[Advanced Power Flow Capstone Project B팀]

2024학년도 1학기 전기공학전공 자기설계학점

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Introduction

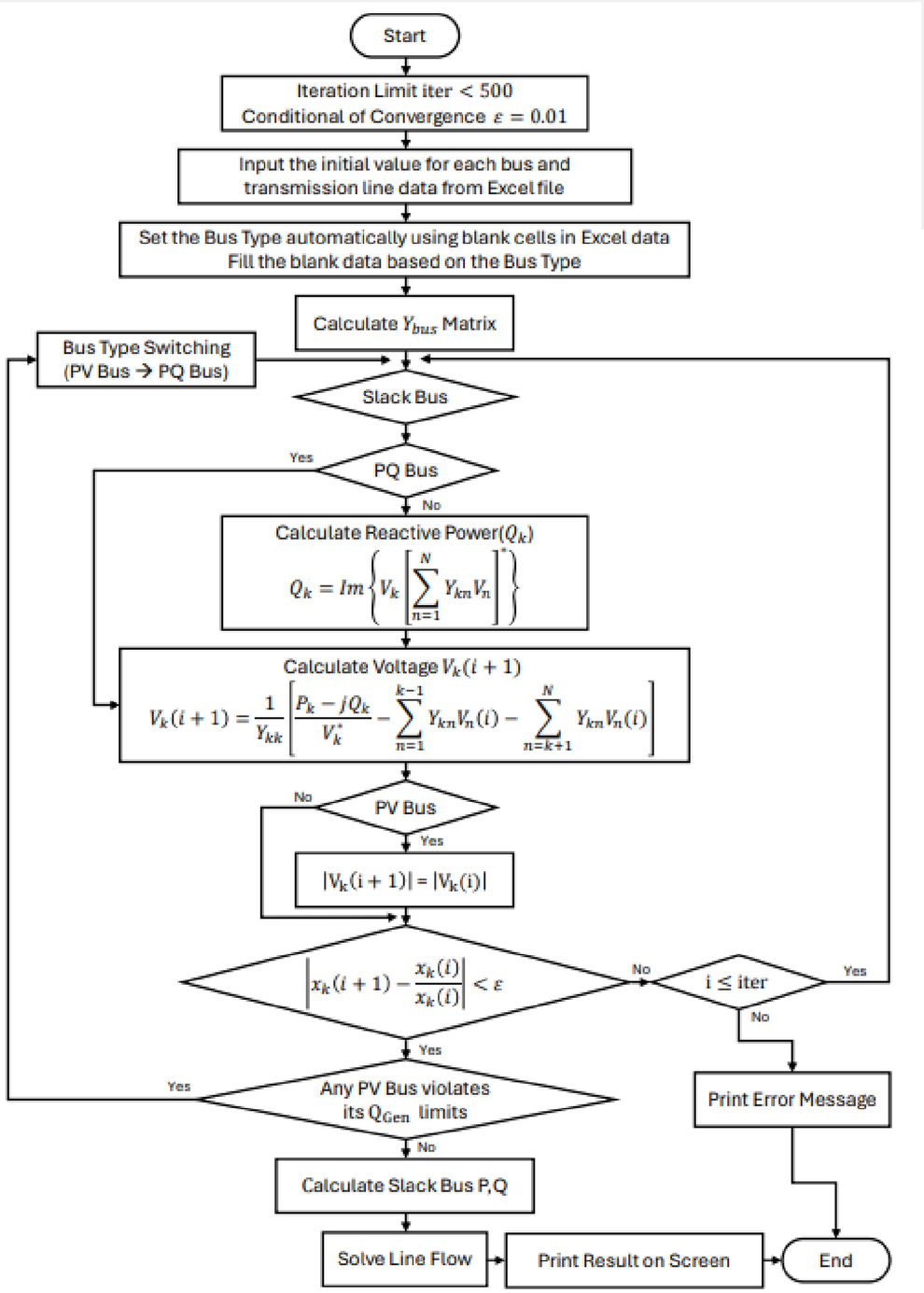
전력 계통을 관리하는데 필요한 전력 조류 계산 프로그램의 기초를 직접 구현하여 계통을 구성하는 각 모선의 전압, 전류, 전력의 분포와 선로에 흐르는 전력을 파악

Jacobi Method를 이용하여 임의의 모선 개수에 대해 전력 조류 계산이 가능한 MATLAB 프로그램 개발

전력공학, 수치해석 등 전공 지식 이해도 및 MATLAB 프로그래밍 능력 향상, 팀별, 단체 세미나를 통한 협동심 증대

Algorithm Flow Chart

1. Read Excel Raw Data
2. Automatic Set of the Bus Type & Initial Value
3. Calculate Y Bus Matrix
4. Calculate Unknown Value of Each Bus
5. Bus Type Switching & Recalculation



Power Flow Calculation

Main Code

```m
% Advanced Power Flow Capstone Project Team B (Jacobi Method)
% Main Code

clear; clc;

format short

fprintf('<2024-1학기 전기공학전공 자기설계학점 : Advanced Power Flow 캡스톤 프로젝트>\n');
fprintf('[융합전자공학과 201910906 이학민]\n\n');

% import Bus Data File
% bus_file = 'example6.10_bus.xlsx';
% bus_file = 'example6.38_bus.xlsx';
% bus_file = 'ieee5bus_bus.xlsx';
bus_file = 'ieee9bus_bus.xlsx';
% bus_file = 'ieee14bus_bus.xlsx';
% bus_file = 'ieee30bus_bus.xlsx';

if exist(bus_file, 'file')
    disp([bus_file ' 파일을 정상적으로 읽었습니다.']);
else
    disp('파일을 정상적으로 불러올 수 없어 프로그램을 종료합니다.');
end

% import Line Data File
% line_file = 'example6.10_line.xlsx';
% line_file = 'example6.38_line.xlsx';
% line_file = 'ieee5bus_line.xlsx';
line_file = 'ieee9bus_line.xlsx';
% line_file = 'ieee14bus_line.xlsx';
% line_file = 'ieee30bus_line.xlsx';

if exist(line_file, 'file')
    disp([line_file ' 파일을 정상적으로 읽었습니다.']);
else
    disp('파일을 정상적으로 불러올 수 없어 프로그램을 종료합니다.');
end

% ITERATION = input('Iteration Limit : ');
ITERATION = 10000;      % [Iteration-1] of Repeat

% thd = input("\nThreshold Value of Approximate Relative Error[%] : ");
thd = 0.00000001;        % Percent[%]

% Initialize Values
[SIZE,V,Delta,P,Q,P_G,Q_G,P_L,Q_L,Q_Gmax,Q_Gmin,Bus_Type,Switch_Sig] = Init_Value(bus_file,ITERATION);

% Set Line Data (Combination of TL & TR data)
[raw_L_data,L_data] = import_L_Data(line_file,SIZE);

% Y matrix Calculation
[Y,Ybus] = Y_Mat_Calc(SIZE,L_data);

% Unknowns Calculation (Jacobi Method)
[V,Delta,P,Q,Bus_Type,P_G,P_L,Q_G,Q_L,Q_Gmax,Q_Gmin,i,err_V,Switch_Sig] ...
    = Unknowns_Calc(SIZE,ITERATION,thd,Y,V,Delta,Bus_Type,P,Q,P_G,P_L,Q_G,Q_L,Q_Gmax,Q_Gmin,Switch_Sig);

% Print Results
[BusOutputData,LineOutputData] = Prt_Result(i,ITERATION,SIZE,Y,err_V,V,Delta,P_G,Q_G,P_L,Q_L,raw_L_data);

% Export Results to Excel File
export_Result(Ybus,BusOutputData,LineOutputData);
```

Power Flow Calculation

Read Excel Raw Data

```
% import Bus Data File
% bus_file = 'example6.10_bus.xlsx';
% bus_file = 'example6.38_bus.xlsx';
% bus_file = 'ieee5bus_bus.xlsx';
bus_file = 'ieee9bus_bus.xlsx';
% bus_file = 'ieee14bus_bus.xlsx';
% bus_file = 'ieee30bus_bus.xlsx';

% import Line Data File
% line_file = 'example6.10_line.xlsx';
% line_file = 'example6.38_line.xlsx';
% line_file = 'ieee5bus_line.xlsx';
line_file = 'ieee9bus_line.xlsx';
% line_file = 'ieee14bus_line.xlsx';
% line_file = 'ieee30bus_line.xlsx';

% Initialize Values
[SIZE,V,Delta,P_G,Q_G,P_L,Q_L,Q_Gmax,Q_Gmin,P,Q,Bus_Type,Switch_Sig] = Init_Value(bus_file,ITERATION);

% Set Line Data (Combination of TL & TR data)
[L_Mat,L_data] = import_L_Data(line_file,SIZE);
```

<5모선(1) - 교재 EX 6.10>

Bus data)

	A	B	C	D	E	F	G	H	I	J
1	Bus Num	Bus Type	V	Delta	Pg	Qg	PL	QL	Q_Gmax	Q_Gmin
2	1		1	0			0	0		
3	2				0	0	8	2.8		
4	3		1.05	0	5.2	0	0.8	0.4	4	-2.8
5	4				0	0	0	0		
6	5				0	0	0	0		

Line data)

	A	B	C	D	E	F	G	H	I
1	Line Num	from	to	R	X	G	B	maxMVA	TAP
2	1	2	4	0.009	0.1	0	1.72	12	0
3	2	2	5	0.0045	0.05	0	0.88	12	0
4	3	4	5	0.00225	0.025	0	0.44	12	0
5	4	1	5	0.0015	0.02	0	0	6	1
6	5	3	4	0.00075	0.01	0	0	10	1

Main code 내에서 Excel 파일을 읽어 Initial Value 지정, Line data 설정

Power Flow Calculation

Bus Type Setting

BusType_Init.m

```
% BusType Initialization

function [raw_B_data] = BusType_Init(raw_B_data,SIZE)

    for i = 1:SIZE
        if isnan(raw_B_data(i,3)) && isnan(raw_B_data(i,4)) % PQ Bus
            raw_B_data(i,2) = 2;    % Bus Type
            raw_B_data(i,3) = 1.0;  % V
            raw_B_data(i,4) = 0;    % Phase
            raw_B_data(i,9) = 0; raw_B_data(i,10) = 0;  % Q_G limit

        elseif ~(isnan(raw_B_data(i,9)) || isnan(raw_B_data(i,10)))   % PV Bus
            raw_B_data(i,2) = 1;    % Bus Type
            raw_B_data(i,4) = 0;    % Phase

        else    % Slack Bus
            raw_B_data(i,2) = 0;    % Bus Type
            raw_B_data(i,5) = 0;    % P_G
            raw_B_data(i,6) = 0;    % Q_G
            raw_B_data(i,9) = 0; raw_B_data(i,10) = 0;  % Q_G limit
        end
    end

end
```

[모선 종류 구분 기준]

PQ Bus(2) : 모선의 전압과 위상의 크기가 입력되어 있지 않을 때

PV Bus(1) : 모선의 Q_G limit이 입력되어 있을 때

Slack bus(0) : 위의 두 가지 경우에 해당하지 않을 때

[모선 종류에 따른 초기화]

