Development and Comparative Analysis of Load Flow Algorithms on the IEEE 9-Bus Test System

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Assignment Deadline: 6th February 2026

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1. Objective

This assignment aims to deepen understanding of power flow analysis and numerical solution techniques through the **implementation and validation of a Full Newton–Raphson load flow program**.

Students will:

- Develop their own **Full Newton–Raphson load flow program** (from first principles).
- Compare results with **PSSE** using Newton–Raphson, Gauss–Seidel, and Fast Decoupled methods.
- Conduct a **voltage sensitivity analysis** on the IEEE 9-bus system to evaluate the impact of load variations on system voltages.

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2. Expected Learning Outcomes

By the end of the assignment, students should be able to:

1. Formulate and solve power flow equations using the Newton–Raphson method.
2. Build a Y-bus matrix and Jacobian programmatically for any system.
3. Compare and interpret the performance of major load flow algorithms.
4. Analyze voltage sensitivity under load variation using statistical measures.
5. Present simulation results and discuss engineering implications clearly and independently.

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3. Assignment Tasks

Task 1 – Program Development

Develop your own **Full Newton–Raphson load flow program** to solve IEEE 9 bus system (data provided at the end of document) using a language of your choice (e.g., MATLAB, Python).

Your program should:

1. Accept input data for bus, line, and generator parameters directly within the code or from a text or CSV file.
2. Construct the **Y-bus matrix** from input data. That is Y bus matrix must be evaluated from the code. No hand calculations.
3. Identify Slack, PV, and PQ buses and solve the load flow iteratively until convergence.
    - You may use generator at bus 1 as the slack generator
4. Compute:
    - Bus voltage magnitudes and angles
    - Power mismatches
    - Line flows and system losses

Implementation Requirements:

- All matrices (Y-bus, Jacobian submatrices J1–J4) must be formed within your program.
- No use of built-in or pre-written power flow solvers.
- Conduct flat start (all bus voltage magnitudes are at 1.0 pu and 0 degree angle at the start of load flow)
- Provide detailed **inline comments** and **function headers**.
- The program must run without external libraries except for standard numerical operations.

Deliverables:

- Source code file(s)
- Flowchart of your loadflow program. Each box of the flowchart should indicate the respective code line number(s) for reference.
- Sample output (IEEE 9-bus) showing 2nd iteration results

Task 2 – Verification and Comparison

Run your program on the **IEEE 9-bus test system** and record:

- Bus voltages and angles
- Line power flows and total system losses
- Number of iterations and convergence tolerance

2. Perform the same study in **PSSE** using:
    - Full Newton–Raphson
    - Gauss–Seidel
    - Fast Decoupled Load Flow
3. Compare your program's results with PSSE:
    - Numerical accuracy (voltage and angle differences)
    - Convergence characteristics (iterations and stability)
    - Discussion of reasons for deviations

Deliverables:

- Comparative tables and plots
- Discussion

Task 3 – Voltage Sensitivity Analysis

Using your developed program, perform the following **voltage sensitivity analysis** on the IEEE 9-bus system:

1. For each load bus, independently vary its (P) and (Q) by **–10 %, 0 %, and +10 %** while keeping other loads constant.
2. For each case, record the **voltage magnitudes at all buses**.
3. For each load bus, calculate:
    - The **variance** and **standard deviation** of all bus voltages corresponding to the load variations.
    - Identify which load has the highest influence on system voltages.

Deliverables:

- Tables of voltage results under each load variation.
- Graphs showing voltage profiles across all buses.
- Sensitivity ranking table.
- Discussion of findings (2–3 pages).

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4. Submission Requirements

To ensure **individual originality** and minimize plagiarism:

1. **Source Code:**
    - Each student must submit **their own original code** file.

- Code will be **automatically checked for similarity** using software.
- Copying code with minor modifications (variable renaming, reformatting) will be treated as plagiarism.
- Each function should include a **header comment** with the student's name, ID, and a brief description of functionality.

