```
clear all;
clc;
close all;
syms V2 V4 V5 delta2 delta3 delta4 delta5
V = [1  V2  1.05  V4  V5];
Delta = [0  delta2  delta3  delta4  delta5];
j = sqrt(-1);
Ybus = sparse(5);
Ybus(    1,    1) =      3.7290+ j*(  -49.7203);
Ybus(    1,    5) =     -3.7290+ j*(   49.7203);
Ybus(    2,    2) =      2.6783+ j*(  -28.4590);
Ybus(    2,    4) =     -0.8928+ j*(    9.9197);
Ybus(    2,    5) =     -1.7855+ j*(   19.8393);
Ybus(    3,    3) =      7.4580+ j*(  -99.4406);
Ybus(    3,    4) =     -7.4580+ j*(   99.4406);
Ybus(    4,    2) =     -0.8928+ j*(    9.9197);
Ybus(    4,    3) =     -7.4580+ j*(   99.4406);
Ybus(    4,    4) =     11.9219+ j*( -147.9589);
Ybus(    4,    5) =     -3.5711+ j*(   39.6786);
Ybus(    5,    1) =     -3.7290+ j*(   49.7203);
Ybus(    5,    2) =     -1.7855+ j*(   19.8393);
Ybus(    5,    4) =     -3.5711+ j*(   39.6786);
Ybus(    5,    5) =      9.0856+ j*( -108.5782);

PG = [0   0    5.2   0  0];
QG = [0   0    0     0   0];
PD = [0   8     0.8  0  0];
QD = [0  2.8  0.4  0  0];


for k=1:5
    for i = 1:5
        P(i,k) = V(k)*V(i)*(real(Ybus(i,k))*cos(Delta(i) - Delta(k)) + imag(Ybus(i,k)*sin(Delta(i) - Delta(k))));
        Q(i,k) = V(k)*V(i)*(real(Ybus(i,k))*sin(Delta(i) - Delta(k)) - imag(Ybus(i,k)*cos(Delta(i) - Delta(k))));
    end
end

PF_Jacobian_P = [P(2,2)+P(2,4)+P(2,5)+PD(2);  P(3,3)+P(3,4)-PG(3)+PD(3);
                            P(4,2)+P(4,3)+P(4,4)+P(4,5);   P(5,5)+P(5,1)+P(5,4)+P(5,2)];
PF_Jacobian_Q = [Q(2,2)+Q(2,4)+Q(2,5)+QD(2);  Q(3,3)+Q(3,4)-QG(3)+QD(3);
                            Q(4,2)+Q(4,3)+Q(4,4)+Q(4,5);   Q(5,5)+Q(5,1)+Q(5,4)+Q(5,2)];

Known = [PF_Jacobian_P(1)  PF_Jacobian_P(2)  PF_Jacobian_P(3)  PF_Jacobian_P(4)  PF_Jacobian_Q(1)  PF_Jacobian_Q(3)  PF_Jacobian_Q(4)];
Unknown  = [delta2  delta3  delta4  delta5  V2  V4  V5];

old_pf = transpose(Known);

for m=1:7
    for n=1:7
        Jacobian(m,n) = diff(Known(m), Unknown(n));
    end
end


delta_X = [1,1,1,1,1,1,1];
[deltaa2, deltaa3, deltaa4, deltaa5] = deal(0);
[v2, v4, v5,l] = deal(1);

Old = [delta2, delta3, delta4, delta5,V2, V4, V5];
New = [deltaa2, deltaa3, deltaa4, deltaa5,v2,v4,v5];

while (norm(delta_X,inf) > 0.001)
    new_pf = double(subs(old_pf, Old, New));
    new_jacobian = double(subs(Jacobian, Old, New));

    delta_X = -inv(new_jacobian)*new_pf;