PQ Bus : V=1.0, δ=0, Q_G 의 max, min =0 으로 설정

PV Bus : δ =0으로 설정

Slack Bus : P_G, Q_G의 limit을 모두 0으로 설정

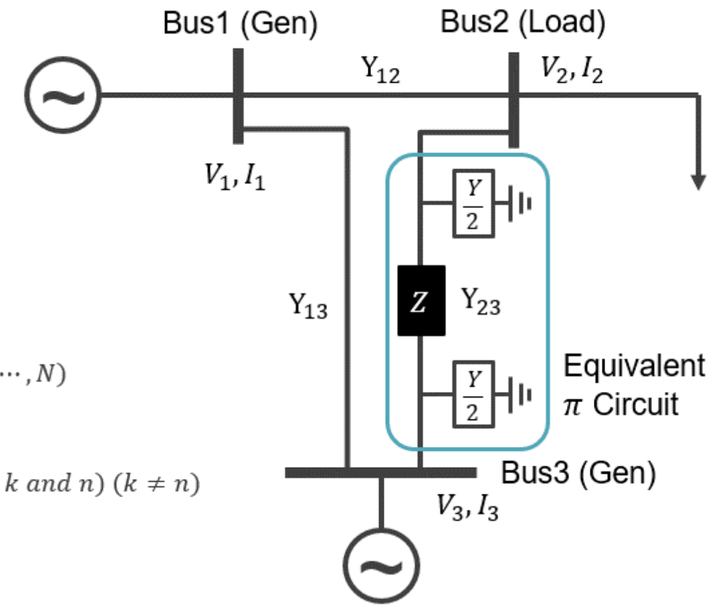
Power Flow Calculation

Y Bus Matrix

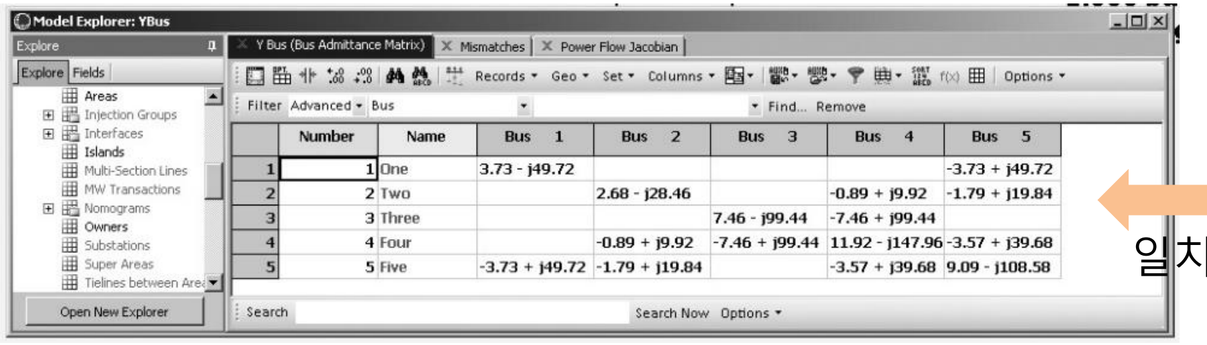
- Node Voltage Method based on KCL
- Network Equation : $\boldsymbol{YV} = \boldsymbol{I}$
- $\boldsymbol{Y}$ is called "**Y** bus Matrix"
- $\boldsymbol{I}$: Bus로 주입되는 전류
- N x N bus admittance matrix (symmetric)
  - Diagonal elements

    : $Y_{kk} = sum\ of\ Y\ connected\ to\ bus\ k\ (k = 1, 2, \cdots, N)$
  - Off-diagonal elements

    : $Y_{kn} = -\ (sum\ of\ Y\ connected\ between\ buses\ k\ and\ n)\ (k \neq n)$




```
% Y matrix Calculation

function Y = Y_Mat_Calc(SIZE,L_data)

    Y = zeros(SIZE);

    for i = 1:SIZE          % Diagonal elements
        for j = 1:SIZE
            if i==j
                for k = 1:SIZE
                    if complex(L_data(i,1,k),L_data(i,2,k)) ~= 0
                        Y(i,j) = Y(i,j) + 1/complex(L_data(i,1,k),L_data(i,2,k));
                    end
                    Y(i,j) = Y(i,j) + complex(L_data(i,3,k),L_data(i,4,k))/2;
                end

            else          % Off-diagonal elements
                if complex(L_data(i,1,j),L_data(i,2,j)) ~= 0
                    Y(i,j) = -(1/complex(L_data(i,1,j),L_data(i,2,j)));
                else
                    Y(i,j) = 0;
                end
            end
        end
    end
end
```



Number	Name	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5
1	One	3.73 - j49.72				-3.73 + j49.72
2	Two		2.68 - j28.46		-0.89 + j9.92	-1.79 + j19.84
3	Three			7.46 - j99.44	-7.46 + j99.44	
4	Four		-0.89 + j9.92	-7.46 + j99.44	11.92 - j147.96	-3.57 + j39.68
5	Five	-3.73 + j49.72	-1.79 + j19.84		-3.57 + j39.68	9.09 - j108.58

일치!

Y

5x5 complex double

	1	2	3	4	5
1	3.7290 - 49.7203i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	-3.7290 + 49.7203i
2	0.0000 + 0.0000i	2.6783 - 28.4590i	0.0000 + 0.0000i	-0.8928 + 9.9197i	-1.7855 + 19.8393i
3	0.0000 + 0.0000i	0.0000 + 0.0000i	7.4580 - 99.4406i	-7.4580 + 99.4406i	0.0000 + 0.0000i
4	0.0000 + 0.0000i	-0.8928 + 9.9197i	-7.4580 + 99.4406i	1.1922e+01 - 1.4796e+02i	-3.5711 + 39.6786i
5	-3.7290 + 49.7203i	-1.7855 + 19.8393i	0.0000 + 0.0000i	-3.5711 + 39.6786i	9.0856e+00 - 1.0858e+02i

Power Flow Calculation

Power Flow Calculation Module

```
% Unknowns Calculation using Jacobi Method

function [V,Delta,P,Q,Bus_Type,P_G,P_L,Q_G,Q_L,Q_Gmax,Q_Gmin,i,err_V,Switch_Sig] ...
    = Unknowns_Calc(SIZE,ITERATION,thd,Y,V,Delta,Bus_Type,P,Q,P_G,P_L,Q_G,Q_L,Q_Gmax,Q_Gmin,Switch_Sig)

    Recal = 0;

    for i = 1:ITERATION

        if i == ITERATION
            break;
        end

        for k = 1:SIZE      % Bus1 ~ Bus(SIZE)
            [V,Delta,P,Q,P_G,P_L,Q_G,Q_L,Bus_Type,Switch_Sig] ...
            = Total_Bus_Calc(i,k,SIZE,Y,V,Delta,P,Q,P_G,P_L,Q_G,Q_L,Q_Gmax,Q_Gmin,Bus_Type,Switch_Sig);
        end

        err_V = Error_Calc(SIZE,ITERATION,i,V);
        STOP = STOP_SIGNAL(i,err_V,thd);

        if STOP == 1            % STOP signal이 발생하면 Slack Bus의 P,Q를 계산
            for k = 1:SIZE
                if Bus_Type(k,i+1) == 0
                    [P,Q,P_G,Q_G] = Slack_Bus_Calc(SIZE,k,i,Y,V,Delta,P,Q,P_G,Q_G,P_L,Q_L);
                end
            end

            for k = 1:SIZE          % Q_G limit 벗어날 시 PQ Bus 전환 계산
                if Bus_Type(k,i+1) == 1 & (Q_G(k,i+1) < Q_Gmin(k,1) | Q_G(k,i+1) > Q_Gmax(k,1))  % PV Bus에만 적용, 최종 결과의 Q_G 수렴 여부를 판단
                    Recal = 1;
                    for n = 1:ITERATION
                        if Q_G(k,n) < Q_Gmin(k,1)   % Bus별 Q_G의 min limit 미만 최초 위치를 찾음
                            Switch_Sig(k,n-1) = 1;
                            Bus_Type(k,n-1:ITERATION) = 3;  % Load Bus로 전환
                            break;
                        elseif Q_G(k,n) > Q_Gmax(k,1) % Bus별 Q_G의 max limit 초과 최초 위치를 찾음
                            Switch_Sig(k,n-1) = 2;
                            Bus_Type(k,n-1:ITERATION) = 3;  % Load Bus로 전환
                            break;
                        end
                    end
                end
            end
            break;
        end
    end

    if Recal == 1

        for i = 1:ITERATION     % 바뀐 Bus Type으로 재계산

            if i == ITERATION
                break;
            end

            for k = 1:SIZE      % Bus1 ~ Bus(SIZE)
                [V,Delta,P,Q,P_G,P_L,Q_G,Q_L,Bus_Type,Switch_Sig] ...
                    = Total_Bus_Calc(i,k,SIZE,Y,V,Delta,P,Q,P_G,P_L,Q_G,Q_L,Q_Gmax,Q_Gmin,Bus_Type,Switch_Sig);
            end

            err_V = Error_Calc(SIZE,ITERATION,i,V);
            STOP2 = STOP_SIGNAL(i,err_V,thd);

            if STOP2 == 1           % STOP signal이 발생하면 Slack Bus의 P,Q를 계산
                for k = 1:SIZE
                    if Bus_Type(k,i+1) == 0
                        [P,Q,P_G,Q_G] = Slack_Bus_Calc(SIZE,k,i,Y,V,Delta,P,Q,P_G,Q_G,P_L,Q_L);
                    end
                end
                break;
            end
        end
    end
```

1. 근사 상대 백분율 오차에 따른 정지 신호 생성
2. Slack Bus의 P, Q 계산
3. PV Bus의 Q_G limit 초과 시 Bus Type Switching 후 처음부터 재계산

Power Flow Calculation

Unknowns Calculation for each bus (iterations)

```
function [V,Delta,P,Q,P_G,P_L,Q_G,Q_L,Bus_Type,Switch_Sig] ...
            = Total_Bus_Calc(i,k,SIZE,Y,V,Delta,P,Q,P_G,P_L,Q_G,Q_L,Q_Gmax,Q_Gmin,Bus_Type,Switch_Sig)

    switch Bus_Type(k,i)
        case 0  % For Slack Bus (Swing)
            V(k,i+1) = V(k,i);  % V = 1R0 (초기 설정)을 계속 유지
            Delta(k,i+1) = Delta(k,i+1);
            P_G(k,i+1) = P_G(k,i);
            Q_G(k,i+1) = Q_G(k,i);
            P_L(k,i+1) = P_L(k,i);
            Q_L(k,i+1) = Q_L(k,i);
            P(k,i+1) = P_G(k,i+1) - P_L(k,i+1);
            Q(k,i+1) = Q_G(k,i+1) - Q_L(k,i+1);

        case 1  % For PV Bus (Gen)
            [Q,Q_G,Q_L] = PV_Q_Calc(k,i,Y,V,Delta,Q_G,Q_L,Q,SIZE);
            P_G(k,i+1) = P_G(k,i);
            P_L(k,i+1) = P_L(k,i);
            P(k,i+1) = P_G(k,i+1) - P_L(k,i+1);

            [Delta,V] = PV_Bus_Calc(SIZE,k,i,Y,V,Delta,P,Q);

        case 2  % For PQ Bus (Load)
            P_G(k,i+1) = P_G(k,i);
            P_L(k,i+1) = P_L(k,i);
            Q_G(k,i+1) = Q_G(k,i);
            Q_L(k,i+1) = Q_L(k,i);
            P(k,i+1) = P_G(k,i+1) - P_L(k,i+1);
            Q(k,i+1) = Q_G(k,i+1) - Q_L(k,i+1);

            [V,Delta] = PQ_Bus_Calc(SIZE,k,i,Y,V,Delta,P,Q);
```

P

9x10000 double

	1	2	3	4	5	6	7	8	9	10
1	0	0	0	0	0	0	0	0	0	0
2	1.6300	1.6300	1.6300	1.6300	1.6300	1.6300	1.6300	1.6300	1.6300	1.6300
3	0.8500	0.8500	0.8500	0.8500	0.8500	0.8500	0.8500	0.8500	0.8500	0.8500
4	0	0	0	0	0	0	0	0	0	0
5	-1.2500	-1.2500	-1.2500	-1.2500	-1.2500	-1.2500	-1.2500	-1.2500	-1.2500	-1.2500
6	-0.9000	-0.9000	-0.9000	-0.9000	-0.9000	-0.9000	-0.9000	-0.9000	-0.9000	-0.9000
7	0	0	0	0	0	0	0	0	0	0
8	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
9	0	0	0	0	0	0	0	0	0	0

Q

9x10000 double

	1	2	3	4	5	6	7	8	9	10
1	0	0	0	0	0	0	0	0	0	0
2	0	0.4100	0.2016	0.2959	0.1350	0.1894	0.0964	0.1293	0.0770	0.0962
3	0	0.4373	0.0746	0.1411	-0.0324	0.0211	-0.0748	-0.0406	-0.0946	-0.0739
4	0	0	0	0	0	0	0	0	0	0
5	-0.5000	-0.5000	-0.5000	-0.5000	-0.5000	-0.5000	-0.5000	-0.5000	-0.5000	-0.5000
6	-0.3000	-0.3000	-0.3000	-0.3000	-0.3000	-0.3000	-0.3000	-0.3000	-0.3000	-0.3000
7	0	0	0	0	0	0	0	0	0	0
8	-0.3500	-0.3500	-0.3500	-0.3500	-0.3500	-0.3500	-0.3500	-0.3500	-0.3500	-0.3500
9	0	0	0	0	0	0	0	0	0	0

V

9x10000 double

	1	2	3	4	5	6	7	8	9	10
1	1.0400	1.0400	1.0400	1.0400	1.0400	1.0400	1.0400	1.0400	1.0400	1.0400
2	1.0250	1.0250	1.0250	1.0250	1.0250	1.0250	1.0250	1.0250	1.0250	1.0250
3	1.0250	1.0250	1.0250	1.0250	1.0250	1.0250	1.0250	1.0250	1.0250	1.0250
4	1	1.0218	1.0109	1.0234	1.0179	1.0250	1.0220	1.0259	1.0243	1.0265
5	1	0.9718	0.9930	0.9817	0.9944	0.9886	0.9958	0.9925	0.9966	0.9947
6	1	0.9846	1.0074	0.9981	1.0103	1.0052	1.0120	1.0092	1.0130	1.0114
7	1	1.0176	1.0103	1.0217	1.0175	1.0240	1.0215	1.0251	1.0236	1.0257
8	1	0.9867	1.0066	1.0005	1.0117	1.0078	1.0140	1.0117	1.0152	1.0138
9	1	1.0220	1.0179	1.0280	1.0249	1.0304	1.0284	1.0315	1.0303	1.0321

