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EE 454
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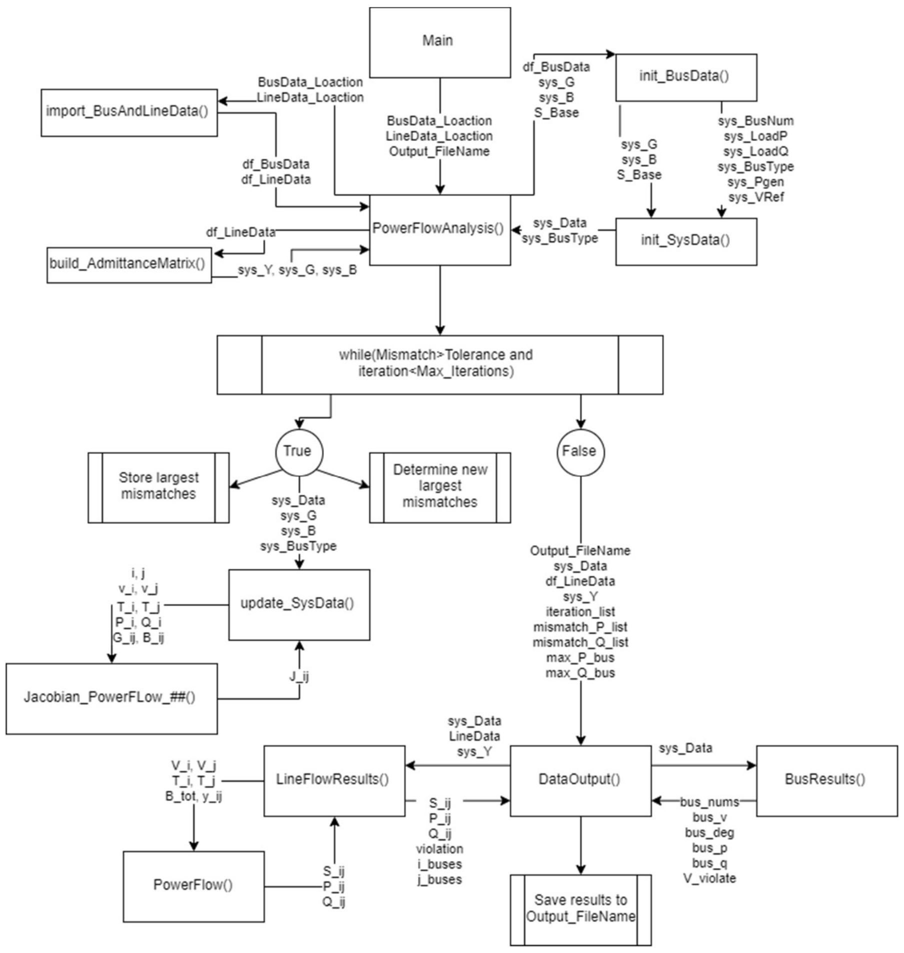
Project 2 Report

Program Overview

Our program operates by calling a main PowerFlowAnalysis() function for each of the three cases. This function uses the information location to solve for a desired power flow case. Fig. 1 show's a basic overview of how our power flow analysis program operates. The line data is parsed to create the admittance matrix for the system, and the bus data is turned into a 2D array containing each buses power and voltage information. This 2D matrix is then sent through the power flow process to give each bus's voltage magnitude and angle, and the real and reactive power.


Main
BusData_Loaction LineData_Loaction
import_BusAndLineData()
BusData_Loaction LineData_Loaction Output_FileName
df_BusData sys_G sys_B S_Base
init_BusData()
sys_G sys_B S_Base
sys_BusNum sys_LoadP sys_LoadQ sys_BusType sys_Pgen sys_VRef
df_BusData df_LineData
PowerFlowAnalysis()
sys_Data sys_BusType
init_SysData()
df_LineData
build_AdmittanceMatrix()
sys_Y, sys_G, sys_B
while(Mismatch>Tolerance and iteration<Max_Iterations)
True
False
Store largest mismatches
Determine new largest mismatches
sys_Data sys_G sys_B sys_BusType
i, j v_i, v_j T_i, T_j P_i, Q_i G_ij, B_ij
update_SysData()
J_ij
Jacobian_PowerFLow_##()
Output_FileName sys_Data df_LineData sys_Y iteration_list mismatch_P_list mismatch_Q_list max_P_bus max_Q_bus
sys_Data LineData sys_Y
LineFlowResults()
DataOutput()
sys_Data
BusResults()
V_i, V_j T_i, T_j B_tot, y_ij
S_ij P_ij Q_ij violation i_buses j_buses
bus_nums bus_v bus_deg bus_p bus_q V_violate
PowerFlow()
S_ij P_ij Q_ij
Save results to Output_FileName
Figure 1: Flow chart of Power Flow Analysis program

The parameters passed to and returned from each function is placed near its corresponding arrow. Important internal processes are shown by process boxes that have stripped left and right borders. A more complete description of each function and variable can be obtained from the code comments in the Appendix.