    new_X = transpose(New) + delta_X;
    New = transpose(new_X);

    x(:, l) = new_X;
    n(:, l) = norm(delta_X,inf);
    l = l +1;
end
```

```
Power_gens = [P(1,1) + P(1,5);  Q(1,1) + Q(1,5); Q(3,3) + Q(3,4) + QD(3)];
New_power_gens = double(subs(Power_gens, Old, New));

fprintf('\nResults\n')
fprintf('\t\t Iterations\n')
fprintf('Unknowns \t 1 \t\t 2 \t\t3 \t\t4 \n')
fprintf('delta2    \t %f \t%f  \t%f  \t%f  \n', x(1,1), x(1,2), x(1,3), x(1,4))
fprintf('delta3    \t %f \t%f  \t%f  \t%f  \n', x(2,1), x(2,2), x(2,3), x(2,4))
fprintf('delta4    \t %f \t%f  \t%f  \t%f  \n', x(3,1), x(3,2), x(3,3), x(3,4))
fprintf('delta5    \t %f \t%f  \t%f  \t%f  \n', x(4,1), x(4,2), x(4,3), x(4,4))
fprintf('V2         \t%f  \t%f  \t%f  \t%f  \n', x(5,1), x(5,2), x(5,3), x(5,4))
fprintf('V4         \t%f  \t%f  \t%f  \t%f  \n', x(6,1), x(6,2), x(6,3), x(6,4))
fprintf('V5         \t%f  \t%f  \t%f  \t%f  \n', x(7,1), x(7,2), x(7,3), x(7,4))

fprintf('\n \t\t Inifinity Norm \n')
fprintf('Iterations  \t 1 \t\t 2  \t\t 3  \t\t 4 \n')
fprintf('Inf Norm  \t%f  \t%f  \t%f  \t%f \n',n(1), n(2), n(3), n(4))

fprintf('\n \t\t Power Output \n')
fprintf('Power \t\t Bus \t Value \t \n')
fprintf('P \t\t1 \t\t%f \n',New_power_gens(1))
fprintf('Q \t\t1 \t\t%f \n', New_power_gens(2))
fprintf('Q \t\t3  \t\t%f \n', New_power_gens(3))
```

```
Results
                 Iterations
Unknowns         1               2              3               4
delta2           -0.323084       -0.375481      -0.390274       -0.391063
delta3           0.003507        -0.008509      -0.010350       -0.010426
delta4           -0.038055       -0.047692      -0.049391       -0.049462
delta5           -0.073017       -0.078276      -0.079328       -0.079375
V2              0.942894        0.851802        0.834606        0.833771
V4              1.042285        1.022136        1.019430        1.019303
V5              1.011622        0.979366        0.974519        0.974289

                 Inifinity Norm
Iterations       1               2               3               4
Inf Norm        0.323084        0.091092        0.017197        0.000835

                 Power Output
Power            Bus     Value
P               1               3.948380
Q               1               1.142793
Q               3               3.374752
```