Delta

9x10000 double

	1	2	3	4	5	6	7	8	9	10
1	0	0	0	0	0	0	0	0	0	0
2	0	5.5384	5.5269	6.4794	6.4345	6.9314	6.9134	7.2078	7.2112	7.4063
3	0	2.7144	2.6325	2.8208	2.7761	2.8324	2.8313	2.8721	2.8953	2.9450
4	0	-0.1027	-2.0805	-2.0375	-2.6860	-2.6208	-2.8256	-2.7708	-2.8261	-2.7849
5	0	-3.9546	-3.9190	-4.9751	-4.8626	-5.1638	-5.0679	-5.1279	-5.0566	-5.0414
6	0	-3.0834	-3.0666	-4.3314	-4.2510	-4.6788	-4.5986	-4.7326	-4.6673	-4.6948
7	0	-0.0784	0.8517	0.8516	1.3316	1.3433	1.6263	1.6474	1.8356	1.8633
8	0	-2.3841	-2.3836	-1.7959	-1.7537	-1.4721	-1.4318	-1.2630	-1.2220	-1.0995
9	0	-0.0933	0.0860	0.0668	0.1148	0.1282	0.1637	0.1950	0.2415	0.2806

Power Flow Calculation

PQ(Load) Bus

- For Load Bus(PQ Bus)
  - To computes V_k and δ_k

$$S_k = V_k I_k^* \rightarrow I_k^* = \frac{S_k}{V_k} = \frac{P_k + jQ_k}{V_k} \rightarrow I_k = \frac{P_k - jQ_k}{V_k^*}$$

$$YV = I$$

$$V_k(i+1) = V_k \angle \delta_k(i+1)$$

$$= \frac{1}{Y_{kk}} \left[\frac{P_k - jQ_k}{V_k^*(i)} - \sum_{n=1}^{k-1} Y_{kn} V_n(\cancel{i+1}\ i) - \sum_{n=k+1}^{N} Y_{kn} V_n(i) \right]$$

```
1   % PQ(Load) Bus Calculation
2
3   function [V,Delta] = PQ_Bus_Calc(SIZE,k,i,Y,V,Delta,P,Q)
4       
5       I_k = (P(k,i)-sqrt(-1)*Q(k,i)) / (V(k,i)*exp(-sqrt(-1)*Delta(k,i)*(pi/180)));
6
7       Sum_YV_1 = 0;
8       Sum_YV_2 = 0;
9
10      for n = 1:k-1
11          Sum_YV_1 = Sum_YV_1 + Y(k,n) * (V(n,i)*exp(sqrt(-1)*Delta(n,i)*(pi/180)));
12      end
13
14      for n = k+1:SIZE
15          Sum_YV_2 = Sum_YV_2 + Y(k,n) * (V(n,i)*exp(sqrt(-1)*Delta(n,i)*(pi/180)));
16      end
17
18      V_k = (1/Y(k,k)) * (I_k - Sum_YV_1 - Sum_YV_2);    % k모선의 i번째 iteration 값 계산
19      V(k,i+1) = sqrt(power(real(V_k),2) + power(imag(V_k),2));
20      Delta(k,i+1) = atan(imag(V_k) / real(V_k)) * (180/pi);
21
22      % Recalculation
23      I_k = (P(k,i)-sqrt(-1)*Q(k,i)) / (V(k,i+1)*exp(-sqrt(-1)*Delta(k,i+1)*(pi/180)));
24      V_k = (1/Y(k,k)) * (I_k - Sum_YV_1 - Sum_YV_2);
25      V(k,i+1) = sqrt(power(real(V_k),2) + power(imag(V_k),2));
26      Delta(k,i+1) = atan(imag(V_k) / real(V_k)) * (180/pi);
```

Update V, δ

Input Data : P, Q
Output Data : V, δ

Power Flow Calculation

PV(Gen) Bus

- For Voltage-controlled Bus(PV Bus)
  - To computes Q_k and δ_k
    - ✓ If Q_G violates its limit, cannot maintain voltage

$$YV = I$$

$$V_k(i+1) = V_k \angle \delta_k(i+1)$$

$$Q_k = V_k(i)\sum_{n=1}^{N} Y_{kn} V_n(i)\sin[\delta_k(i) - \delta_n(i) - \theta_{kn}]$$

$$= \frac{1}{Y_{kk}}\left[\frac{P_k - jQ_k}{V_k^*(i)} - \sum_{n=1}^{k-1} Y_{kn} V_n(\cancel{i+1}\ i) - \sum_{n=k+1}^{N} Y_{kn} V_n(i)\right]$$

```
% PV(Gen) Bus Calculation

function [Delta,V] = PV_Bus_Calc(SIZE,k,i,Y,V,Delta,P,Q)

    I_k = (P(k,i)-sqrt(-1)*Q(k,i+1)) / (V(k,i)*exp(-sqrt(-1)*Delta(k,i)*(pi/180)));

    Sum_YV_1 = 0;
    Sum_YV_2 = 0;

    for n = 1:k-1
        Sum_YV_1 = Sum_YV_1 + Y(k,n) * (V(n,i)*exp(sqrt(-1)*Delta(n,i)*(pi/180)));
    end

    for n = k+1:SIZE
        Sum_YV_2 = Sum_YV_2 + Y(k,n) * (V(n,i)*exp(sqrt(-1)*Delta(n,i)*(pi/180)));
    end

    V_k = (1/Y(k,k)) * (I_k - Sum_YV_1 - Sum_YV_2);    % k모선의 i번째 iteration 값 계산

    Delta(k,i+1) = atan(imag(V_k) / real(V_k)) * (180/pi);

    V(k,i+1) = V(k,i);  % V value never change if it's PV Bus
```

Update δ

```
% Calculate PV Bus' Q

function [Q,Q_G,Q_L] = PV_Q_Calc(k,i,Y,V,Delta,Q_G,Q_L,Q,SIZE)

    Sum_YVsin = 0;
    for n = 1:SIZE
        Sum_YVsin = Sum_YVsin + abs(Y(k,n)) * V(n,i) ...
                    * sin((Delta(k,i) - Delta(n,i) - angle(Y(k,n))*(180/pi)) * (pi/180));
    end

    Q(k,i+1) = V(k,i) * Sum_YVsin;
    Q_L(k,i+1) = Q_L(k,i);
    Q_G(k,i+1) = Q(k,i+1) + Q_L(k,i+1);

end
```

Update Q

Input Data : P, V
Output Data : Q, δ

Power Flow Calculation

Slack(Swing) Bus

```
% Slack(Swing) Bus Calculation

function [P,Q,P_G,Q_G] = Slack_Bus_Calc(SIZE,k,i,Y,V,Delta,P,Q,P_G,Q_G,P_L,Q_L)

    for n = 1:SIZE
        P(k,i+1) = P(k,i+1) + V(k,1)*abs(Y(1,n))*V(n,i+1)*cos((Delta(n,i+1)+angle(Y(1,n))*(180/pi))*(pi/180))
    end

    for n = 1:SIZE
        Q(k,i+1) = Q(k,i+1) + V(k,1)*abs(Y(1,n))*V(n,i+1)*sin((Delta(n,i+1)+angle(Y(1,n))*(180/pi))*(pi/180))
    end
    Q(k,i+1) = -Q(k,i+1);

    P_G(k,i+1) = P(k,i+1) - P_L(k,i+1);
    Q_G(k,i+1) = Q(k,i+1) - Q_L(k,i+1);

end
```

Update P, Q

Input Data : V, δ
Output Data : P, Q

- For Swing Bus(Slack Bus)
  - No iterations are needed to computes P_1 and Q_1 for swing bus

$$P_1 = V_1 \sum_{n=1}^{N} Y_{1n} V_n \cos(\delta_1 - \delta_n - \theta_{1n}) = \sum_{n=1}^{N} Y_{1n} V_n \cos(\delta_n + \theta_{1n})$$

$$Q_1 = V_1 \sum_{n=1}^{N} Y_{1n} V_n \sin(\delta_1 - \delta_n - \theta_{1n}) = -\sum_{n=1}^{N} Y_{1n} V_n \sin(\delta_n + \theta_{1n})$$

  - 최종적으로 구해진 V, δ의 값을 대입하여 P, Q를 계산할 수 있음.

Power Flow Calculation

Bus Type Switching

```
        case 3   % For PV -> PQ Bus (for keep voltage value)
            P_G(k,i+1) = P_G(k,i);
            P_L(k,i+1) = P_L(k,i);
            Q_L(k,i+1) = Q_L(k,i);
            P(k,i+1) = P_G(k,i+1) - P_L(k,i+1);

            if Switch_Sig(k,i) == 1
                Q_G(k,i) = Q_Gmin(k,1);
                Q(k,i) = Q_G(k,i) - Q_L(k,i);
                Q_G(k,i+1) = Q_G(k,i);
                Q(k,i+1) = Q_G(k,i+1) - Q_L(k,i+1);

            elseif Switch_Sig(k,i) == 2
                Q_G(k,i) = Q_Gmax(k,1);
                Q(k,i) = Q_G(k,i) - Q_L(k,i);
                Q_G(k,i+1) = Q_G(k,i);
                Q(k,i+1) = Q_G(k,i+1) - Q_L(k,i+1);

            else
                Q_G(k,i+1) = Q_G(k,i);
                Q(k,i+1) = Q_G(k,i+1) - Q_L(k,i+1);
            end

            [V,Delta] = PV2PQ_Bus_Calc(SIZE,k,i,Y,V,Delta,P,Q);
    end
```

```
% PV->PQ Bus Calculation

function [V,Delta] = PV2PQ_Bus_Calc(SIZE,k,i,Y,V,Delta,P,Q)

    I_k = (P(k,i)-sqrt(-1)*Q(k,i)) / (V(k,i)*exp(-sqrt(-1)*Delta(k,i)*(pi/180)));

    Sum_YV_1 = 0;
    Sum_YV_2 = 0;

    for n = 1:k-1
        Sum_YV_1 = Sum_YV_1 + Y(k,n) * (V(n,i)*exp(sqrt(-1)*Delta(n,i)*(pi/180)));
    end

    for n = k+1:SIZE
        Sum_YV_2 = Sum_YV_2 + Y(k,n) * (V(n,i)*exp(sqrt(-1)*Delta(n,i)*(pi/180)));
    end

    V_k = (1/Y(k,k)) * (I_k - Sum_YV_1 - Sum_YV_2);    % k모선의 i번째 iteration 값 계산
    Delta(k,i+1) = atan(imag(V_k) / real(V_k)) * (180/pi);
    V(k,i+1) = V(k,i);  % 원래 PV Bus였으면 PQ Bus로 전환되었다고해도 전압은 유지되어야 함.

    % Recalculation
    I_k = (P(k,i)-sqrt(-1)*Q(k,i)) / (V(k,i+1)*exp(-sqrt(-1)*Delta(k,i+1)*(pi/180)));
    V_k = (1/Y(k,k)) * (I_k - Sum_YV_1 - Sum_YV_2);
    Delta(k,i+1) = atan(imag(V_k) / real(V_k)) * (180/pi);

end
```