2. **Execution Proof:**
   - Submit at least **one screenshot** showing the program output (terminal or plot) with a visible **timestamp** and your **student ID** printed by the program itself (add a print statement like: print("Student ID: XXXXXX")).
3. **Report:**
   - Must be written in your own words.
   - Include relevant tables, figures, and discussions generated by your own runs.
   - Plagiarism detection will be applied.
   - Shared or copied reports will result in **zero marks** for all parties involved.
4. **File Naming Convention: (XXX is the registration number)**
   - Code: E21xxx_LoadFlow.py (or .m)
   - Report: E21xxx _LoadFlow_Report.pdf
   - Supporting data: E21xxx _Data.csv
5. **Submission Package:**
   - Submit a single ZIP file named:

     E21xxx_LoadFlow_Assignment.zip

     containing:
     - Code files
     - Input data
     - Output screenshots
     - Report (PDF)

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5. Evaluation Scheme

Component	Weight (%)	Description
Program Implementation	40	Correctness, structure, clarity, and originality of code
PSSE Comparison and Analysis	25	Accuracy of results, interpretation, completeness
Voltage Sensitivity Analysis	25	Correct execution, variance/SD calculations, discussion depth
Report Quality	10	Technical writing, organization, clarity, originality

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6. Additional Guidelines

- Convergence tolerance: (10^{-4}) p.u. on power mismatch.
- Use the per-unit system for all data.
- Plagiarism or shared work will receive **zero marks** without exception.
- Late submissions will incur a **10% penalty per day**, unless approved beforehand.

Appendix- IEEE 9 bus system data

Bus Data

Bus Number	Base kV
1	16.5
2	18.0
3	13.8
4	230.0
5	230.0
6	230.0
7	230.0
8	230.0
9	230.0

Generator Data

Bus No	MVA	Scheduled active power (MW)	Scheduled Voltage (pu)	Maximum reactive power (MW)	Minimum reactive power (MW)
1	100	71.6448	1.04	9999.99	-9999.99
2	100	163.00	1.025	9999.99	-9999.99
3	100	85.00	1.025	9999.99	-9999.99

Transformer Data

From Bus	To Bus	R (pu)	X (pu)	G (pu)	B (pu)
1	4	0.0	0.0576	0.0	0.0
2	7	0.0	0.0625	0.0	0.0
3	9	0.0	0.0586	0.0	0.0

Transmission Line Data

From Bus	To Bus	R (pu)	X (pu)	G (pu)	B (pu)
4	5	0.010000	0.085000	0.0	0.176000
4	6	0.017000	0.092000	0.0	0.158000
5	7	0.032000	0.161000	0.0	0.306000
6	9	0.039000	0.170000	0.0	0.358000
7	8	0.008500	0.072000	0.0	0.149000
8	9	0.011900	0.100800	0.0	0.209000

Load Data

Bus No	Load Type	P (MW)	Q (MW)
5	Constant PQ	125.0000	50.0000
6	Constant PQ	90.0000	30.0000
8	Constant PQ	100.0000	35.0000