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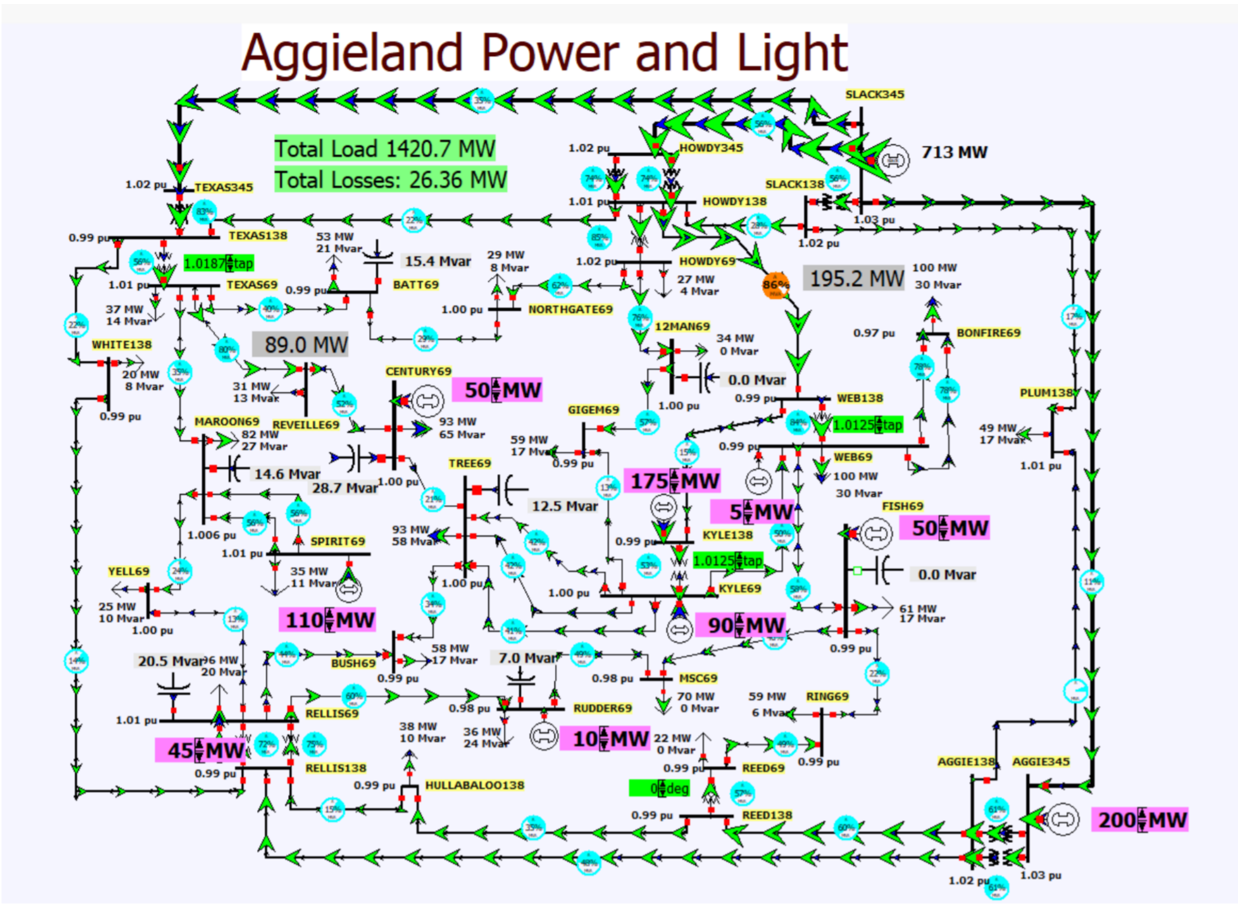
2. In PowerWorld using the case ECEN615_HW2_37 manually try to minimize the system losses by adjusting 1) the phase shifter at the REED substation, 2) the status of the capacitors, and 3) the LTCs at the TEXAS, WEB, KYLE and RELLIS substations. Turn in your minimum losses and an explanation of the manual procedure that you used to determine the minimum lossesl. Also, explain why you think your solution actually minimizes the losses.