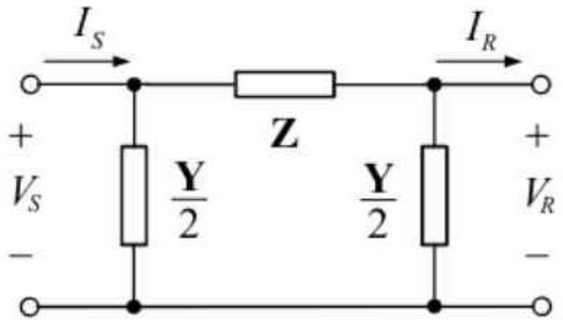
Power Flow Calculation

Line Flow Calculation

$$S_{Zn} = V_n * (V_n^* - V_k^*) * Y_{nk} \qquad S_{Yn} = V_k * V_k^* * y_{kn}$$

$$S_{Zr} = V_k * (V_k^* - V_n^*) * Y_{kn} \qquad S_{Yr} = V_n * V_n^* * y_{nk}$$

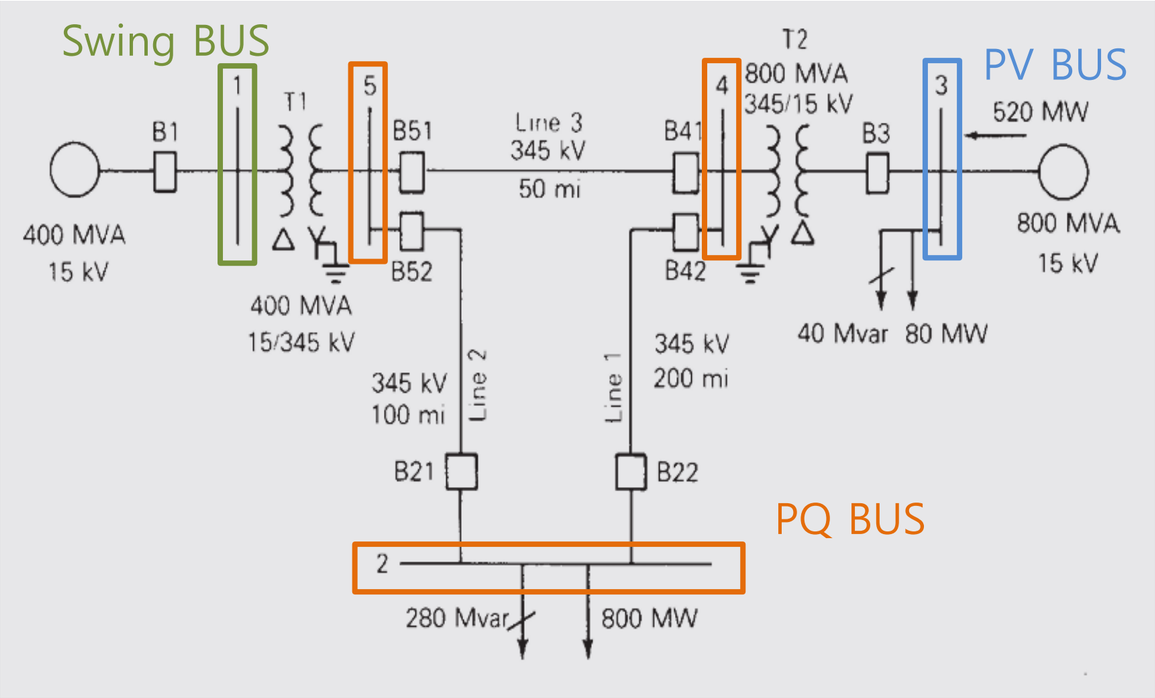
$$S_{nor} = S_{Zn} + S_{Yn} \qquad S_{rev} = S_{Zr} + S_{Yr}$$




```
% Line Flow Calculation

function LineOutputData = Line_Flow_Calc(L_Mat,i,V,Delta,Y)

    L_Mat = repelem(L_Mat,2,1);
    [rows,~] = size(L_Mat);

    LineOutputData = zeros(rows,6);     % Line Flow Data

    LineOutputData(:,1) = L_Mat(:,1);

    for j = 1:rows            % Bus to Bus
        if mod(j,2) == 0
            LineOutputData(j,2) = L_Mat(j,3);
            LineOutputData(j,3) = L_Mat(j,2);
        else
            LineOutputData(j,2) = L_Mat(j,2);
            LineOutputData(j,3) = L_Mat(j,3);
        end
    end

    V_vector = V(:,i+1) .* exp(Delta(:,i+1)*(sqrt(-1)*(pi/180)));

    for j = 1:rows      % P, Q, S

        E = (V_vector(LineOutputData(j,2)) - V_vector(LineOutputData(j,3)));    % Vs - Vr
        I = conj(-1*Y(LineOutputData(j,2),LineOutputData(j,3)))*conj(E);
        S = V_vector(LineOutputData(j,2))*I + V_vector(LineOutputData(j,2))*conj(V_vector(LineOutputData(j,2))*(L_Mat(j,6)+L_Mat(j,7)*sqrt(-1))/2);

        LineOutputData(j,4) = real(S);     % P
        LineOutputData(j,5) = imag(S);     % Q
        LineOutputData(j,6) = abs(S);      % S
    end
end
```

Power Flow Result

Example 6.10 (교재 예제)



Bus-to-Bus	R′ per unit	X′ per unit	G′ per unit	B′ per unit	Maximum MVA per unit
2–4	0.0090	0.100	0	1.72	12.0
2–5	0.0045	0.050	0	0.88	12.0
4–5	0.00225	0.025	0	0.44	12.0

TABLE 6.2
Line input data for Example 6.9

Bus-to-Bus	R per unit	X per unit	G_c per unit	B_m per unit	Maximum MVA per unit	Maximum TAP Setting per unit
1–5	0.00150	0.02	0	0	6.0	—
3–4	0.00075	0.01	0	0	10.0	—

Bus	Input Data	Unknowns
1	$V_1 = 1.0, \delta_1 = 0$	P_1, Q_1
2	$P_2 = P_{G2} - P_{L2} = -8$ $Q_2 = Q_{G2} - Q_{L2} = -2.8$	V_2, δ_2
3	$V_3 = 1.05$ $P_3 = P_{G3} - P_{L3} = 4.4$	Q_3, δ_4
4	$P_4 = 0, Q_4 = 0$	V_4, δ_4
5	$P_5 = 0, Q_5 = 0$	V_5, δ_5

TABLE 6.4
Input data and unknowns for Example 6.9

Power Flow Result

Example 6.10 (교재 예제)

<Bus Output Data for the Power System>

Bus#	Voltage Magnitude(p.u.)	Phase Angle(Deg)	P_G(p.u.)	Q_G(p.u.)	P_L(p.u.)	Q_L(p.u.)
1	1.0000	0.0000	3.9484	1.1428	0.0000	0.0000
2	0.8338	-22.4064	0.0000	0.0000	8.0000	2.8000
3	1.0500	-0.5973	5.2000	3.3748	0.8000	0.4000
4	1.0193	-2.8340	0.0000	0.0000	0.0000	0.0000
5	0.9743	-4.5479	0.0000	0.0000	0.0000	0.0000
	----- TOTAL -----		9.1484	4.5176	8.8000	3.2000

<Line Output Data for the Power System>

Line#	Bus to Bus		P	Q	S
1	2	4	-2.9184	-1.3911	3.2330
1	4	2	3.0368	1.2154	3.2710
2	2	5	-5.0816	-1.4089	5.2733
2	5	2	5.2566	2.6302	5.8779
3	4	5	1.3440	1.5035	2.0167
3	5	4	-1.3336	-1.8253	2.2606
4	1	5	3.9484	1.1428	4.1105
4	5	1	-3.9230	-0.8049	4.0048
5	3	4	4.4000	2.9748	5.3113
5	4	3	-4.3808	-2.7189	5.1560

일치!

Bus #	Voltage Magnitude (per unit)	Phase Angle (degrees)	Generation PG (per unit)	Generation QG (per unit)	Load PL (per unit)	Load QL (per unit)
1	1.000	0.000	3.948	1.144	0.000	0.000
2	0.834	−22.407	0.000	0.000	8.000	2.800
3	1.050	−0.597	5.200	3.376	0.800	0.400
4	1.019	−2.834	0.000	0.000	0.000	0.000
5	0.974	−4.548	0.000	0.000	0.000	0.000
		TOTAL	9.148	4.516	8.800	3.200

Line #	Bus to Bus		P	Q	S
1	2	4	−2.920	−1.392	3.232
	4	2	3.036	1.216	3.272
2	2	5	−5.080	−1.408	5.272
	5	2	5.256	2.632	5.876
3	4	5	1.344	1.504	2.016
	5	4	−1.332	−1.824	2.260

Tran. #	Bus to Bus		P	Q	S
1	1	5	3.948	1.144	4.112
	5	1	−3.924	−0.804	4.004
2	3	4	4.400	2.976	5.312
	4	3	−4.380	−2.720	5.156

TABLE 6.8

Transformer output data for the power system given in Example 6.9

Power Flow Result

Example 6.38 (교재 예제)

Bus Num	Bus Type	V	Delta	Pg	Qg	PL	QL	Q_Gmax	Q_Gmin
1		1	0			0	0		0
2				0	0	1.8	0.6		

Bus Data

Line Num	from	to	R	X	G	B	maxMVA	TAP
1	1	2	0	0.1	0	0	0	0

Line Data

<Bus Output Data for the Power System>

Bus#	Voltage Magnitude(p.u.)	Phase Angle(Deg)	P_G(p.u.)	Q_G(p.u.)	P_L(p.u.)	Q_L(p.u.)
1	1.0000	0.0000	1.8000	1.0301	0.0000	0.0000
2	0.9149	-11.3469	0.0000	0.0000	1.8000	0.6000
----- TOTAL -----			1.8000	1.0301	1.8000	0.6000

<Line Output Data for the Power System>

Line#	Bus to Bus	P	Q	S
1	1 2	1.8000	1.0301	2.0739
1	2 1	-1.8000	-0.6000	1.8974

Power Flow Result

IEEE 5 Bus

Bus Num	Bus Type	V	Delta	Pg	Qg	PL	QL	Q_Gmax	Q_Gmin
1		1.06	0			0	0		
2		1		0.4	0.3	0.2	0.1	9	-9
3				0	0	0.45	0.15		
4				0	0	0.4	0.05		
5				0	0	0.6	0.1		

Bus Data

Line Num	from	to	R	X	G	B	maxMVA	TAP
1	1	2	0.02	0.06	0	0	0.8	0
2	1	3	0.08	0.24	0	0.025	0.3	0
3	2	3	0.06	0.25	0	0.02	0.2	0
4	2	4	0.06	0.18	0	0.02	0.2	0
5	2	5	0.04	0.12	0	0.015	0.6	0
6	3	4	0.01	0.03	0	0.01	0.1	0
7	4	5	0.08	0.24	0	0.025	0.1	0

Line Data

<Bus Output Data for the Power System>

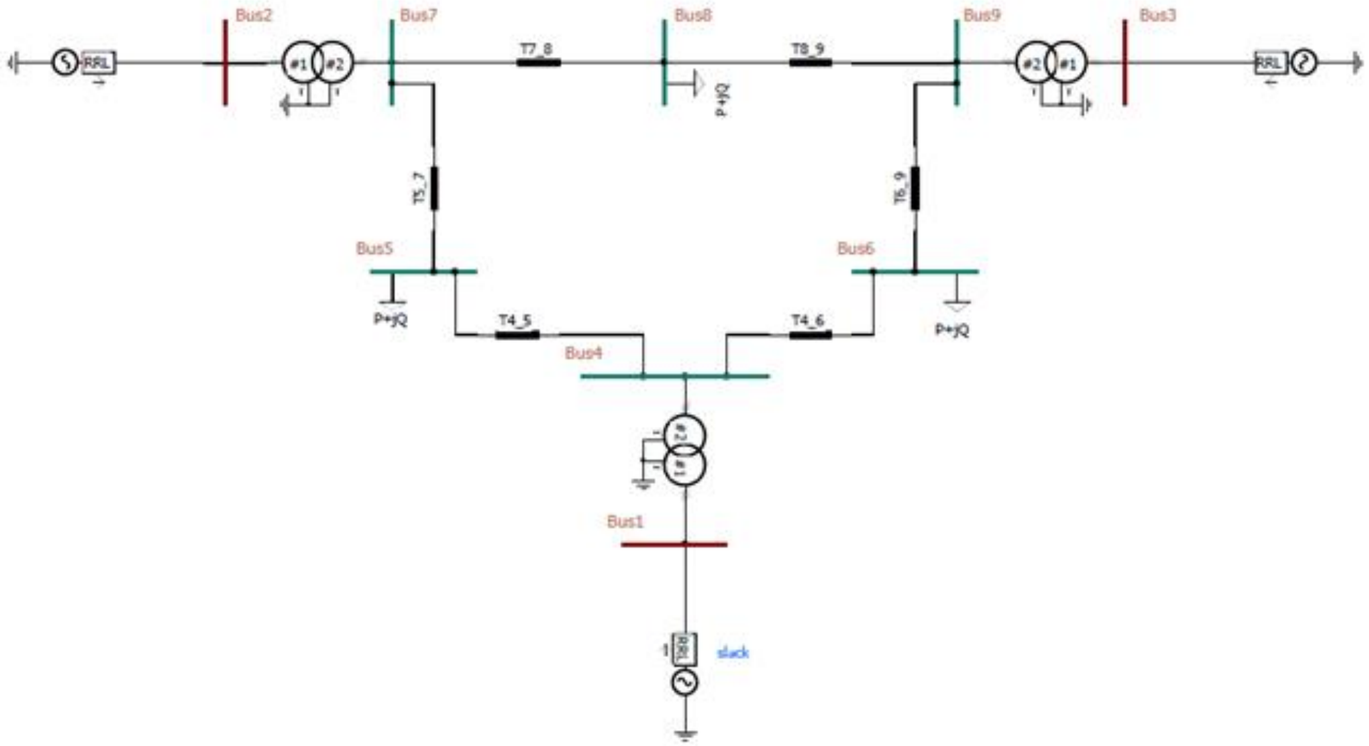
Bus#	Voltage Magnitude(p.u.)	Phase Angle(Deg)	P_G(p.u.)	Q_G(p.u.)	P_L(p.u.)	Q_L(p.u.)
1	1.0600	0.0000	1.3122	0.9734	0.0000	0.0000
2	1.0000	-2.0066	0.4000	-0.4974	0.2000	0.1000
3	0.9833	-4.8137	0.0000	0.0000	0.4500	0.1500
4	0.9801	-5.0757	0.0000	0.0000	0.4000	0.0500
5	0.9687	-5.7467	0.0000	0.0000	0.6000	0.1000
----- TOTAL -----			1.7122	0.4760	1.6500	0.4000

