



An Efficient Intrusion Detection System Using Data Mining Techniques for Network Security

Yazmin D'Costa

Department of Electronics and Communication Engineering, Basra Institute of Business Technology, Iraq
yazmin.d.costa@bibt-iq.org

Peer Review Information	Abstract
<i>Submission: 06 Jan 2016</i> <i>Revision: 22 Feb 2016</i> <i>Acceptance: 09 March 2016</i> Keywords <i>Load flow analysis, Newton-Raphson method, power system, Jacobian matrix, Ybus matrix.</i>	Load flow analysis is a fundamental steady-state study used to determine bus voltages, power injections, transmission-line flows, and system losses for a specified operating condition. This paper presents a step-by-step methodology for solving the AC load-flow problem using the Newton-Raphson (NR) method. The method converts the nonlinear active- and reactive-power equations into a sequence of linear correction equations through the Jacobian matrix. A three-bus test system is used to demonstrate the implementation, including formation of the bus-admittance matrix, selection of initial conditions, mismatch calculation, Jacobian construction, solution of the correction vector, and convergence checking. The numerical example converges in four iterations to a maximum power mismatch below 10^{-10} p.u. The results illustrate the fast convergence and numerical accuracy that have made the NR method a standard power-flow technique for transmission-system studies. The methodology is also related to earlier developments in Newton-based and decoupled load-flow methods and to later work on computational acceleration and alternative coordinate formulations [1]–[7].

Introduction

A power system must maintain acceptable voltage magnitudes and phase angles while supplying the required active and reactive power. Load flow analysis provides the steady-state operating point corresponding to specified generation, load, and network parameters. The solution gives the voltage magnitude and phase angle at each bus and, from these quantities, the real and reactive power flowing through transmission elements. These results support planning, operation, voltage assessment, loss calculation, and contingency studies.

The AC power-flow problem is nonlinear because bus power depends on products of voltage magnitudes and trigonometric functions of voltage-angle differences. Tinney and Hart established the practical Newton-based formulation for power-flow solution and

demonstrated its suitability for digital computation [1]. Subsequent work addressed starting procedures and computational efficiency [2], while Stott and Alsac developed the widely used fast-decoupled approximation [3].

The objective of this paper is to provide a compact, reproducible methodology for conventional Newton-Raphson load flow. The focus is on the algorithmic steps rather than on a particular software package. A three-bus numerical example is included so that the complete calculation can be followed from input data to converged bus voltages and line losses.

Literature Review

Tinney and Hart [1] presented the Newton method for power-flow solution and showed how the nonlinear equations can be solved through successive corrections. Their work is a

foundation for modern AC load flow because the Jacobian formulation provides rapid local convergence and is suitable for sparse network computation.

Stott [2] investigated the starting process for Newton–Raphson load flows. Good initial estimates are important because Newton iterations are local numerical steps; a suitable starting point can improve robustness and reduce unnecessary iterations. Stott and Alsac [3] subsequently introduced the fast decoupled load-flow formulation, exploiting the approximate separation between active-power/angle and reactive-power/voltage relationships.

Hubbi and Refsum [4] proposed modifications to the Newton–Raphson load-flow procedure, including an alternative starting algorithm and additional higher-order terms. Their work reflects the continuing interest in improving convergence behavior without abandoning the Newton framework.

Kumar and Chandrasekharan [5] investigated a parallel and distributed framework for Newton–Raphson load flow in large interconnected systems. Their results on the IEEE 118-bus system showed that parallelization can reduce

computation time, especially when the network is partitioned into suitable subsystems. This is relevant to large interconnected grids where computational efficiency becomes important.

Derakhshandeh [6] studied higher-order Newton-like methods and reported reductions in iteration count and computation time on standard test systems ranging from 9 to 2383 buses. Okon and Wilkosz [7] examined Newton–Raphson load-flow calculations in different coordinate systems for systems containing a UPFC and reported numerical differences between rectangular and polar formulations. Together, these studies show that the conventional NR formulation remains a reference method while its initialization, coordinate representation, and computational implementation continue to be investigated.

Methodology

The conventional Newton–Raphson load-flow procedure is implemented in polar coordinates. The system contains one slack bus, one or more PV buses, and PQ buses. In the present example, bus 1 is the slack bus, bus 2 is a PV bus, and bus 3 is a PQ bus. The calculation uses per-unit quantities.