Explanation: Shunt capacitors are local sources of reactive power. By switching them ON, the demand for reactive power sourced from long distances can be reduced, thus decreasing I^2R line losses. Further system loss reduction is achieved by adjusting LTC tap settings, which have the effect of controlling line reactive power flow and boosting node voltages. This has an added effect of reducing system losses. While phase-shifting transformers control real power flow, the phase shift with 0.0 degrees appears to be optimal for system loss – a change in either direction of the phase angle increases the total loss.

Strategy for loss minimization in the given case: First switch in shunt capacitors to supply local vars. Then, compare different combinations of all LTCs in the system. Check for circulating var flows, and adjust LTC taps to reduce them. Arrive at a minimum system loss.

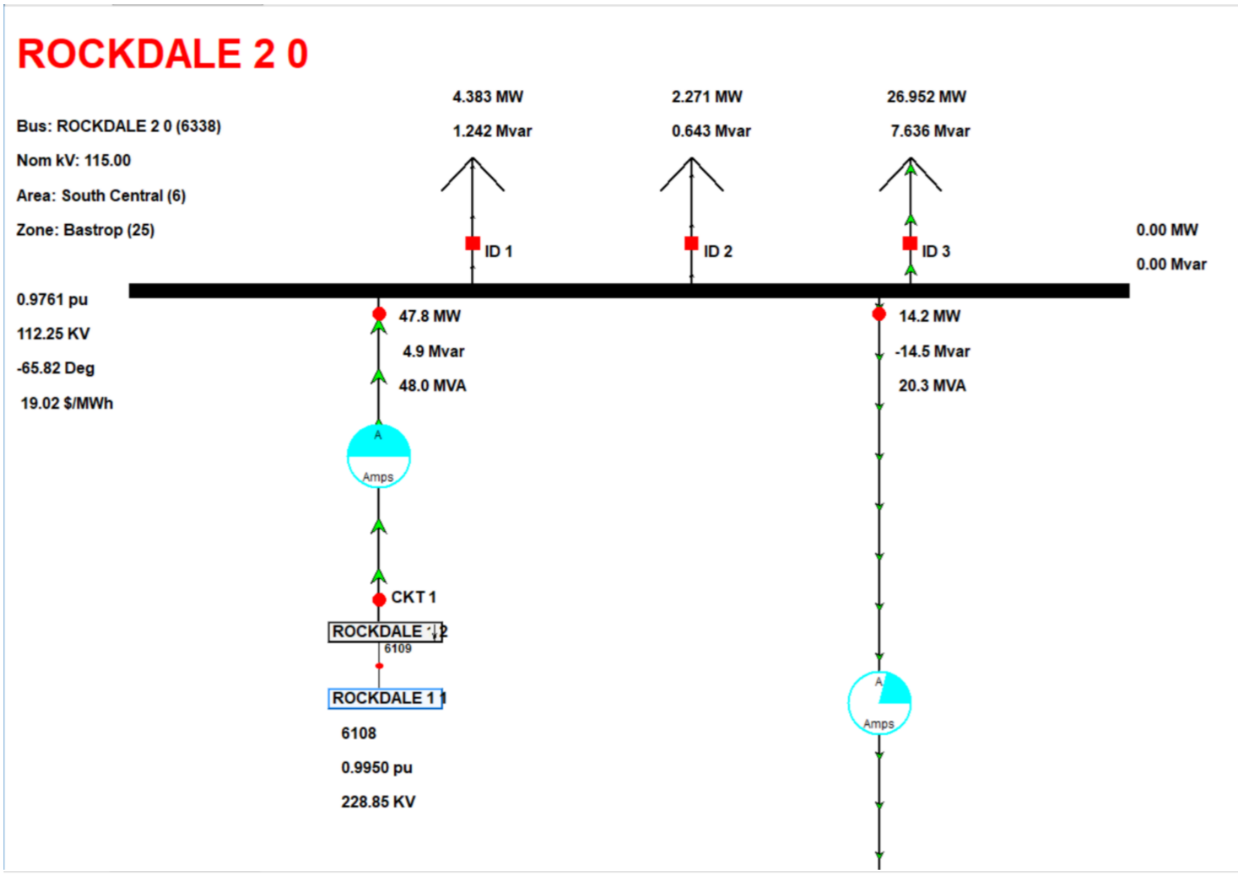
Note: While an outage of some of the lines can reduce system losses, this will often result in fewer loads served, and hence defeating the purpose of a reliable system. Thus, line removal is discouraged