<Line Output Data for the Power System>

Line#	Bus to Bus		P	Q	S
1	1	2	0.8780	0.7782	1.1732
1	2	1	-0.8535	-0.7047	1.1068
2	1	3	0.4342	0.1952	0.4760
2	3	1	-0.4177	-0.1717	0.4516
3	2	3	0.1983	0.0138	0.1988
3	3	2	-0.1960	-0.0235	0.1974
4	2	4	0.2978	0.0088	0.2980
4	4	2	-0.2925	-0.0124	0.2927
5	2	5	0.5573	0.0846	0.5637
5	5	2	-0.5445	-0.0609	0.5479
6	3	4	0.1636	0.0452	0.1697
6	4	3	-0.1633	-0.0539	0.1720
7	4	5	0.0558	0.0164	0.0581
7	5	4	-0.0555	-0.0391	0.0679

Power Flow Result

IEEE 9 Bus



Bus Num	Bus Type	V	Delta	Pg	Qg	PL	QL	Q_Gmax	Q_Gmin
1		1.04	0			0	0		
2		1.025		1.63	0	0	0	3	-3
3		1.025		0.85	0	0	0	3	-3
4				0	0	0	0		
5				0	0	1.25	0.5		
6				0	0	0.9	0.3		
7				0	0	0	0		
8				0	0	1	0.35		
9				0	0	0	0		

Bus Data

Line Num	from	to	R	X	G	B	maxMVA	TAP
1	1	4	0	0.0576	0	0	0	1
2	4	6	0.017	0.092	0	0.158	0	0
3	6	9	0.039	0.17	0	0.358	0	0
4	3	9	0	0.0586	0	0	0	1
5	9	8	0.0119	0.1008	0	0.209	0	0
6	8	7	0.0085	0.072	0	0.149	0	0
7	7	2	0	0.0625	0	0	0	1
8	7	5	0.032	0.161	0	0.306	0	0
9	5	4	0.01	0.085	0	0.176	0	0

Line Data

Power Flow Result

IEEE 9 Bus

Bus		Power at Bus & Line Flow			
From	To	MW[pu]	Mvar[pu]	MVA[pu]	Line Loss[pu]
1	4	0.720	0.270	0.769	0.000
4	1	-0.720	-0.239	0.759	0.000
4	6	0.308	0.010	0.309	0.000
6	4	-0.307	-0.165	0.348	0.002
6	9	-0.593	-0.135	0.609	0.000
9	6	0.607	-0.181	0.633	0.013
3	9	0.849	-0.109	0.856	0.000
9	3	-0.849	0.150	0.862	0.000
9	8	0.242	0.031	0.244	0.000
8	9	-0.241	-0.243	0.342	0.001
8	7	-0.759	-0.107	0.767	0.000
7	8	0.764	-0.008	0.764	0.005
7	2	-1.629	0.092	1.632	0.000
2	7	1.629	0.066	1.631	0.000
7	5	0.865	-0.084	0.869	0.000
5	7	-0.842	-0.113	0.849	0.023
5	4	-0.408	-0.387	0.562	0.000
4	5	0.411	0.229	0.470	0.003

<Bus Output Data for the Power System>

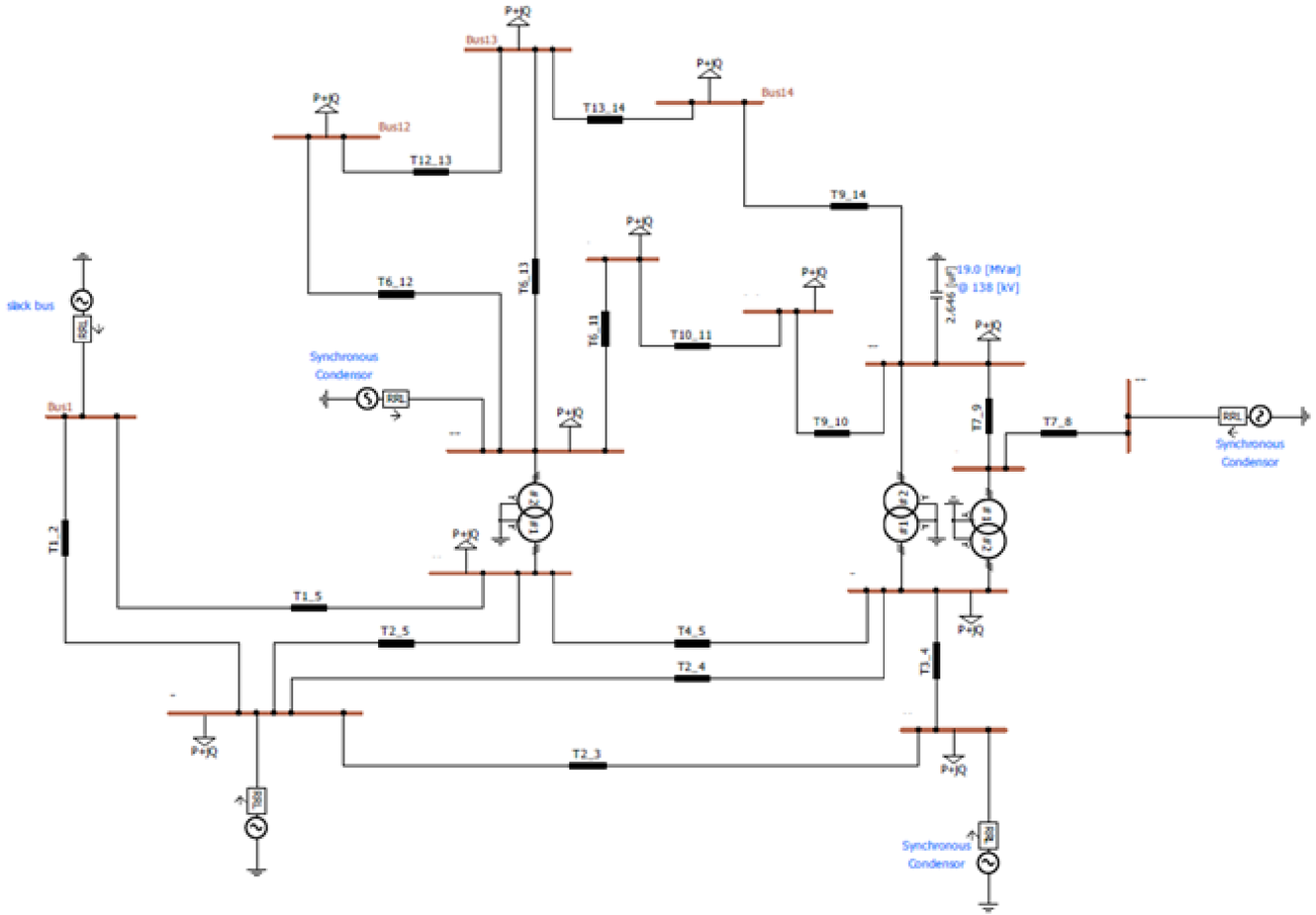
Bus#	Voltage Magnitude(p.u.)	Phase Angle(Deg)	P_G(p.u.)	Q_G(p.u.)	P_L(p.u.)	Q_L(p.u.)
1	1.0400	0.0000	0.7164	0.2705	0.0000	0.0000
2	1.0250	9.2800	1.6300	0.0665	0.0000	0.0000
3	1.0250	4.6647	0.8500	-0.1086	0.0000	0.0000
4	1.0258	-2.2168	0.0000	0.0000	0.0000	0.0000
5	0.9956	-3.9888	0.0000	0.0000	1.2500	0.5000
6	1.0127	-3.6874	0.0000	0.0000	0.9000	0.3000
7	1.0258	3.7197	0.0000	0.0000	0.0000	0.0000
8	1.0159	0.7275	0.0000	0.0000	1.0000	0.3500
9	1.0324	1.9667	0.0000	0.0000	0.0000	0.0000
----- TOTAL -----			3.1964	0.2284	3.1500	1.1500

<Line Output Data for the Power System>

Line#	Bus to Bus		P	Q	S
1	1	4	0.7164	0.2705	0.7658
1	4	1	-0.7164	-0.2392	0.7553
2	4	6	0.3070	0.0103	0.3072
2	6	4	-0.3054	-0.1654	0.3473
3	6	9	-0.5946	-0.1346	0.6097
3	9	6	0.6082	-0.1807	0.6345
4	3	9	0.8500	-0.1086	0.8569
4	9	3	-0.8500	0.1496	0.8631
5	9	8	0.2418	0.0312	0.2438
5	8	9	-0.2410	-0.2430	0.3422
6	8	7	-0.7590	-0.1070	0.7666
6	7	8	0.7638	-0.0080	0.7638
7	7	2	-1.6300	0.0918	1.6326
7	2	7	1.6300	0.0665	1.6314
8	7	5	0.8662	-0.0838	0.8702
8	5	7	-0.8432	-0.1131	0.8508
9	5	4	-0.4068	-0.3869	0.5614
9	4	5	0.4094	0.2289	0.4690

Power Flow Result

IEEE 14 Bus



Bus Num	Bus Type	V	Delta	Pg	Qg	PL	QL	Q_Gmax	Q_Gmin
1		1.06	0			0	0		
2		1.045		0.4	0.424	0.217	0.127	0.5	-0.4
3		1.01		0	0.234	0.942	0.19	0.4	0
4				0	0	0.478	0.039		
5				0	0	0.076	0.016		
6		1.07		0	0.122	0.112	0.075	0.24	-0.06
7				0	0	0	0		
8		1.09		0	0.174	0	0	0.24	-0.06
9				0	0	0.295	0.166		
10				0	0	0.09	0.058		
11				0	0	0.035	0.018		
12				0	0	0.061	0.016		
13				0	0	0.135	0.058		
14				0	0	0.149	0.05		

Bus Data

Line Num	from	to	R	X	G	B	maxMVA	TAP
1	1	2	0.01938	0.05917	0	0.0528	0	0
2	1	5	0.05403	0.22304	0	0.0492	0	0
3	2	3	0.04699	0.19797	0	0.0438	0	0
4	2	4	0.05811	0.17632	0	0.034	0	0
5	2	5	0.05695	0.17388	0	0.0346	0	0
6	3	4	0.06701	0.17103	0	0.0128	0	0
7	4	5	0.01335	0.04211	0	0.0001	0	0
8	4	7	0	0.20912	0	0	0	0.978
9	4	9	0	0.55618	0	0	0	0.969
10	5	6	0	0.25202	0	0	0	0.932
11	6	11	0.09498	0.1989	0	0.0001	0	0
12	6	12	0.12291	0.25581	0	0.0001	0	0
13	6	13	0.06615	0.13027	0	0.0001	0	0
14	7	8	0.0001	0.17615	0	0.0001	0	0
15	7	9	0.0001	0.11001	0	0.0001	0	0
16	9	10	0.03181	0.0845	0	0.0001	0	0
17	9	14	0.12711	0.27038	0	0.0001	0	0
18	10	11	0.08205	0.19207	0	0.0001	0	0
19	12	13	0.22092	0.19988	0	0.0001	0	0
20	13	14	0.17093	0.34802	0	0.0001	0	0

Line Data

Power Flow Result

IEEE 14 Bus

<Bus Output Data for the Power System>

Bus#	Voltage Magnitude(p.u.)	Phase Angle(Deg)	P_G(p.u.)	Q_G(p.u.)	P_L(p.u.)	Q_L(p.u.)
1	1.0600	0.0000	2.2255	-0.2051	0.0000	0.0000
2	1.0450	-4.7514	0.4000	0.3095	0.2170	0.1270
3	1.0100	-12.3143	0.0000	0.2129	0.9420	0.1900
4	1.0241	-9.8924	0.0000	0.0000	0.4780	0.0390
5	1.0322	-8.4888	0.0000	0.0000	0.0760	0.0160
6	1.0700	-13.6122	0.0000	0.2400	0.1120	0.0750
7	1.0435	-12.7779	0.0000	0.0000	0.0000	0.0000
8	1.0900	-12.7791	0.0000	0.2400	0.0000	0.0000
9	1.0258	-14.2921	0.0000	0.0000	0.2950	0.1660
10	1.0259	-14.4528	0.0000	0.0000	0.0900	0.0580
11	1.0440	-14.1477	0.0000	0.0000	0.0350	0.0180
12	1.0530	-14.4875	0.0000	0.0000	0.0610	0.0160
13	1.0459	-14.5391	0.0000	0.0000	0.1350	0.0580
14	1.0162	-15.4336	0.0000	0.0000	0.1490	0.0500
----- TOTAL -----			2.6255	0.7972	2.5900	0.8130

6,8번 PV Bus의 Q_G수렴값이
최대값을 벗어나 PQ Bus로 전환되었음.