Program Validation

Verification of our program was broken up into two main steps: individual function verification, and overall functionality. Individual functions were first tested by having them attempt to return specific values. For instance, the Jacobian support functions were initially assigned to return a unique value for each of the 8 possibilities to ensure it was placing the desired values in the desired locations. After ensuring that the intent was being fulfilled, specific input and output pairs were used to verify that internal processing of the functions were working correctly. This was accomplished through the use of previous homework problems to ensure that things like the admittance matrix and Jacobian were being correctly built.

Finally, overall functionality was verified by testing it on a simple three-bus network. The expected values for this network were calculated by hand so that we would have a reference expectation for each variable in our program. We then systematically checked each variable to ensure that the program was creating the expected values. Both at the output, and internally from each function.

Results

<u>Base Case</u>

Bus Number	V (pu)	Angle (deg)	P inj. (MW)	Q inj. (MVar)	Voltage Violation
1	1.05	0	145.6856	-26.0757	FALSE
2	1.045	-3.28899	18.3	26.91573	FALSE
3	1.01	-9.40654	-61.2	2.797827	FALSE
4	1.026686	-6.44693	-57.8	3.9	FALSE
5	1.030416	-5.44317	-7.6	-1.6	FALSE
6	1.023128	-7.93228	-13.5	-8.5	FALSE
7	0.9899	-10.6247	-29.5	-13.6	FALSE
8	0.98714	-10.4719	-9	-5.8	FALSE
9	0.999982	-9.37929	-4.3	-2.1	FALSE
10	1.06	-6.81345	27.8	11.53806	TRUE
11	1.024521	-8.13704	-13.5	-5.8	FALSE
12	1.04	-9.24019	12.1	18.43624	FALSE

Table 1: Table showing the voltage in per unit, angle in degrees, active power injected in MW, reactive power injected in MVar, and whether the voltage limit was violated at each bus.

From Bus	To Bus	P Flow (MW)	Q Flow (MVar)	S Flow (MVA)	Line MVA Violation
1	2	99.61155	-23.6093	102.3712	TRUE
1	5	46.07401	-2.46643	46.13998	FALSE
2	3	58.61897	5.205768	58.84967	FALSE
2	4	33.73802	-1.19732	33.75926	FALSE
2	5	23.7444	-0.46364	23.74893	FALSE
3	4	-4.08192	6.295154	7.502737	FALSE
4	5	-42.4995	4.764792	42.76578	FALSE
4	7	13.31228	7.276089	15.17097	FALSE
5	6	18.16744	3.374567	18.47819	FALSE
6	9	15.27092	4.777734	16.00087	FALSE
6	10	-12.4507	-8.6842	15.18007	FALSE
6	11	1.846623	-2.02636	2.741556	FALSE
7	8	-1.63333	3.852514	4.184453	FALSE
7	12	-14.5541	-11.389	18.48059	FALSE
8	9	-10.6386	-1.96216	10.81799	FALSE
10	11	15.08206	2.290741	15.25503	FALSE
11	12	2.968071	-5.95796	6.656329	FALSE

Table 2: Table showing the active, reactive, and apparent power flowing from one bus to another and whether the line MVA limit is violated.

Iteration	Max P Misr	P Bus	Max Q Misr	Q Bus
0	0.586028	3	0.642762	2
1	0.034927	2	0.045026	5
2	0.000156	5	0.00016	5

Table 3: Table showing the iterations of convergence with the max active and reactive mismatches and what bus they belong to.

Contingency 1

Bus Number	V (pu)	Angle (deg)	P inj. (MW)	Q inj. (MVar)	Voltage Violation
1	1.05	0	147.2691	-25.2576	FALSE
2	1.045	-5.77589	18.3	33.12146	FALSE
3	1.01	-11.8486	-61.2	4.033702	FALSE
4	1.027447	-8.34706	-57.8	3.9	FALSE
5	1.030785	-7.18776	-7.6	-1.6	FALSE
6	1.023313	-9.70917	-13.5	-8.5	FALSE
7	0.990003	-12.4463	-29.5	-13.6	FALSE
8	0.987246	-12.2855	-9	-5.8	FALSE
9	1.000113	-11.1745	-4.3	-2.1	FALSE
10	1.06	-8.58742	27.8	11.41097	TRUE
11	1.024605	-9.91867	-13.5	-5.8	FALSE
12	1.04	-11.0418	12.1	18.37847	FALSE

Table 4: Table showing the voltage in per unit, angle in degrees, active power injected in MW, reactive power injected in MVar, and whether the voltage limit was violated at each bus.