Appendix: IEEE 9 bus system data as PSSE raw file format

You may copy the data and save it as .raw extension using notepad

```
0,   100.00,  32, 0, 1, 60.00     / PSS(R)E 32 RAW created by
rawd32  MON, AUG 29 2011  17:08
JANATH GEEGANAGE
UNIVERSITY OF MANITOBA
     1,'            ',  16.5000,3,   1,   1,   1,1.04000,
0.0000
     2,'            ',  18.0000,2,   1,   1,   1,1.02500,
9.2805
     3,'            ',  13.8000,2,   1,   1,   1,1.02500,
4.6651
     4,'            ', 230.0000,1,   1,   1,   1,1.02579,  -
2.2168
     5,'            ', 230.0000,1,   1,   1,   1,0.99562,  -
3.9890
     6,'            ', 230.0000,1,   1,   1,   1,1.01265,  -
3.6875
     7,'            ', 230.0000,1,   1,   1,   1,1.02577,
3.7200
     8,'            ', 230.0000,1,   1,   1,   1,1.01588,
0.7277
     9,'            ', 230.0000,1,   1,   1,   1,1.03235,
1.9669
 0 /End of Bus data, Begin Load data
     5,'1 ',1,   1,   1,   125.000,    50.000,     0.000,
0.000,     0.000,     0.000,   1,1
     6,'1 ',1,   1,   1,    90.000,    30.000,     0.000,
0.000,     0.000,     0.000,   1,1
     8,'1 ',1,   1,   1,   100.000,    35.000,     0.000,
0.000,     0.000,     0.000,   1,1
 0 /End of Load data, Begin Fixed shunt data
 0 /End of Fixed shunt data, Begin Generator data
     1,'1 ',    71.642,    27.052,  9999.000, -
9999.000,1.04000,     0,   100.000, 0.00000E+0, 6.08000E-2,
0.00000E+0, 0.00000E+0,1.00000,1,  100.0,  9999.000, -
9999.000,   1,1.0000
     2,'1 ',   163.000,     6.659,  9999.000, -
9999.000,1.02500,     0,   100.000, 0.00000E+0, 1.19800E-1,
0.00000E+0, 0.00000E+0,1.00000,1,  100.0,  9999.000, -
9999.000,   1,1.0000
     3,'1 ',    85.000,   -10.856,  9999.000, -
9999.000,1.02500,     0,   100.000, 0.00000E+0, 1.81300E-1,
0.00000E+0, 0.00000E+0,1.00000,1,  100.0,  9999.000, -
9999.000,   1,1.0000
 0 /End of Generator data, Begin Branch data
     4,      5,'1 ', 1.00000E-2, 8.50000E-2,   0.17600,
0.00,    0.00,    0.00,  0.00000,  0.00000,  0.00000,
0.00000,1,2,   0.00,   1,1.0000
```

```
     4,      6,'1 ', 1.70000E-2, 9.20000E-2,   0.15800,
0.00,    0.00,    0.00,  0.00000,  0.00000,  0.00000,
0.00000,1,2,   0.00,   1,1.0000
     5,      7,'1 ', 3.20000E-2, 1.61000E-1,   0.30600,
0.00,    0.00,    0.00,  0.00000,  0.00000,  0.00000,
0.00000,1,2,   0.00,   1,1.0000
     6,      9,'1 ', 3.90000E-2, 1.70000E-1,   0.35800,
0.00,    0.00,    0.00,  0.00000,  0.00000,  0.00000,
0.00000,1,2,   0.00,   1,1.0000
     7,      8,'1 ', 8.50000E-3, 7.20000E-2,   0.14900,
0.00,    0.00,    0.00,  0.00000,  0.00000,  0.00000,
0.00000,1,2,   0.00,   1,1.0000
     8,      9,'1 ', 1.19000E-2, 1.00800E-1,   0.20900,
0.00,    0.00,    0.00,  0.00000,  0.00000,  0.00000,
0.00000,1,2,   0.00,   1,1.0000
 0 /End of Branch data, Begin Transformer data
     4,     1,     0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
',1,   1,1.0000
 0.00000E+0, 5.76000E-2,   100.00
1.00000,   0.000,   0.000,     0.00,     0.00,     0.00, 0,
0, 1.10000, 0.90000, 1.10000, 0.90000,  33, 0, 0.00000,
0.00000,  0.000
1.00000,   0.000
     7,     2,     0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
',1,   1,1.0000
 0.00000E+0, 6.25000E-2,   100.00
1.00000,   0.000,   0.000,     0.00,     0.00,     0.00, 0,
0, 1.10000, 0.90000, 1.10000, 0.90000,  33, 0, 0.00000,
0.00000,  0.000
1.00000,   0.000
     9,     3,     0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
',1,   1,1.0000
 0.00000E+0, 5.86000E-2,   100.00
1.00000,   0.000,   0.000,     0.00,     0.00,     0.00, 0,
0, 1.10000, 0.90000, 1.10000, 0.90000,  33, 0, 0.00000,
0.00000,  0.000
1.00000,   0.000
 0 /End of Transformer data, Begin Area data
 0 /End of Area data, Begin Two-terminal dc data
 0 /End of Two-terminal dc data, Begin VSC dc line data
 0 /End of VSC dc line data, Begin Impedance correction data
 0 /End of Impedance correction data, Begin Multi-terminal dc
data
 0 /End of Multi-terminal dc data, Begin Multi-section line
data
 0 /End of Multi-section line data, Begin Zone data
 0 /End of Zone data, Begin Inter-area transfer data
 0 /End of Inter-area transfer data, Begin Owner data
 0 /End of Owner data, Begin FACTS device data
 0 /End of FACTS device data, Begin Switched shunt data
 0 /End of Switched shunt data, Begin GNE data
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 0 /End of GNE data
Q
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Appendix: Obtain PSSE Student Version

Visit https://www.siemens.com/global/en/products/energy/grid-software/planning/pss-software/psse-xplore-order-form.html and request for the free version using your university email address.