Power Flow Result

IEEE 14 Bus

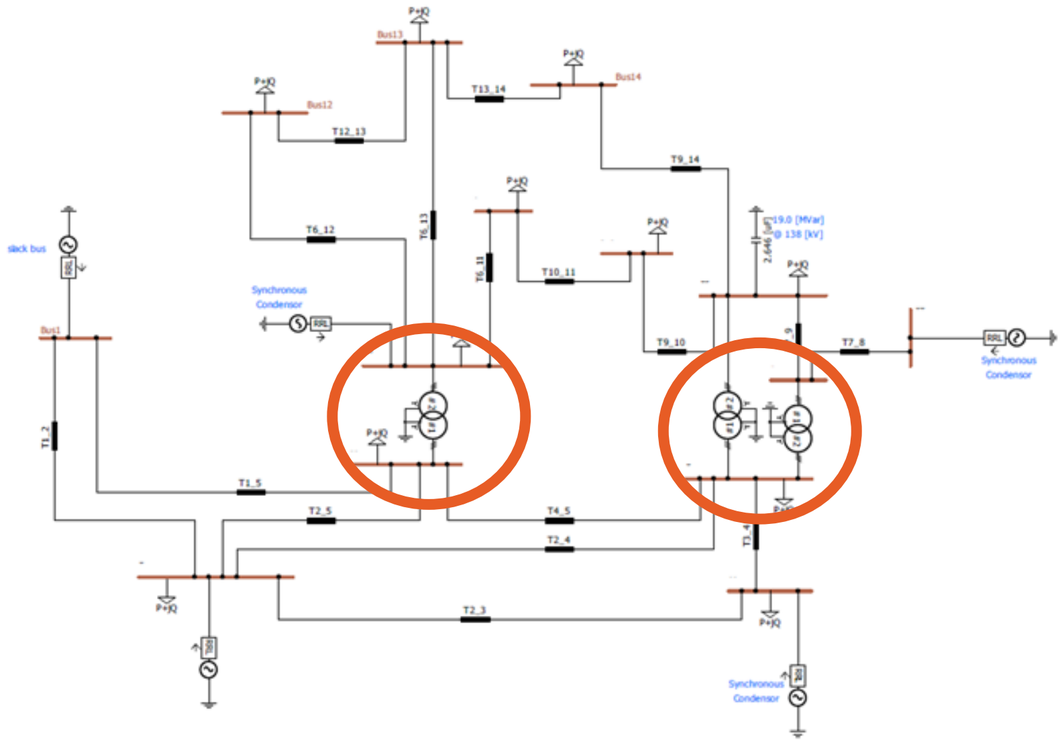
Bus		Power at Bus & Line Flow			
From	To	MW[pu]	Mvar[pu]	MVA[pu]	Line Loss[pu]
1	2	1.464	-0.149	1.471	
2	1	-1.426	0.263	1.450	-0.037
1	5	0.707	0.010	0.707	
5	1	-0.683	0.089	0.688	-0.024
2	3	0.676	0.065	0.680	
3	2	-0.657	0.018	0.657	-0.020
2	4	0.516	-0.026	0.517	
4	2	-0.502	0.069	0.506	-0.014
2	5	0.379	-0.037	0.381	
5	2	-0.372	0.060	0.377	-0.008
3	4	-0.226	0.007	0.226	
4	3	0.229	0.001	0.229	0.003
4	5	-0.587	-0.002	0.587	
5	4	0.592	0.016	0.592	0.004
4	7	0.245	-0.043	0.249	
7	4	-0.245	0.055	0.251	0.000
4	9	0.138	0.039	0.143	
9	4	-0.138	-0.028	0.140	0.000
5	6	0.387	-0.136	0.410	
6	5	-0.387	0.176	0.425	0.000
6	11	0.109	0.133	0.172	
11	6	-0.106	-0.128	0.167	-0.002
6	12	0.085	0.037	0.093	
12	6	-0.084	-0.035	0.091	-0.001
6	13	0.198	0.123	0.233	
13	6	-0.194	-0.117	0.227	-0.003
7	8	0.000	-0.326	0.326	
8	7	0.000	0.344	0.344	0.000
7	9	0.246	0.271	0.366	
9	7	-0.246	-0.257	0.355	0.000
9	10	0.020	-0.049	0.053	
10	9	-0.020	0.049	0.053	0.000
9	14	0.069	-0.022	0.072	
14	9	-0.068	0.024	0.072	-0.001
10	11	-0.070	-0.107	0.128	
11	10	0.071	0.110	0.131	0.001
12	13	0.023	0.019	0.030	
13	12	-0.023	-0.019	0.030	0.000
13	14	0.083	0.078	0.114	
14	13	-0.081	-0.074	0.109	-0.002

<Line Output Data for the Power System>

Line#	Bus to Bus		P	Q	S
1	1	2	1.4989	-0.1876	1.5106
1	2	1	-1.4598	0.2487	1.4808
2	1	5	0.7265	-0.0176	0.7268
2	5	1	-0.7012	0.0685	0.7045
3	2	3	0.7162	0.0372	0.7172
3	3	2	-0.6940	0.0102	0.6940
4	2	4	0.5347	-0.0466	0.5367
4	4	2	-0.5194	0.0565	0.5225
5	2	5	0.3919	-0.0569	0.3960
5	5	2	-0.3838	0.0442	0.3864
6	3	4	-0.2480	0.0127	0.2484
6	4	3	0.2521	-0.0156	0.2526
7	4	5	-0.6129	0.0062	0.6129
7	5	4	0.6176	0.0087	0.6177
8	4	7	0.2573	-0.0887	0.2721
8	7	4	-0.2573	0.1034	0.2773
9	4	9	0.1449	0.0025	0.1449
9	9	4	-0.1449	0.0086	0.1452
10	5	6	0.3913	-0.1375	0.4148
10	6	5	-0.3913	0.1782	0.4300
11	6	11	0.0972	0.0936	0.1349
11	11	6	-0.0957	-0.0905	0.1317
12	6	12	0.0827	0.0319	0.0886
12	12	6	-0.0818	-0.0303	0.0872
13	6	13	0.1909	0.1022	0.2165
13	13	6	-0.1882	-0.0970	0.2117
14	7	8	-0.0000	-0.2753	0.2753
14	8	7	0.0000	0.2874	0.2874
15	7	9	0.2573	0.1718	0.3094
15	9	7	-0.2573	-0.1622	0.3042
16	9	10	0.0300	-0.0131	0.0327
16	10	9	-0.0300	0.0130	0.0327
17	9	14	0.0772	0.0007	0.0772
17	14	9	-0.0764	0.0007	0.0764
18	10	11	-0.0600	-0.0710	0.0930
18	11	10	0.0607	0.0725	0.0946
19	12	13	0.0208	0.0143	0.0253
19	13	12	-0.0207	-0.0143	0.0251
20	13	14	0.0739	0.0533	0.0911
20	14	13	-0.0726	-0.0507	0.0885

Power Flow Result

IEEE 14 Bus

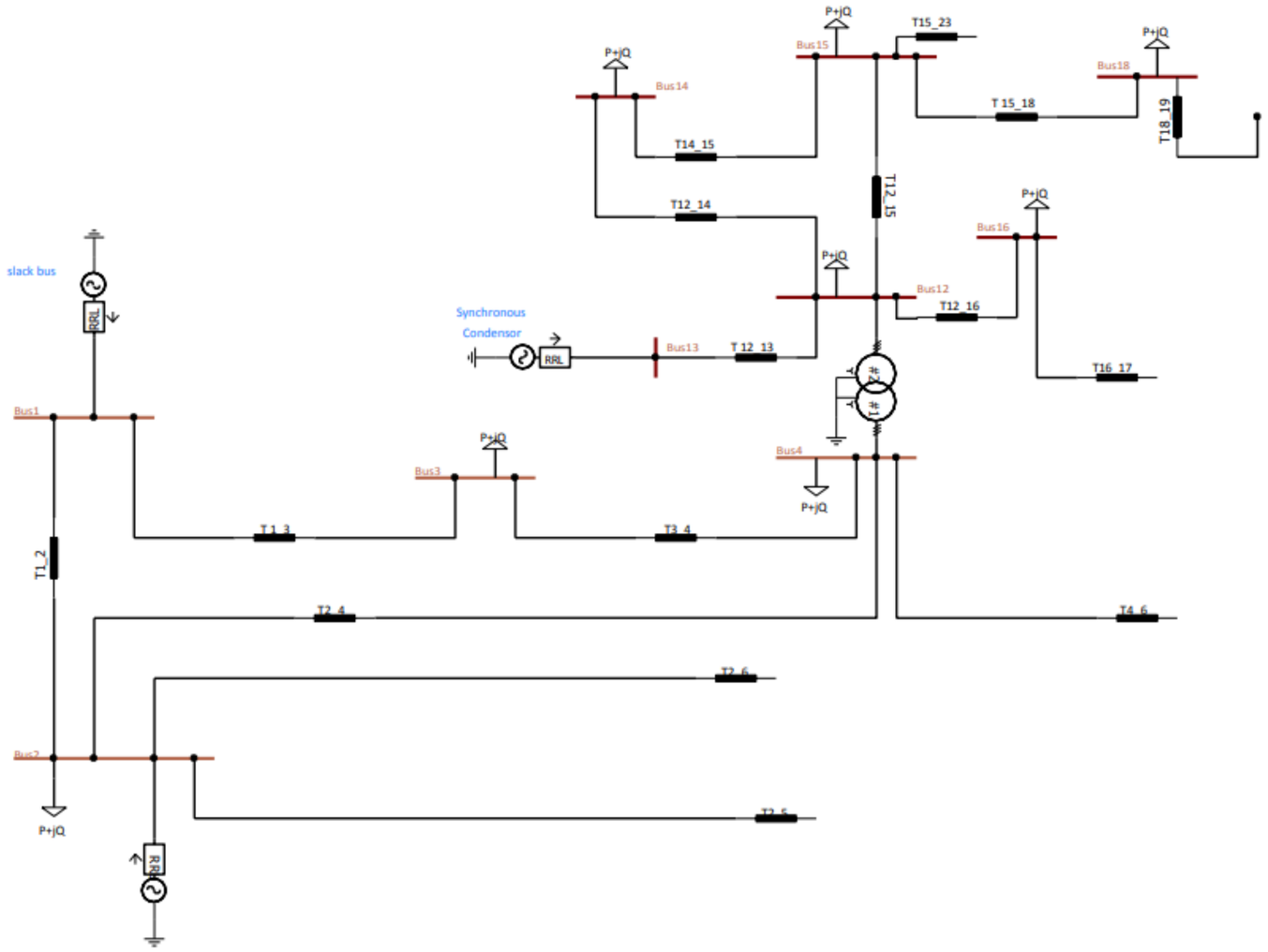


계산 결과가 실제 결과값과 다소 차이가 있음을 확인

→ Transformer Tap 값이 반영되지 않아 생긴 차이로 추정

Power Flow Result

IEEE 30 Bus



Power Flow Result

IEEE 30 Bus

Bus Num	Bus Type	V	Delta	Pg	Qg	PL	QL	Q_Gmax	Q_Gmin
1		1.06	0			0	0		
2		1.04313		0.4	0.5	0.217	0.127	9	-9
3				0	0	0.024	0.012		
4				0	0	0.076	0.016		
5		1.011		0	0.3685	0.942	0.19	9	-9
6				0	0	0	0		
7				0	0	0.228	0.109		
8		1.01		0	0.3714	0.3	0.3	9	-9
9				0	0	0	0		
10				0	0	0.058	0.02		
11		1.082		0	0.1617	0	0	9	-9
12				0	0	0.112	0.075		
13		1.071		0	0.1062	0	0	9	-9
14				0	0	0.062	0.016		
15				0	0	0.082	0.025		
16				0	0	0.035	0.018		
17				0	0	0.09	0.058		
18				0	0	0.032	0.009		
19				0	0	0.095	0.034		
20				0	0	0.022	0.007		
21				0	0	0.175	0.112		
22				0	0	0	0		
23				0	0	0.032	0.016		
24				0	0	0.087	0.067		
25				0	0	0	0		
26				0	0	0.035	0.023		
27				0	0	0	0		
28				0	0	0	0		
29				0	0	0.024	0.009		
30				0	0	0.106	0.019		