From Bus	To Bus	P Flow (MW)	Q Flow (MVar)	S Flow (MVA)	Line MVA Violation
1	2	86.97579	-20.7989	89.42809	TRUE
1	5	60.29327	-4.45868	60.4579	FALSE
2	3	58.21651	5.257021	58.45339	FALSE
2	4	27.91578	-0.04022	27.91581	FALSE
2	5	16.36755	1.48101	16.43441	FALSE
3	4	-4.46377	7.666111	8.87099	FALSE
4	5	-48.4361	7.724335	49.04811	FALSE
4	7	13.07348	7.384894	15.01507	FALSE
5	6	18.41296	3.461424	18.73549	FALSE
6	9	15.42169	4.739988	16.13369	FALSE
6	10	-12.4414	-8.61682	15.13399	FALSE
6	11	1.931911	-1.99082	2.774102	FALSE
7	8	-1.77747	3.904416	4.289971	FALSE
7	12	-14.6488	-11.3054	18.50403	FALSE
8	9	-10.783	-1.91098	10.95098	FALSE
10	11	15.09363	2.234642	15.25815	FALSE
11	12	3.064908	-5.97884	6.718643	FALSE

Table 5: Table showing the active, reactive, and apparent power flowing from one bus to another and whether the line MVA limit is violated.

Iteration	Max P Misr	P Bus	Max Q Misr	Q Bus
0	0.586028	3	0.697052	2
1	0.03508	2	0.058125	5
2	0.000211	5	0.000262	5

Table 6: Table showing the iterations of convergence with the max active and reactive mismatches and what bus they belong to.

<u>Contingency 2</u>

Bus Number	V (pu)	Angle (deg)	P inj. (MW)	Q inj. (MVar)	Voltage Violation
1	1.05	0	146.1084	-25.4523	FALSE
2	1.045	-3.30292	18.3	28.7638	FALSE
3	1.01	-9.44286	-61.2	2.965406	FALSE
4	1.025269	-6.46012	-57.8	3.9	FALSE
5	1.028827	-5.43151	-7.6	-1.6	FALSE
6	1.015803	-7.83903	-13.5	-8.5	FALSE
7	0.988043	-11.0063	-29.5	-13.6	FALSE
8	0.984175	-10.7768	-9	-5.8	FALSE
9	0.994724	-9.4945	-4.3	-2.1	FALSE
10	1.06	-4.42512	27.8	5.701583	TRUE
11	1.010304	-9.01272	-13.5	-5.8	FALSE
12	1.04	-10.0433	12.1	23.28966	FALSE

Table 7: Table showing the voltage in per unit, angle in degrees, active power injected in MW, reactive power injected in MVar, and whether the voltage limit was violated at each bus.

From Bus	To Bus	P Flow (MW)	Q Flow (MVar)	S Flow (MVA)	Line MVA Violation
1	2	100.0258	-23.719	102.7995	TRUE
1	5	46.0826	-1.73325	46.11519	FALSE
2	3	58.81998	5.18029	59.04766	FALSE
2	4	33.93844	-0.42501	33.9411	FALSE
2	5	23.742	0.481022	23.74687	FALSE
3	4	-3.89086	6.395161	7.485777	FALSE
4	5	-43.2405	5.447717	43.58236	FALSE
4	7	14.43659	7.435188	16.23876	FALSE
5	6	17.41949	5.683032	18.32309	FALSE
6	9	16.21961	3.232004	16.53849	FALSE
6	10	-26.9234	-3.86746	27.19973	FALSE
6	11	14.62643	-2.97445	14.92581	FALSE
7	8	-2.54199	5.488936	6.048976	FALSE
7	12	-12.5206	-13.0466	18.08257	FALSE
8	9	-11.5529	-0.34215	11.55798	FALSE
11	12	0.98303	-9.05463	9.107835	FALSE

Table 8: Table showing the active, reactive, and apparent power flowing from one bus to another and whether the line MVA limit is violated.

Iteration	Max P Misr	P Bus	Max Q Misr	Q Bus
0	0.586028	3	0.642762	2
1	0.034186	2	0.043841	5
2	0.000147	5	0.000166	5

Table 6: Table showing the iterations of convergence with the max active and reactive mismatches and what bus they belong to.

Discussion of Results

The results of contingency case 1 appear to make sense. In contingency case 1, one of the two lines connecting bus 1 and 2 is taken offline. This results in an increase in the impedance between the two lines. As such the increase in power injection from bus 1 would make sense as it would be compensating the additional power loss. Additionally, the power flow information shows that bus 2 is exporting less power to it's connected busses. This also makes sense as the generator from bus 1 would no longer be as effective at providing power to bus 2, and so the generator at bus 2 would need to cover that load.

The results from contingency case 2 also make sense. In contingency case 2, the line connecting bus 10 and 11 is taken offline. The effects of this is most evident in the line flow analysis. It can be seen that bus 6 starts drawing more power from its connecting busses and exports more power to bus 11. It can also be seen how the loss of that line most impacts the region around bus 11, where the lower region maintains fairly similar results for bus and line results.

Team Contribution

Both members contributed to writing the power flow program. In addition to writing specific functions, both members reviewed the others work to ensure understanding of process. Main focus of each member was as follows:

Brandon Beaty	Admittance Matrix, initializing bus and system data, solving the system
Eliot Nichols	Data import, line flow analysis, violation check, data export

Additionally, both members contributed to writing report and discussing results.