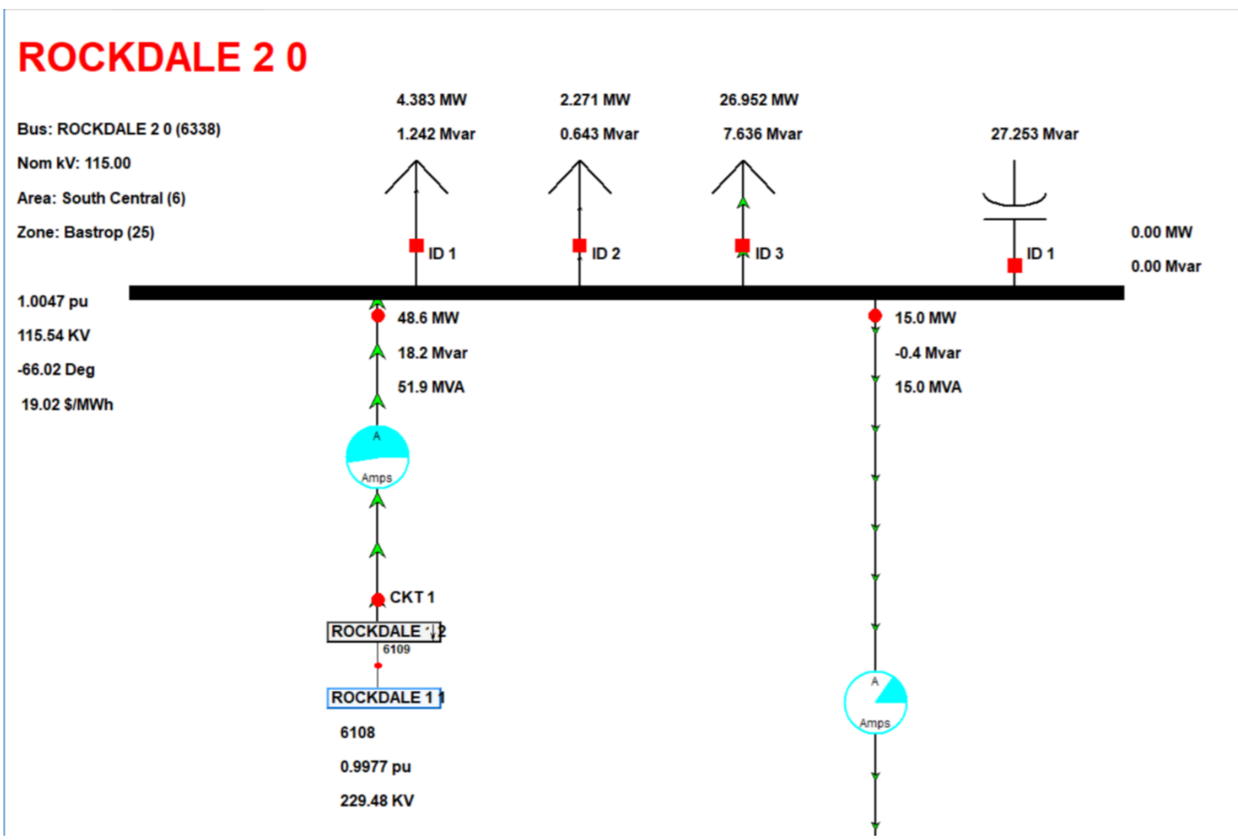


3. For this problem, you are tasked with adding additional shunt capacitors to improve the system voltage profile. To make the results unqiue for each student, first open one generator that has a current output of between 200 and 400 MW. Then, using you engineering judgment, select a bus that currently does not have a capacitor and could benefit from additional reactive power support during this contingency. Then, size your capacitor so that when added it changes the voltage at its bus by three percent. Describe the technique you used to size the capacitor. Turn in a zoomed oneline showing you before and after solution.

Sample answer:

For Problem 3 I disabled the Coal generator at ROCKDALE 1 3. I chose this generator because it was supply a proportionally significant number of positive Vars in the area and was also between 200-400MW. I then added a stunt to ROCKDALE 2 0 as show below. The starting voltage was 0.9761pu so 3% higher is 1.005pu. I achieved this by slowly increasing the vars of the capacitor I added which ended up being a nominal 27 Vars. See Before/After screenshots below.


ROCKDALE 2 0
Bus: ROCKDALE 2 0 (6338)
Nom kV: 115.00
Area: South Central (6)
Zone: Bastrop (25)
4.383 MW
1.242 Mvar
2.271 MW
0.643 Mvar
26.952 MW
7.636 Mvar
ID 1
ID 2
ID 3
0.00 MW
0.00 Mvar
0.9761 pu
112.25 KV
-65.82 Deg
19.02 $/MWh
47.8 MW
4.9 Mvar
48.0 MVA
14.2 MW
-14.5 Mvar
20.3 MVA
Amps
CKT 1
ROCKDALE 1 2
6109
ROCKDALE 1 1
6108
0.9950 pu
228.85 KV


ROCKDALE 2 0
Bus: ROCKDALE 2 0 (6338)
Nom kV: 115.00
Area: South Central (6)
Zone: Bastrop (25)
4.383 MW
1.242 Mvar
2.271 MW
0.643 Mvar
26.952 MW
7.636 Mvar
27.253 Mvar
ID 1
ID 2
ID 3
ID 1
0.00 MW
0.00 Mvar
1.0047 pu
115.54 KV
-66.02 Deg
19.02 $/MWh
48.6 MW
18.2 Mvar
51.9 MVA
15.0 MW
-0.4 Mvar
15.0 MVA
Amps
CKT 1
ROCKDALE 1 2
6109
ROCKDALE 1 1
6108
0.9977 pu
229.48 KV