Bus Data

Line Num	from	to	R	X	G	B	maxMVA	TAP
1	1	2	0.0192	0.0575	0	0.0528	0	0
2	1	3	0.0452	0.165	0	0.0408	0	0
3	2	4	0.057	0.174	0	0.0368	0	0
4	2	5	0.0472	0.198	0	0.0418	0	0
5	2	6	0.0581	0.176	0	0.0374	0	0
6	3	4	0.0132	0.0379	0	0.0084	0	0
7	4	6	0.0119	0.0414	0	0.009	0	0
8	5	7	0.046	0.116	0	0.0204	0	0
9	6	7	0.0267	0.082	0	0.017	0	0
10	6	8	0.012	0.042	0	0.009	0	0
11	6	28	0.0169	0.0599	0	0.013	0	0
12	8	28	0.0636	0.2	0	0.0428	0	0
13	9	10	0.0001	0.11	0	0.0001	0	0
14	9	11	0.0001	0.208	0	0.0001	0	0
15	10	17	0.0324	0.0845	0	0.0001	0	0
16	10	20	0.0936	0.209	0	0.0001	0	0
17	10	21	0.0348	0.0749	0	0.0001	0	0
18	10	22	0.0727	0.15	0	0.0001	0	0
19	12	13	0.0001	0.14	0	0.0001	0	0
20	12	14	0.123	0.256	0	0.0001	0	0
21	12	15	0.0662	0.13	0	0.0001	0	0
22	12	16	0.0945	0.199	0	0.0001	0	0
23	14	15	0.221	0.2	0	0.0001	0	0
24	15	18	0.107	0.219	0	0.0001	0	0
25	15	23	0.1	0.202	0	0.0001	0	0
26	16	17	0.0524	0.192	0	0.0001	0	0
27	18	19	0.0639	0.129	0	0.0001	0	0
28	19	20	0.034	0.068	0	0.0001	0	0
29	21	22	0.0116	0.0236	0	0.0001	0	0
30	22	24	0.115	0.179	0	0.0001	0	0
31	23	24	0.132	0.27	0	0.0001	0	0
32	24	25	0.189	0.329	0	0.0001	0	0
33	25	26	0.254	0.38	0	0.0001	0	0
34	25	27	0.109	0.209	0	0.0001	0	0
35	27	29	0.22	0.415	0	0.0001	0	0
36	27	30	0.32	0.603	0	0.0001	0	0
37	29	30	0.24	0.453	0	0.0001	0	0
38	4	12	0	0.256	0	0	0	0.932
39	27	28	0	0.396	0	0	0	0.968
40	6	10	0	0.556	0	0	0	0.969
41	6	9	0	0.208	0	0	0	0.978

Line Data

Power Flow Result

IEEE 30 Bus

<Bus Output Data for the Power System>

Bus#	Voltage Magnitude(p.u.)	Phase Angle(Deg)	P_G(p.u.)	Q_G(p.u.)	P_L(p.u.)	Q_L(p.u.)
1	1.0600	0.0000	2.6110	-0.1942	0.0000	0.0000
2	1.0431	-5.3461	0.4000	0.4573	0.2170	0.1270
3	1.0249	-7.5847	0.0000	0.0000	0.0240	0.0120
4	1.0170	-9.3468	0.0000	0.0000	0.0760	0.0160
5	1.0110	-14.1515	0.0000	0.3730	0.9420	0.1900
6	1.0113	-11.0591	0.0000	0.0000	0.0000	0.0000
7	1.0034	-12.8549	0.0000	0.0000	0.2280	0.1090
8	1.0100	-11.7906	0.0000	0.3444	0.3000	0.3000
9	1.0239	-14.2797	0.0000	0.0000	0.0000	0.0000
10	1.0012	-15.9983	0.0000	0.0000	0.0580	0.0200
11	1.0820	-14.2812	0.0000	0.3019	0.0000	0.0000
12	1.0262	-15.5487	0.0000	0.0000	0.1120	0.0750
13	1.0710	-15.5505	0.0000	0.3425	0.0000	0.0000
14	1.0088	-16.4634	0.0000	0.0000	0.0620	0.0160
15	1.0023	-16.4791	0.0000	0.0000	0.0820	0.0250
16	1.0078	-15.9944	0.0000	0.0000	0.0350	0.0180
17	0.9980	-16.2403	0.0000	0.0000	0.0900	0.0580
18	0.9893	-17.0619	0.0000	0.0000	0.0320	0.0090
19	0.9849	-17.2005	0.0000	0.0000	0.0950	0.0340
20	0.9881	-16.9608	0.0000	0.0000	0.0220	0.0070
21	0.9878	-16.4660	0.0000	0.0000	0.1750	0.1120
22	0.9883	-16.4452	0.0000	0.0000	0.0000	0.0000
23	0.9867	-16.7615	0.0000	0.0000	0.0320	0.0160
24	0.9746	-16.7653	0.0000	0.0000	0.0870	0.0670
25	0.9749	-16.3948	0.0000	0.0000	0.0000	0.0000
26	0.9565	-16.8538	0.0000	0.0000	0.0350	0.0230
27	0.9840	-15.8768	0.0000	0.0000	0.0000	0.0000
28	1.0069	-11.6746	0.0000	0.0000	0.0000	0.0000
29	0.9633	-17.2100	0.0000	0.0000	0.0240	0.0090
30	0.9514	-18.1693	0.0000	0.0000	0.1060	0.0190
----- TOTAL -----			3.0110	1.6250	2.8340	1.2620

Power Flow Result

IEEE 30 Bus

<Line Output Data for the Power System>

Line#	Bus to Bus		P	Q	S
1	1	2	1.7305	-0.2129	1.7436
1	2	1	-1.6788	0.3094	1.7070
2	1	3	0.8805	0.0187	0.8807
2	3	1	-0.8492	0.0510	0.8508
3	2	4	0.4349	0.0092	0.4350
3	4	2	-0.4250	-0.0179	0.4254
4	2	5	0.8238	0.0129	0.8239
4	5	2	-0.7943	0.0667	0.7971
5	2	6	0.6030	-0.0013	0.6030
5	6	2	-0.5836	0.0207	0.5839
6	3	4	0.8252	-0.0630	0.8276
6	4	3	-0.8166	0.0790	0.8205
7	4	6	0.7252	-0.0641	0.7280
7	6	4	-0.7191	0.0761	0.7231
8	5	7	-0.1477	0.1162	0.1879
8	7	5	0.1494	-0.1326	0.1998
9	6	7	0.3812	-0.0292	0.3823
9	7	6	-0.3774	0.0236	0.3781
10	6	8	0.2962	-0.0548	0.3012
10	8	6	-0.2951	0.0493	0.2992
11	6	28	0.1889	0.0153	0.1895
11	28	6	-0.1883	-0.0265	0.1901
12	8	28	-0.0049	-0.0049	0.0069
12	28	8	0.0049	-0.0386	0.0389
13	9	10	0.2797	0.2160	0.3534
13	10	9	-0.2797	-0.2030	0.3456
14	9	11	0.0000	-0.2858	0.2858
14	11	9	0.0000	0.3019	0.3019
15	10	17	0.0562	0.0163	0.0585
15	17	10	-0.0561	-0.0161	0.0584
16	10	20	0.0898	0.0228	0.0926
16	20	10	-0.0890	-0.0211	0.0914
17	10	21	0.1570	0.1058	0.1893
17	21	10	-0.1557	-0.1032	0.1868
18	10	22	0.0755	0.0497	0.0904
18	22	10	-0.0750	-0.0485	0.0893
19	12	13	0.0000	-0.3283	0.3283
19	13	12	0.0000	0.3425	0.3425
20	12	14	0.0798	0.0318	0.0859
20	14	12	-0.0790	-0.0301	0.0845
21	12	15	0.1787	0.0986	0.2041
21	15	12	-0.1761	-0.0936	0.1994
22	12	16	0.0698	0.0619	0.0933
22	16	12	-0.0691	-0.0604	0.0917
23	14	15	0.0170	0.0141	0.0221
23	15	14	-0.0169	-0.0141	0.0220
24	15	18	0.0608	0.0300	0.0678
24	18	15	-0.0603	-0.0291	0.0670
25	15	23	0.0502	0.0526	0.0727
25	23	15	-0.0497	-0.0517	0.0717
26	16	17	0.0341	0.0424	0.0543
26	17	16	-0.0339	-0.0419	0.0539
27	18	19	0.0283	0.0201	0.0347
27	19	18	-0.0282	-0.0201	0.0346
28	19	20	-0.0668	-0.0139	0.0682
28	20	19	0.0670	0.0141	0.0684
29	21	22	-0.0193	-0.0088	0.0212
29	22	21	0.0193	0.0087	0.0212
30	22	24	0.0557	0.0398	0.0684
30	24	22	-0.0551	-0.0390	0.0675
31	23	24	0.0177	0.0357	0.0398
31	24	23	-0.0175	-0.0353	0.0394
32	24	25	-0.0144	0.0074	0.0162
32	25	24	0.0145	-0.0074	0.0162
33	25	26	0.0355	0.0236	0.0426
33	26	25	-0.0350	-0.0230	0.0419
34	25	27	-0.0500	-0.0163	0.0525
34	27	25	0.0503	0.0168	0.0530
35	27	29	0.0620	0.0167	0.0642
35	29	27	-0.0611	-0.0150	0.0629
36	27	30	0.0710	0.0168	0.0730
36	30	27	-0.0693	-0.0136	0.0706
37	29	30	0.0371	0.0060	0.0376
37	30	29	-0.0367	-0.0054	0.0371
38	4	12	0.4404	-0.0129	0.4406
38	12	4	-0.4404	0.0610	0.4446
39	27	28	-0.1833	-0.0503	0.1901
39	28	27	0.1833	0.0651	0.1945
40	6	10	0.1568	0.0253	0.1588
40	10	6	-0.1568	-0.0116	0.1572
41	6	9	0.2797	-0.0534	0.2848
41	9	6	-0.2797	0.0699	0.2883

Power Flow Result

IEEE 30 Bus

Table 4 - Source and line power comparison of IEEE 30-bus system

Bus		PSS/E		PSCAD	
		P [pu]	Q [pu]	P [pu]	Q [pu]
1		2.609	-0.168	2.6070	-0.1530
2		0.400	0.500	0.3992	0.5167
5		0.000	0.369	0.0025	0.3868
8		0.000	0.371	-0.0000	0.4047
11		0.000	0.162	0.0004	0.1662
13		0.000	0.106	0.0009	0.1111
From Bus	To Bus				
1	2	1.732	-0.2130	1.7320	-0.2098
1	3	0.846	-0.0240	0.8442	-0.0128
2	4	0.426	0.0470	0.4253	0.0589
2	5	0.824	0.0180	0.8239	0.0142
2	6	0.603	0.0050	0.6026	0.0169
3	4	0.813	-0.0360	0.8116	-0.0408
4	6	0.715	-0.1760	0.7128	-0.1745
5	7	0.148	-0.1330	0.1469	-0.1465
6	7	0.377	-0.0300	0.3749	-0.0375
6	8	0.296	-0.0810	0.2947	-0.0990
6	28	0.186	0.0110	0.1861	0.0112
8	28	0.005	-0.0040	0.0052	-0.0045
9	10	0.277	0.0590	0.2776	0.0567
9	11	0.000	0.1620	0.0004	0.1662
10	17	0.053	0.0440	0.0531	0.0428
10	20	0.090	0.0370	0.0900	0.0362
10	21	0.157	0.0980	0.1574	0.0980
10	22	0.076	0.0450	0.0754	0.0450
12	13	0.000	0.1060	0.0009	0.1111
12	14	0.078	0.0220	0.0779	0.0227
12	15	0.177	0.0640	0.1771	0.0648
12	16	0.072	0.0340	0.0721	0.0335
14	15	0.016	0.0060	0.0159	0.0067
15	18	0.060	0.0160	0.0590	0.0157
15	23	0.050	0.0290	0.0503	0.0296
16	17	0.037	0.0140	0.0370	0.0154
18	19	0.028	0.0060	0.0279	0.0067
19	20	0.067	0.0280	0.0671	0.0273
21	22	0.018	0.0140	0.0176	0.0138
22	24	0.057	0.0310	0.0573	0.0306
23	24	0.018	0.0120	0.0183	0.0136
24	25	0.012	-0.0200	0.0116	-0.0214
25	26	0.035	0.0230	0.0350	0.0230
25	27	0.048	0.0040	0.0473	0.0025
27	29	0.061	0.0150	0.0610	0.0150
27	30	0.071	0.0170	0.0709	0.0175
29	30	0.037	0.0050	0.0367	0.0054