Appendix

Main

```python
"""
Power Flow Analysis: Main Function
Created By:
    Brandon Beaty
    Eliot Nichols
"""
from PowerSysAnalysis_HeaderFile import *

"""
########################
    Main Section of Code
########################
"""

"""
Loction for Bus and line data
First variable is for file location, Second variable is for sheet name
"""
BusData_Location = ['system_basecase.xlsx', 'BusData'] #BaseCase Data
LineData_Location_BaseCase = ['system_basecase.xlsx', 'LineData'] #BaseCase Data
LineData_Location_Contingency1 = ['system_basecase.xlsx', 'ContingencyCase1'] #BaseCase Data
LineData_Location_Contingency2 = ['system_basecase.xlsx', 'ContingencyCase2'] #BaseCase Data

tolerance = [.001, .001] #P.U.
S_Base = 100 #MW

PowerFlowAnalysis(BusData_Location, LineData_Location_BaseCase, "Base Case Solution", tolerance, S_Base)
PowerFlowAnalysis(BusData_Location, LineData_Location_Contingency1, "Contingency Case 1 Solution", tolerance, S_Base)
PowerFlowAnalysis(BusData_Location, LineData_Location_Contingency2, "Contingency Case 2 Solution", tolerance, S_Base)
```

Support Files

```python
"""
Power Flow Analysis: Support Functions
Created By:
    Brandon Beaty
    Eliot Nichols
"""

import numpy as np
from numpy.linalg import inv
import pandas as pd


"""
Imports Bus and line data from excel sheets
Takes in an array containing ['File Location', 'Sheet Name']
Returns two panda data frames for the bus and line data
"""
def import_BusAndLineData(BusData_Location, LineData_Location):
    BusData = pd.read_excel(BusData_Location[0], sheet_name=BusData_Location[1])
    LineData = pd.read_excel(LineData_Location[0], sheet_name=LineData_Location[1])
    return BusData, LineData


"""
Builds G and B matrices to be used in Power Flow calculations
Takes in data frame containing all line information, and number of busses in system
Returns G and B arrays
"""
def build_AdmittanceMatrix(LineData, sys_Size):
    col = np.array(LineData.columns)
    line_From = np.array(LineData[col[0]])
    line_To = np.array(LineData[col[1]])
    line_R = np.array(LineData[col[2]])
    line_X = np.array(LineData[col[3]])
    line_Z = np.array(LineData[col[2]]) + 1j*np.array(LineData[col[3]])
    line_Y = 1/line_Z
    line_B = np.array(LineData[col[4]])
    line_Fmax = np.array(LineData[col[5]])
    sys_Y = np.array([[0 for j in range(sys_Size)] for i in range(sys_Size)], dtype = complex)
    sys_G = np.zeros((sys_Size, sys_Size))
    sys_B = np.zeros((sys_Size, sys_Size))

    #X_ij
    for i in range(sys_Size): #Row
        for j in range(sys_Size): #Column
            if i==j: # Diagonal, sum of Y(From==i || To==i) + .5B(From==i || To ==i)
                sys_Y[i][j] = np.sum(line_Y[np.array(line_From==i+1) + np.array(line_To==i+1)]) \
                        +.5j*np.sum(line_B[np.array(line_From==i+1) + np.array(line_To==i+1)])
            elif i<j: #Non Diagonal, -Y(From==i && To==j)
                sys_Y[i][j] = -np.sum(line_Y[np.multiply(np.array(line_From==i+1), np.array(line_To==j+1))])
            else: #i>j =[j][i]
               sys_Y[i][j] = sys_Y[j][i]
    sys_G = sys_Y.real
    sys_B = sys_Y.imag
    return sys_Y, sys_G, sys_B

"""
Parses intial bus information from data
Takes in Bus Data data frame
Returns sys_:
    LoadP - active power consumed at node
    LoadQ - reactive power consumed at node
    BusType - type of bus<(S)lack, (G)enerator, (D)rain>
    PGen - Active Power produced by each generator node
    VRef - Reference voltages at PV busses
"""
def init_BusData(BusData):
    col = np.array(BusData.columns)
    sys_BusNum = np.array(BusData[col[0]])
    sys_LoadP = np.array(BusData[col[1]])
    sys_LoadQ = np.array(BusData[col[2]])
    sys_BusType = np.array(BusData[col[3]])
    sys_PGen = np.array(BusData[col[4]])
    sys_VRef = np.array(BusData[col[5]])
    return sys_BusNum, sys_LoadP, sys_LoadQ, sys_BusType, sys_PGen, sys_VRef
