

error =

    0.1122

For iteration 3 :
The Value of Voltage magnitude at bus 1 is 1.000: with an angle of 0.000
The Value of Voltage magnitude at bus 2 is 0.883: with an angle of -21.247
The Value of Voltage magnitude at bus 3 is 1.050: with an angle of 0.227
The Value of Voltage magnitude at bus 4 is 1.025: with an angle of -2.129
The Value of Voltage magnitude at bus 5 is 0.985: with an angle of -4.214
```

```
error =

    0.0030

For iteration 4 :
The Value of Voltage magnitude at bus 1 is 1.000: with an angle of 0.000
The Value of Voltage magnitude at bus 2 is 0.883: with an angle of -21.261
The Value of Voltage magnitude at bus 3 is 1.050: with an angle of 0.227
The Value of Voltage magnitude at bus 4 is 1.025: with an angle of -2.129
The Value of Voltage magnitude at bus 5 is 0.985: with an angle of -4.214

error =

   2.2597e-06

For iteration 5 :
The Value of Voltage magnitude at bus 1 is 1.000: with an angle of 0.000
The Value of Voltage magnitude at bus 2 is 0.883: with an angle of -21.261
The Value of Voltage magnitude at bus 3 is 1.050: with an angle of 0.227
The Value of Voltage magnitude at bus 4 is 1.025: with an angle of -2.129
The Value of Voltage magnitude at bus 5 is 0.985: with an angle of -4.214
```

Calculating the P and Q generated

```
Pgen=zeros(5,1);
Qgen=zeros(5,1);
Vm = V.*cos(Theta) + 1i*V.*sin(Theta);% Complex voltage in PU
% currents at each node
I=ybus*Vm;
% Power at each node
S=Vm.*conj(I); % Complex power
for k=1:5
    if bustype(k)==1
        % Real and reactive generation at the Slack bus
        Pgen(k)=real(S(k));
        Qgen(k)=imag(S(k));
    end
    if bustype(k)==3
        % Real and reactive generation at the PV buses
        Pgen(k)=real(S(k))+busdata(k,6);
        Qgen(k)=imag(S(k))+busdata(k,7);
    end
end

fprintf('Total number of iterations are: %i \n',iter);
fprintf('The Value of Real and Reactive Power at bus 1 is %.2f and %.2f MW\n',Pgen(1)*100, Qgen(1)*100);
fprintf('The Value of Real and Reactive Power at bus 3 is %.2f and %.2f MW\n',Pgen(3)*100,Qgen(3)*100 );
timeelapsed = toc;
fprintf('Total Elapsed: %.2f seconds \n',timeelapsed);
```

```
Total number of iterations are: 5
The Value of Real and Reactive Power at bus 1 is 366.50 and 59.67 MW
The Value of Real and Reactive Power at bus 3 is 540.22 and 276.64 MW
Total Elapsed: 0.07 seconds
```

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2. In PowerWorld using the case ECEN615_HW2_37_2022 manually try to minimize the system losses by adjusting 1) the phase shifter at the REED substation, 2) the status of the capacitors, and 3) the LTCs at the TEXAS, WEB, KYLE and RELLIS substations. Turn in your minimum losses and an explanation of the manual procedure that you used to determine the minimum lossesl. Also, explain why you think your solution actually minimizes the losses. Note several transmission lines are open; do not change their statuses. Also, you may ignore transmission line transformer overloads.

We start out with the system losses at 18.8 MW.

Varying phase angle varies the flow of real power in the system. First, we modify the phase shifter value and increase it to 4 degrees. This lowers real power flows on a few lines and redirects the power. The losses are reduced to 15.66 MW.

Next, we redirect the reactive power flows. Reactive power generation and consumption is highly local and follow the power system adage “vars don’t travel”.

We switch on the 12.7 Mvar capacitor at bus TREE69, 20.3 MVAR at bus 12MAN69, 7.3 MVar at bus Rudder 69, 14.8Mvar at bus Maroon69, which further reduces the losses to 15.5 MW.

As observed a large amount of reactive power flows from bus SLACK345 to Texas345 which can be controlled by controlling the tap on transformer from Texas345 to Texas69. Lowering the tap ratio lowers the system losses to 14.56 MW.

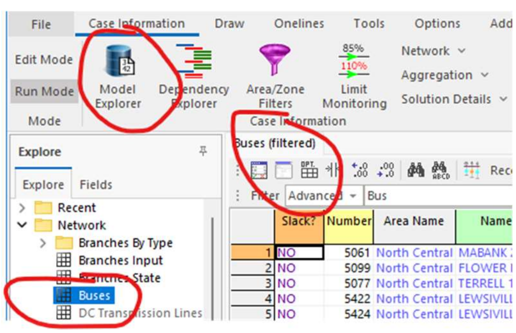
Now switching on the capacitor bank at BATT69 makes use of local reactive power and further reduces losses to 14.46 MW.

Again, large reactive power flows from Slack345 to WEB138. Lowering the tap ratio of the transformer at WEB138 to WEB69 reduces the losses to 14.16 MW.

3. This is the first of several problems over the semester that will be using a 2000 bus synthetic (fictional) grid that serves a load that roughly approximates the load of ERCOT. Since it is synthetic it contains no CEII and hence can be used for classroom assignments. To solve this case with PowerWorld you will need the commercial version; details were provided in an email on how to obtain this.

For this problem, you'll be dealing with the common issue of the voltages being too high, often during times of light load. For this problem we'll just be looking at are portion of the system, the North Central Area shown in yellow in the below figure (it is area number 5). Open the case ECEN615_2K_HW2. This case has the PowerWorld **Area/Zone Filters** set to only show in the Case Information displays information about the the North Central Area. Select a 161 kV bus that has a voltage above 1.05 per unit. Then, determine a set of capacitors and/or 500 kV lines that should be opened so the voltage on your selected bus drops by at least 0.02 per unit. Turn in the number of the bus you selected (you only need to select one bus), your control actions (which could be more than one), and your rationale for selecting these controls.

Easy way to access all buses in powerworld is by using Model Explorer which provides a list of all buses. Same applies for all shunts. The shunt status can be controlled by using model explorer.



Selected bus for observation : 5424 (V = 1.07837pu)

Capacitor bank near the observed bus is connected to bus 5422. This capacitor is switched OFF.

Now the voltage of the observed bus is lowered to 1.02830pu.

Now, with the capacitor at bus 5422 switched ON again, about 8 to 10 500kV lines around our observed bus are taken out of service after which the voltage on observed bus is lowered to 1.055pu.