Power Flow Result

MATLAB 콘솔 창 출력 결과

```
<2024-1학기 전기공학전공 자기설계학점 : Advanced Power Flow 캡스톤 프로젝트>
[융합전자공학과 201910906 이학민]

ieee5bus_bus.xlsx 파일을 정상적으로 읽었습니다.
ieee5bus_line.xlsx 파일을 정상적으로 읽었습니다.

Iteration Limit : 1000

Threshold Value of Approximate Relative Error[%] : 0.0000001
```

[Bus Data]

Bus Num	Bus Type	V	Delta	P_G	Q_G	P_L	Q_L	Q_Gmax	Q_Gmin
1.0000	0	1.0600	0	0	0	0	0	0	0
2.0000	1.0000	1.0000	0	0.4000	0.3000	0.2000	0.1000	9.0000	-9.0000
3.0000	2.0000	1.0000	0	0	0	0.4500	0.1500	0	0
4.0000	2.0000	1.0000	0	0	0	0.4000	0.0500	0	0
5.0000	2.0000	1.0000	0	0	0	0.6000	0.1000	0	0

[Transmission Line Data]

Line Num	from	to	Rpu	Xpu	Gpu	Bpu	maxMVA	TAP
1.0000	1.0000	2.0000	0.0200	0.0600	0	0	0.8000	0
2.0000	1.0000	3.0000	0.0800	0.2400	0	0.0250	0.3000	0
3.0000	2.0000	3.0000	0.0600	0.2500	0	0.0200	0.2000	0
4.0000	2.0000	4.0000	0.0600	0.1800	0	0.0200	0.2000	0
5.0000	2.0000	5.0000	0.0400	0.1200	0	0.0150	0.6000	0
6.0000	3.0000	4.0000	0.0100	0.0300	0	0.0100	0.1000	0
7.0000	4.0000	5.0000	0.0800	0.2400	0	0.0250	0.1000	0

[Y Bus Matrix]

6.2500 -18.7375i	-5.0000 +15.0000i	-1.2500 + 3.7500i	0.0000 + 0.0000i	0.0000 + 0.0000i
-5.0000 +15.0000i	10.0744 -31.2546i	-0.9077 + 3.7821i	-1.6667 + 5.0000i	-2.5000 + 7.5000i
-1.2500 + 3.7500i	-0.9077 + 3.7821i	12.1577 -37.5046i	-10.0000 +30.0000i	0.0000 + 0.0000i
0.0000 + 0.0000i	-1.6667 + 5.0000i	-10.0000 +30.0000i	12.9167 -38.7225i	-1.2500 + 3.7500i
0.0000 + 0.0000i	-2.5000 + 7.5000i	0.0000 + 0.0000i	-1.2500 + 3.7500i	3.7500 -11.2300i

```
<Final Approximate Percent Relative Error>
-------------------------------------------
err_V(Bus1) = 0.0000000000[%]
err_V(Bus2) = 0.0000000000[%]
err_V(Bus3) = 0.0000000931[%]
err_V(Bus4) = 0.0000000904[%]
err_V(Bus5) = 0.0000000446[%]

<Bus Output Data for the Power System>
```

Bus#	Voltage Magnitude(p.u.)	Phase Angle(Deg)	P_G(p.u.)	Q_G(p.u.)	P_L(p.u.)	Q_L(p.u.)
1	1.0600	0.0000	1.3122	0.9734	0.0000	0.0000
2	1.0000	-2.0066	0.4000	-0.4974	0.2000	0.1000
3	0.9833	-4.8137	0.0000	0.0000	0.4500	0.1500
4	0.9801	-5.0757	0.0000	0.0000	0.4000	0.0500
5	0.9687	-5.7467	0.0000	0.0000	0.6000	0.1000
----- TOTAL -----			1.7122	0.4760	1.6500	0.4000

```
<Line Output Data for the Power System>
```

Line#	Bus to Bus		P	Q	S
1	1	2	0.8780	0.7782	1.1732
1	2	1	-0.8535	-0.7047	1.1068
2	1	3	0.4342	0.1952	0.4760
2	3	1	-0.4177	-0.1717	0.4516
3	2	3	0.1983	0.0138	0.1988
3	3	2	-0.1960	-0.0235	0.1974
4	2	4	0.2978	0.0088	0.2980
4	4	2	-0.2925	-0.0124	0.2927
5	2	5	0.5573	0.0846	0.5637
5	5	2	-0.5445	-0.0609	0.5479
6	3	4	0.1636	0.0452	0.1697
6	4	3	-0.1633	-0.0539	0.1720
7	4	5	0.0558	0.0164	0.0581
7	5	4	-0.0555	-0.0391	0.0679

```
x모선의 n번째 iteration 결과(x,n) / (0,0)을 눌러 종료 : 4,30

<4모선의 30번째 iteration 결과>
Voltage Magnitude(p.u.) | Phase Angle(Deg) |   P(p.u.)   |   Q(p.u.)
        0.9803          |     -4.9445      |   -0.4000   |   -0.0500
```

Power Flow Result

	A	B	C	D	E	F	G	H	I
1	0-17.3611i	0+0i	0+0i	0+17.3611i	0+0i	0+0i	0+0i	0+0i	0+0i
2	0+0i	0-16i	0+0i	0+0i	0+0i	0+0i	0+16i	0+0i	0+0i
3	0+0i	0+0i	0-17.0648i	0+0i	0+0i	0+0i	0+0i	0+0i	0+17.0648i
4	0+17.3611i	0+0i	0+0i	3.30738-39.3089i	-1.36519+11.6041i	-1.94219+10.5107i	0+0i	0+0i	0+0i
5	0+0i	0+0i	0+0i	-1.36519+11.6041i	2.55279-17.3382i	0+0i	-1.1876+5.97513i	0+0i	0+0i
6	0+0i	0+0i	0+0i	-1.94219+10.5107i	0+0i	3.2242-15.8409i	0+0i	0+0i	-1.28201+5.58824i
7	0+0i	0+16i	0+0i	0+0i	-1.1876+5.97513i	0+0i	2.80473-35.4456i	-1.61712+13.698i	0+0i
8	0+0i	0+0i	0+0i	0+0i	0+0i	0+0i	-1.61712+13.698i	2.77221-23.3032i	-1.15509+9.78427i
9	0+0i	0+0i	0+17.0648i	0+0i	0+0i	-1.28201+5.58824i	0+0i	-1.15509+9.78427	2.4371-32.1539i

Export Result to Excel File

```
% Export Ybus, Bus/Line Output data to Excel file

function export_Result(Ybus,BusOutputData,LineOutputData)

    result_file = 'Power_Flow_Result.xlsx';
    if exist(result_file, 'file')
        delete(result_file);
    end

    % Y Bus Matrix
    writematrix(Ybus,'Power_Flow_Result.xlsx','sheet','Y Bus Matrix');

    % Bus Output Data
    headers = {'Bus#','Voltage Magnitude(p.u.)','Phase Angle(Deg)','P_G(p.u.)','Q_G(p.u.)','P_L(p.u.)','Q_L(p.u.)'};
    BusData = [headers; num2cell(BusOutputData)];
    writecell(BusData,'Power_Flow_Result.xlsx','sheet','Bus Output Data');

    % Line Output Data
    headers = {'Line#','from','to','P','Q','S'};
    LineData = [headers; num2cell(LineOutputData)];
    writecell(LineData,'Power_Flow_Result.xlsx','sheet','Line Output Data');

end
```

	A	B	C	D	E	F	G
1	Bus#	Voltage Magnitude(p.u.)	Phase Angle(Deg)	P_G(p.u.)	Q_G(p.u.)	P_L(p.u.)	Q_L(p.u.)
2	1	1.04	0	0.71641043	0.270459208	0	0
3	2	1.025	9.280003346	1.63	0.066536586	0	0
4	3	1.025	4.664749223	0.85	-0.108597101	0	0
5	4	1.025788395	-2.216788471	0	0	0	0
6	5	0.995630861	-3.988806446	0	0	1.25	0.5
7	6	1.012654326	-3.687397357	0	0	0.9	0.3
8	7	1.025769373	3.719699124	0	0	0	0
9	8	1.015882584	0.727533959	0	0	1	0.35
10	9	1.03235295	1.966714065	0	0	0	0

	A	B	C	D	E	F
1	Line#	from	to	P	Q	S
2	1	1	4	0.716410433	0.270459208	0.765762425
3	1	4	1	-0.716410433	-0.239231227	0.755298278
4	2	4	6	0.307036797	0.010300044	0.307209514
5	2	6	4	-0.305372727	-0.165433629	0.347305036
6	3	6	9	-0.594627289	-0.134566366	0.609663612
7	3	9	6	0.608165774	-0.180748357	0.634456915
8	4	3	9	0.849999969	-0.108597101	0.856909142
9	4	9	3	-0.849999969	0.149553281	0.863056273
10	5	9	8	0.24183416	0.03119508	0.243837843
11	5	8	9	-0.240954194	-0.242958221	0.342180684
12	6	8	7	-0.759045848	-0.107041771	0.766556287
13	6	7	8	0.763798685	-0.007973315	0.763840301
14	7	7	2	-1.629999971	0.0917815	1.632581927
15	7	2	7	1.629999971	0.066536586	1.631357417
16	8	7	5	0.866201246	-0.083808181	0.870246178
17	8	5	7	-0.843201538	-0.113127531	0.850756529
18	9	5	4	-0.406798479	-0.386872464	0.561386948
19	9	4	5	0.409373622	0.228931186	0.469037579

Power Flow Result

임의 모선의 n번째 Iteration 결과 출력

```
62        % x모선의 n번째 iteration 결과
63        values = input('\nx모선의 n번째 iteration 결과(x,n) / (0,0)을 눌러 종료 : ', 's');
64
65        % 쉼표를 기준으로 입력 문자열을 분리
66        split_values = strsplit(values, ',');
67        x = str2double(split_values{1});
68        n = str2double(split_values{2});
69
70        if x == 0 & n == 0
71            fprintf('프로그램을 종료합니다.\n');
72        elseif (x<1 | x>SIZE) | (n<0 | n>i)
73            fprintf('정보를 잘못 입력하였습니다. 프로그램을 종료합니다.\n');
74        else
75            fprintf('\n<%d모선의 %d번째 iteration 결과>\n',x,n);
76            fprintf('Voltage Magnitude(p.u.) | Phase Angle(Deg) |   P(p.u.)   |   Q(p.u.)\n');
77            fprintf('%15.4f         | %11.4f      |   %7.4f   |   %7.4f\n',V(x,n+1),Delta(x,n+1), P_G(x,n+1)-P_L(x,n+1),Q_G(x,n+1)-Q_L(x,n+1));
78        end
79    end
```

전공 수업의 보조 자료로써 활용 가능할 것으로 기대함.

```
x모선의 n번째 iteration 결과(x,n) / (0,0)을 눌러 종료 : 5,10

<5모선의 10번째 iteration 결과>
Voltage Magnitude(p.u.) | Phase Angle(Deg) |   P(p.u.)   |   Q(p.u.)
         0.9970         |      -4.9890     |   -1.2500   |   -0.5000
```

개선 가능한 사항

알고리즘을 최적화하여 코드의 가독성을 높이고, 시간 복잡도 및 공간 복잡도를 개선할 수 있음.

Transformer Tap을 고려하고 전력 계통 고장 계산을 수행하도록 코드를 추가할 수 있음

Jacobi Method는 수렴 속도가 느린 방법이기 때문에 추후 코드 효율성을 개선할 때
다른 수치해석 기법 (Gauss-Seidel, Newton-Raphson)을 적용할 수 있음.

자기 성장에 대한 평가

전력조류계산 이론

전력공학, 수치해석 등 전력 조류 계산을 위한 이론의 이해도가 크게 향상되었음.

MATLAB 활용 능력

MATLAB의 활용하여 복잡한 알고리즘을 설계하는 과정에서 코딩 능력이 향상되었고, 상대방이 이해할 수 있도록 설계 의도를 명확히 기술하는 방법을 익힘.

팀워크 향상

팀별 세미나와 통합 세미나를 통해 서로 피드백을 주고 받으며 협업 능력을 강화하고 동일 전공자 간의 친목을 다질 수 있었음.

향후 계획

1. Jacobi Method 알고리즘 최적화 및 코드 가독성 개선

2. Gauss-Seidel 또는 Newton-Raphson 기법 추가 개발

3. <대한전기학회 전력기술부문회 추계학술대회 – 전력조류계산 관련 SW경진대회> 출전 (https://www.kiee.or.kr/board/?_0000_method=view&ncode=a002&num=2519&page=1)

4. 상명대학교 전기공학과 졸업발표회(ECC)에서 자기설계학점 내용에 대한 발표 예정

Q & A

감사합니다!