```

```python

"""
Initializes System Data for processing
Takes in sys_:
    LoadP - active power consumed at node
    LoadQ - reactive power consumed at node
    BusType - type of bus<(S)lack, (G)enerator, (D)rain>
    PGen - Active Power produced by each generator node
    VRef - Reference voltages at PV busses
Returns a 2D array containing each buses's current information
[i,:] - Bus i's information
[:,0] - Bus #
[:,1] - Voltage (V)
[:,2] - Angle (T)
[:,3] - Active Power (P_inj)
[:,4] - P(T,V)-P_inj (mismatch)
[:,5] - Reactive Power (Q_inj)
[:,6] - Q(T,V)-Q_inj (mismatch)
"""
def init_SysData(sys_BusNum, sys_LoadP, sys_LoadQ, sys_BusType, sys_PGen, sys_VRef, sys_G, sys_B, S_Base):
    n= sys_LoadP.size
    sys_Data = np.zeros((n,7))
    sys_Data[:,0] = sys_BusNum
    sys_Data[:,1] = sys_VRef #Sets initial voltages to provided reference
    sys_Data[:,2] = np.zeros(n) #Sets initial angles to zero
    sys_Data[:,3] = (sys_PGen-sys_LoadP)/S_Base #Sets initial power inject to Bus generation minus load in per unit
    sys_Data[sys_BusType=='S',3] = (np.sum(sys_LoadP)-np.sum(sys_PGen))/S_Base #Sets initial guess for active power required from slack bus
    sys_Data[:,5] = (-sys_LoadQ)/S_Base #Sets initial power inject to Bus generation minus load in per unit

    sys_Data[sys_BusType=='S',5] = (-np.sum(sys_LoadQ))/S_Base #Sets initial guess for reactive power required from slack bus
    for i in range(n): #Sets initial mismatch to calculated power from (V,T) minus expected inject
        sys_Data[i,4] = -sys_Data[i,3]
        sys_Data[i,6] = -sys_Data[i,5]
        for j in range(n):
            sys_Data[i,4] += sys_Data[i,1]*sys_Data[j,1]*\
                            (sys_G[i,j]*np.cos(sys_Data[i,2]-sys_Data[j,2])+\
                             sys_B[i,j]*np.sin(sys_Data[i,2]-sys_Data[j,2]))
            sys_Data[i,6] += sys_Data[i,1]*sys_Data[j,1]*\
                        (sys_G[i,j]*np.sin(sys_Data[i,2]-sys_Data[j,2])-\
                         sys_B[i,j]*np.cos(sys_Data[i,2]-sys_Data[j,2]))

    return sys_Data

"""
Determines Jacobian value for a given J_11 cell (dP/dT)
Takes in: i, j, n, V_i, V_j, T_i, T_j, P_i, Q_i, G_ij, B_ij
Returns Jacobian cell value
"""
def Jacobian_PowerFlow_11(i, j, V_i, V_j, T_i, T_j, P_i, Q_i, G_ij, B_ij):
    if(i==j):
        J_ij = -Q_i - B_ij*(V_i**2)
    else:
        J_ij =  V_i*V_j*(G_ij*np.sin(T_i-T_j)-B_ij*np.cos(T_i-T_j))
    return J_ij
```

```

"""
Determines Jacobian value for a given J_12 cell (dP/dV)
Takes in: i, j, n, V_i, V_j, T_i, T_j, P_i, Q_i, G_ij, B_ij
Returns Jacobian cell value
"""
def Jacobian_PowerFlow_12(i, j, V_i, V_j, T_i, T_j, P_i, Q_i, G_ij, B_ij):
    if(i==j):
        J_ij = (P_i/V_i) + G_ij*V_i
    else:
        J_ij = V_i*(G_ij*np.cos(T_i-T_j)+B_ij*np.sin(T_i-T_j))
    return J_ij

"""
Determines Jacobian value for a given J_21 cell (dQ/dT)
Takes in: i, j, n, V_i, V_j, T_i, T_j, P_i, Q_i, G_ij, B_ij
Returns Jacobian cell value
"""
def Jacobian_PowerFlow_21(i, j, V_i, V_j, T_i, T_j, P_i, Q_i, G_ij, B_ij):
    if(i==j):
        J_ij = P_i-G_ij*(V_i**2)
    else:
        J_ij = -V_i*V_j*(G_ij*np.cos(T_i-T_j)+B_ij*np.sin(T_i-T_j))
    return J_ij

"""
Determines Jacobian value for a given J_22 cell (dQ/dV)
Takes in: i, j, n, V_i, V_j, T_i, T_j, P_i, Q_i, G_ij, B_ij
Returns Jacobian cell value
"""
def Jacobian_PowerFlow_22(i, j, V_i, V_j, T_i, T_j, P_i, Q_i, G_ij, B_ij):
    if(i==j):
        J_ij = (Q_i/V_i)-B_ij*V_i
    else:
        J_ij = V_i*(G_ij*np.sin(T_i-T_j)-B_ij*np.cos(T_i-T_j))
    return J_ij


"""
Processes 1 iteration of current system data
Takes in sys_Data, a 2D array containing each node's current information
[0] - Bus #
[1] - Voltage (V)
[2] - Angle (T)
[3] - Active Power (P_inj)
[4] - P(T,V)-P_inj (mismatch)
[5] - Reactive Power (Q_inj)
[6] - Q(T,V)-Q_inj (mismatch)
As well as, the systems G and B matrices, and node types
Returns the updated array
