McGill University

ECSE 563 Power System Operation and Planning—Fall 2024

Assignment 2
Power Flow Analysis

Complete the following function programming assignments. In all cases, provide fully-documented code with appropriate software validation as instructed.

Throughout this assignment, to mirror how practical power systems are handled, you are forbidden from using a full matrix inversion function. If using Matlab, rely on functions like `linsolve()` or the backslash operator.

Submit a report in .pdf demonstrating your development process and your validation evidence. In your report, provide a link to an online repository to access your code (e.g., github, One Drive, etc.)

1. Develop a callable function to perform power flow calculations using the *Newton-Raphson solution method* on an arbitrary network.

   The module should use as inputs: `Y` the network admittance matrix, `is` the index of the slack node, `ipq` a vector of indices of the PQ nodes, `ipv` a vector of indices of the PV nodes, `Pg` (MW) and `Qg` (Mvar) vectors of specified active and reactive power generation, `Pd` (MW) and `Qd` (Mvar) vectors of specified active and reactive power demand, `V0` (p.u.) a vector of specified voltage magnitudes, `Sbase` (MVA) the network power base, `toler` (p.u.) the Newton-Raphson algorithm convergence tolerance and `maxiter` the maximum number of Newton-Raphson iterations allowed.

   The output should be the node voltage magnitudes and angles, `V` (p.u.) and `delta` (radians), `Psl` (MW) the active generation at the slack node, `Qgv` (Mvar) the reactive power generation at voltage-controlled nodes, `N` the number of iterations to convergence and `time` (s) the cpu time taken by the Newton-Raphson algorithm to converge. Use the following function prototype:

   ```
   [V, delta, Psl, Qgv, N, time] = nrpf(Y, is, ipq, ipv, Pg, Qg, Pd,
                         Qd, V0, Sbase, toler, maxiter)
   ```

   Provide fully-documented code with appropriate validation using the data found in the .m file representing the IEEE 9 bus test system provided on myCourses. Use `toler = 1e-4` p.u. and `maxiter = 20`. Discuss your results briefly.

2. Repeat question 1, but this time use the *decoupled power flow solution method*; use the following function prototype:

   ```
   [V, delta, Psl, Qgv, N, time] = decpf(Y, is, ipq, ipv, Pg, Qg, Pd,
                         Qd, V0, Sbase, toler, maxiter)
   ```

Provide fully-documented code with appropriate validation using the IEEE 9 bus test system. Comment and compare (with respect to the full Newton-Raphson methodology) solution accuracy, cpu times and iteration numbers for the same convergence tolerance. Comment as to whether or not the numerical results make sense given how you would expect active and reactive power to flow.

3. Repeat question 1, but this time use the *fast decoupled power flow solution method*; use the following function prototype:

```
[V, delta, Psl, Qgv, N, time] = fastdecpf(Y, is, ipq, ipv, Pg, Qg,
                  Pd, Qd, V0, Sbase, toler, maxiter)
```

   Provide fully-documented code with appropriate validation using the IEEE 9 bus test system. Comment and compare (with respect to the full Newton-Raphson and decoupled methodologies) solution accuracy, cpu times and iteration numbers for the same convergence tolerance.

4. Repeat question 1, but this time use the *dc power flow solution method*; use the following function prototype:

```
[delta, Psl, Pf] = dcpf(nfrom, nto, x, is, Pg, Pd, Sbase)
```

   where `nfrom`, `nto` and `x` are the same as in `Y = admittance(nfrom, nto, r, x, b)` and `Pf` (MW) is the vector of active power flowing on the transmission lines (with assumed flow directions set by `nfrom` and `nto`).

   Provide fully-documented code with appropriate validation using the IEEE 9 bus test system. Comment and compare (with respect to the full Newton-Raphson and decoupled/fast-decoupled methodologies) solution accuracy and cpu times. Comment on the validity of the approximation in the current sample case.

5. Compare the active power flows found with the dc power flow with those corresponding to the full ac power flow solution. How do these flows compare to the apparent power flows on the lines of the network? Comment accordingly.

6. Using your full Newton-Raphson solution code, determine in the (P_{d7}, Q_{d7}) plane the power flow feasibility region of the IEEE 9 bus test system for load at node 7. Do so for $P_{d7} \geq 0$ and $Q_{d7} \in \mathbb{R}$. Assume that all other pre-specified injections and voltages remain as specified in the network data file.

   Explain the methodology you have used to obtain the feasibility region boundary and comment on the shape of the feasibility region and on how to increase its size.

7. Perform a security analysis of the IEEE 9 bus test system. Credible contingencies include the loss of the following circuits: line 4-5, line 4-9, line 5-6, line 6-7, line 7-8, and line 8-9. Which contingency or contingencies lead to unacceptable bus voltage

levels in the test system? Here, an acceptable voltage is in the range of 0.95 to 1.05 per unit.

Propose some mitigation measures to help maintain the bus voltages in the correct range. The measures put in place should keep the voltages within range regardless of the applied contingency. *Hint:* Recall the fundamental principles of voltage control in ac power systems.