"""
def update_SysData(sys_Data, sys_G, sys_B, sys_BusType):
    n = sys_BusType.size
    D_index = sys_BusType=='D'
    G_index = sys_BusType=='G'
    S_index = sys_BusType=='S'

    """Determine Jacobian"""
    J = np.zeros((2*n,2*n))
    for i in range(n):
        for j in range(n):                  #(i, j, V_i,           V_j,           T_i,           T_j,           P_i(T,V),                    Q_i(T,V),                    G_ij,       B_ij)
            J[i,j] =    Jacobian_PowerFlow_11(i, j, sys_Data[i,1], sys_Data[j,1], sys_Data[i,2], sys_Data[j,2], sys_Data[i,4]+sys_Data[i,3], sys_Data[i,6]+sys_Data[i,5], sys_G[i,j], sys_B[i,j])
            J[i,j+n] =  Jacobian_PowerFlow_12(i, j, sys_Data[i,1], sys_Data[j,1], sys_Data[i,2], sys_Data[j,2], sys_Data[i,4]+sys_Data[i,3], sys_Data[i,6]+sys_Data[i,5], sys_G[i,j], sys_B[i,j])
            J[i+n,j] =  Jacobian_PowerFlow_21(i, j, sys_Data[i,1], sys_Data[j,1], sys_Data[i,2], sys_Data[j,2], sys_Data[i,4]+sys_Data[i,3], sys_Data[i,6]+sys_Data[i,5], sys_G[i,j], sys_B[i,j])
            J[i+n,j+n] =Jacobian_PowerFlow_22(i, j, sys_Data[i,1], sys_Data[j,1], sys_Data[i,2], sys_Data[j,2], sys_Data[i,4]+sys_Data[i,3], sys_Data[i,6]+sys_Data[i,5], sys_G[i,j], sys_B[i,j])

    """Remove non-implicit values"""
    for i in range(n-1,-1,-1):
        if S_index[i]:
            J=np.delete(J, i+n, 0)
            J=np.delete(J, i+n, 1)
            J=np.delete(J, i, 0)
            J=np.delete(J, i, 1)
        elif G_index[i]:
            J=np.delete(J, i+n, 0)
            J=np.delete(J, i+n, 1)

    """Determine Inverse"""
    J_inv = inv(J)

    """Determine Delta T,V"""
    PQ = np.concatenate((sys_Data[np.invert(S_index), 4], sys_Data[D_index, 6]))
    Delta = -J_inv @ PQ
    Delta_T = Delta[0:sum(np.invert(S_index))]
    Delta_V = Delta[sum(np.invert(S_index)):sum(np.invert(S_index))+sum(D_index)]
    """Update T for non-slack buses, and V for PQ buses"""
    Delta_T_index = 0
    Delta_V_index = 0
    for i in range(n):
        if G_index[i]:
            sys_Data[i,2] += Delta_T[Delta_T_index]
            Delta_T_index += 1
        elif D_index[i]:
            sys_Data[i,1] += Delta_V[Delta_V_index]
            Delta_V_index += 1
            sys_Data[i,2] += Delta_T[Delta_T_index]
            Delta_T_index += 1

    """Update P_inj for slack bus, and Q_inj for non PQ buses"""
    for i in range(n):
        if S_index[i]:#Update Slack P_inj
            sys_Data[i,3] = 0
        if (S_index[i] or G_index[i]):#Update non PQ Q_inj
            sys_Data[i,5] = 0
        for j in range(n):
            if S_index[i]:#Update Slack
                sys_Data[i,3] += sys_Data[i,1]*sys_Data[j,1]*((sys_G[i,j]*np.cos(sys_Data[i,2]-sys_Data[j,2]))+(sys_B[i,j]*np.sin(sys_Data[i,2]-sys_Data[j,2])))
            if (S_index[i] or G_index[i]):#Update non PQ
                sys_Data[i,5] += sys_Data[i,1]*sys_Data[j,1]*((sys_G[i,j]*np.sin(sys_Data[i,2]-sys_Data[j,2]))-(sys_B[i,j]*np.cos(sys_Data[i,2]-sys_Data[j,2])))
```

```python

    """Update mismatch columns"""
    for i in range(n):
        sys_Data[i,4] = -sys_Data[i,3]
        sys_Data[i,6] = -sys_Data[i,5]
        for j in range(n):
            sys_Data[i,4] += sys_Data[i,1]*sys_Data[j,1]*((sys_G[i,j]*np.cos(sys_Data[i,2]-sys_Data[j,2]))+(sys_B[i,j]*np.sin(sys_Data[i,2]-sys_Data[j,2])))
            sys_Data[i,6] += sys_Data[i,1]*sys_Data[j,1]*((sys_G[i,j]*np.sin(sys_Data[i,2]-sys_Data[j,2]))-(sys_B[i,j]*np.cos(sys_Data[i,2]-sys_Data[j,2])))

    return sys_Data



"""
Takes in voltage and theta values, shunt capacitance, and the admittance matrix
Returns Power Values:
S_ij - Apparent Power
P_ij - Real Power
Q_ij - Reactive Power
"""
def PowerFlow (V_i,T_i,V_j,T_j,B_tot,y_ij):
    I_ij = y_ij * (V_i * np.cos(T_i) + 1j * V_i * np.sin(T_i) - V_j * np.cos(T_j) - 1j * V_j
                   * np.sin(T_j)) + (1j*B_tot / 2) * (V_i * np.cos(T_i) + 1j * V_i * np.sin(T_i))
    S_ij = (V_i*np.cos(T_i)+1j*V_i*np.sin(T_i)) * (I_ij.conjugate())
    return abs(S_ij), S_ij.real, S_ij.imag

"""
Takes in matrices sys_Data, LineData, and sys_Y
Returns lists:
i Bus # (i_buses)
j Bus # (j_buses)
 Apparent Power (S_ij)
Active Power (P_ij)
Reactive Power (Q_ij)
Violation Occurrence (violation)
"""
def LineFlowResults (sys_Data, LineData, sys_Y):
    LD_val = LineData.values
    S_ij = []
    P_ij = []
    Q_ij = []
    i_buses = LD_val[0:,0]
    j_buses = LD_val[0:,1]
    violation = []
    for i in range (0, len(LineData)):
        B_tot = (LD_val[i:i+1,4])
        V_i = sys_Data[(int(LD_val[i:i+1,0]))-1:(int(LD_val[i:i+1,0])),1]
        T_i = sys_Data[(int(LD_val[i:i + 1, 0])) - 1:(int(LD_val[i:i + 1, 0])), 2]
        V_j = sys_Data[(int(LD_val[i:i + 1, 1])) - 1:(int(LD_val[i:i + 1, 1])), 1]
        T_j = sys_Data[(int(LD_val[i:i + 1, 1])) - 1:(int(LD_val[i:i + 1, 1])), 2]
        y_ij = -1 * ( sys_Y[(int(LD_val[i:i + 1, 0]) - 1):(int(LD_val[i:i + 1, 0])),
               (int(LD_val[i:i + 1, 1]) - 1)])

        PowerFlow(V_i, T_i, V_j, T_j, B_tot, y_ij)
        s_ij, p_ij, q_ij = PowerFlow(V_i,T_i,V_j,T_j,B_tot,y_ij)

        if s_ij*100 < (LD_val[i:i+1,5]):
            violation.append('FALSE')
        else:
            violation.append('TRUE')
        S_ij.append(100 * float(s_ij))
        P_ij.append(100 * float(p_ij))
        Q_ij.append(100 * float(q_ij))
    return S_ij, P_ij, Q_ij, violation, i_buses, j_buses

"""
Collects needed bus data from sys_Data
Returns lists:
Bus Number (bus_nums)
Bus Voltages (bus_v)
Bus Thetas (bus_deg)
Bus Active Power (bus_p)
Bus Reactive Power (bus_q)
Reactive Power (Q_ij)
Voltage Violation Occurrence (V_violate)
"""
def BusResults(sys_Data):
    V_violate = []
    for i in range (0,len(sys_Data)):
        if  (sys_Data[i:i+1,1] <= 1.05 and sys_Data[i:i+1,1] >= 0.95):
            V_violate.append('FALSE')
        else:
            V_violate.append('TRUE')
    bus_nums = sys_Data[0:,0]
    bus_v = sys_Data[0:,1]
    bus_deg = 180* sys_Data[0:,2] / np.pi
    bus_p = 100 * sys_Data[0:,3]
    bus_q = 100 * sys_Data[0:,5]
    return bus_nums.astype(int), bus_v, bus_deg, bus_p, bus_q, V_violate

"""
Collects the filename, sys_Data, LineData, sys_Y, list of iterations, lists of max P mismatches and it's bus number,
lists of max q mismatches and it's bus number
Creates excel file with the given file name and given sheetnames:
[0] - BusData - Data of each bus
[1] - LineData - Data of the line between buses
[2] - ConvergenceHistory - History of Convergence
[3] - Y_matrix(Admittance) - Admittance matrix
[4] - G_matrix - Real part of the Admittance matrix
[5] - B_matrix - Imag. part of the Admittance matrix
"""
def DataOutput(FileName, sys_Data, LineData, sys_Y, iteration_list, mismatch_P_list, mismatch_Q_list, max_P_bus, max_Q_bus):

    y_matrix = pd.DataFrame(data=sys_Y)
    g_matrix = pd.DataFrame(data=sys_Y.real)
    b_matrix = pd.DataFrame(data=sys_Y.imag)

    bus_nums, bus_v, bus_deg, bus_p, bus_q, V_violate = BusResults(sys_Data)
    S_ij, P_ij, Q_ij, S_violation, i_buses, j_buses = LineFlowResults(sys_Data, LineData, sys_Y)

    df_Convergence = pd.DataFrame({'Iteration': iteration_list, 'Max P Misr': mismatch_P_list, 'P Bus': max_P_bus
                                    , 'Max Q Misr': mismatch_Q_list, 'Q Bus': max_Q_bus})

    df_BusOutput = pd.DataFrame({'Bus Number':bus_nums,'V (pu)':bus_v,'Angle (deg)':bus_deg
                                    ,'P inj. (MW)':bus_p,'Q inj. (MVar)':bus_q,
                                 'Voltage Violation':V_violate})

    df_LineOutput = pd.DataFrame({'From Bus': i_buses, 'To Bus': j_buses, 'P Flow (MW)': P_ij, 'Q Flow (MVar)': Q_ij, 'S Flow (MVA)': S_ij,
                                 'Line MVA Violation': S_violation})

    writer = pd.ExcelWriter(FileName+".xlsx", engine='xlsxwriter')

    df_BusOutput.to_excel(writer, sheet_name='BusData',startrow=1,header=False,index=False)
    df_LineOutput.to_excel(writer, sheet_name='LineData', startrow=1, header=False, index=False)
    df_Convergence.to_excel(writer, sheet_name='ConvergenceHistory', startrow=1, header=False, index=False)
    y_matrix.to_excel(writer, sheet_name='Y_matrix(Admittance)', startrow=0,header=False,index=False)
    g_matrix.to_excel(writer, sheet_name='G_matrix', startrow=0,header=False,index=False)
    b_matrix.to_excel(writer, sheet_name='B_matrix', startrow=0,header=False,index=False)

    workbook = writer.book
    busworksheet = writer.sheets['BusData']
    lineworksheet = writer.sheets['LineData']
    convergencesheet = writer.sheets['ConvergenceHistory']

    header_format = workbook.add_format({'bold': True,
    'text_wrap': True,
    'valign': 'top',
    'fg_color': '#D7E4BC',
    'border': 1})

    for col_num, value in enumerate(df_BusOutput.columns.values):
        busworksheet.write(0, col_num,value,header_format)
    for col_num, value in enumerate(df_LineOutput.columns.values):
        lineworksheet.write(0, col_num, value, header_format)
    for col_num, value in enumerate(df_Convergence.columns.values):
        convergencesheet.write(0, col_num, value, header_format)

    writer.save()

def PowerFlowAnalysis(BusData_Location, LineData_Location, Output_FileName, tolerance, S_Base):
    """Data Frame creation for initial Bus and Line Data"""
    df_BusData, df_LineData = import_BusAndLineData(BusData_Location, LineData_Location)
    n = df_BusData.shape[0]
    """Create Admittance Matrix in forms of Y and seperated into G and B"""
    sys_Y, sys_G, sys_B = build_AdmittanceMatrix(df_LineData, n)
    """Creation of sys_Data"""
    sys_BusNum, sys_LoadP, sys_LoadQ, sys_BusType, sys_PGen, sys_VRef = init_BusData(df_BusData)
    sys_Data = init_SysData(sys_BusNum, sys_LoadP, sys_LoadQ, sys_BusType, sys_PGen, sys_VRef, sys_G, sys_B, S_Base)
    """Initial Prime for mismatch detetction and storage"""
    mismatch_P = sys_Data[1:n,4]
    mismatch_Q = sys_Data[1:n,6]
    mismatch_max = [max(abs(mismatch_P)), max(abs(mismatch_Q))]
    iteration = 0
    iteration_list = []
    mismatch_P_list = []
    mismatch_Q_list = []
    max_P_bus = []
    max_Q_bus = []

    """Loop until solution is reached or max iteration is exceeded"""
    while(iteration<15 and mismatch_max>tolerance):
        iteration_list.append(iteration)

        bus_P, = np.where(mismatch_P == max(abs(mismatch_P)))
        if len(bus_P) == 0:
            bus_P, = np.where(mismatch_P == -1*max(abs(mismatch_P)))
        max_P_bus.append(int(bus_P+2))
        bus_Q, = np.where(mismatch_Q == max(abs(mismatch_Q)))
        if len(bus_Q) == 0:
            bus_Q, = np.where(mismatch_Q == -1*max(abs(mismatch_Q)))
        max_Q_bus.append(int(bus_Q+2))
        mismatch_P_list.append(max(abs(mismatch_P)))
        mismatch_Q_list.append(max(abs(mismatch_Q)))

        sys_Data = update_SysData(sys_Data, sys_G, sys_B, sys_BusType)
        mismatch_P = sys_Data[1:n,4]
        mismatch_Q = sys_Data[1:n,6]
        mismatch_max = [max(abs(mismatch_P)), max(abs(mismatch_Q))]
        iteration += 1

    """Final add to convergency history"""
    iteration_list.append(iteration)
    bus_P, = np.where(mismatch_P == max(abs(mismatch_P)))
    if len(bus_P) == 0:
        bus_P, = np.where(mismatch_P == -1*max(abs(mismatch_P)))
    max_P_bus.append(int(bus_P+2))
    bus_Q, = np.where(mismatch_Q == max(abs(mismatch_Q)))
    if len(bus_Q) == 0:
        bus_Q, = np.where(mismatch_Q == -1*max(abs(mismatch_Q)))
    max_Q_bus.append(int(bus_Q+2))
    mismatch_P_list.append(max(abs(mismatch_P)))
    mismatch_Q_list.append(max(abs(mismatch_Q)))

    """Export final solution to excel file"""
    DataOutput(Output_FileName, sys_Data, df_LineData, sys_Y,iteration_list,mismatch_P_list,mismatch_Q_list,max_P_bus,max_Q_bus)
```