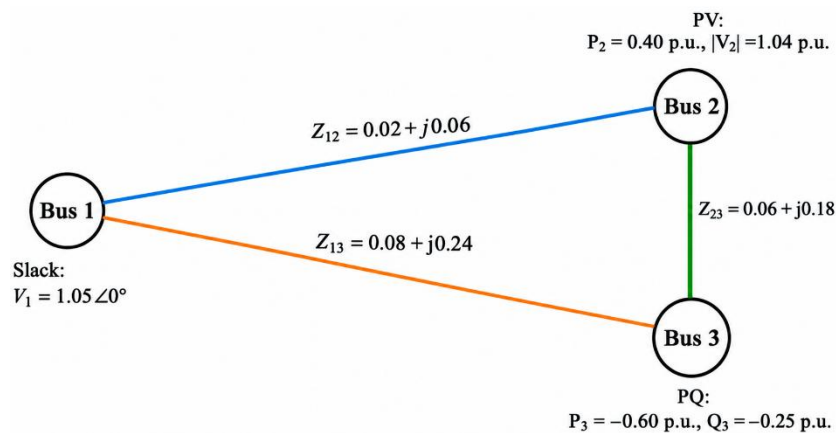


Figure 1. Three-bus test system used for the numerical demonstration.

Step 1 — Define bus and line data

Table 1. Bus specifications for the three-bus example.

Bus	Type	P (p.u.)	Q (p.u.)	V (p.u.)	δ (deg.)
1	Slack	—	—	1.05	0
2	PV	0.40	—	1.04	unknown
3	PQ	-0.60	-0.25	unknown	unknown

The transmission-line series impedances are $Z_{12} = 0.02 + j0.06$ p.u., $Z_{13} = 0.08 + j0.24$ p.u., and $Z_{23} = 0.06 + j0.18$ p.u. Line charging is neglected in this illustrative case. The specified powers follow the sign convention that positive P and Q denote net injection into the network.

Step 2 — Form the bus-admittance matrix

Each line series impedance is converted to admittance using $y_{ij} = 1/Z_{ij}$. The diagonal element of Y_{bus} is the sum of admittances incident on the corresponding bus, while the off-diagonal element is the negative of the mutual admittance. For the selected system:

$Y_{bus} = \begin{bmatrix} [6.25-j18.75, -5+j15, -1.25+j3.75], \\ [-5+j15, 6.6667-j20, -1.6667+j5], [-1.25+j3.75, \\ -1.6667+j5, 2.9167-j8.75] \end{bmatrix}$ p.u.

Step 3 — Select initial voltage values

A flat start is used for unknown variables: voltage angles are initialized at 0° , and the unknown PQ-bus voltage magnitude is initialized at 1.0 p.u. The PV-bus magnitude remains fixed at 1.04 p.u. and the slack-bus voltage is fixed at $1.05\angle 0^\circ$. Therefore, the unknown state vector is $x = [\delta_2, \delta_3, |V_3|]^T$.

Step 4 — Calculate bus powers

For bus i , the complex power injection is $S_i = P_i + jQ_i = V_i I_i^*$ and $I_i = \sum Y_{ij} V_j$. In polar coordinates, the active and reactive powers are

$$P_i = |V_i| \sum |V_j| [G_{ij} \cos(\delta_i - \delta_j) + B_{ij} \sin(\delta_i - \delta_j)]$$

$$Q_i = |V_i| \sum |V_j| [G_{ij} \sin(\delta_i - \delta_j) - B_{ij} \cos(\delta_i - \delta_j)].$$

These equations are evaluated at every iteration to obtain the calculated active and reactive powers.

Step 5 — Calculate power mismatches

The mismatch vector is formed by subtracting calculated power from specified power. For the present system, the mismatch equations are $\Delta P_2 = P_{2,spec} - P_{2,calc}$, $\Delta P_3 = P_{3,spec} - P_{3,calc}$, and $\Delta Q_3 = Q_{3,spec} - Q_{3,calc}$. The mismatch vector therefore has three elements.

Step 6 — Construct the Jacobian matrix

The Newton correction equation is $J\Delta x = [\Delta P_2, \Delta P_3, \Delta Q_3]^T$. The Jacobian contains the partial derivatives of the mismatch equations with respect to the state variables. In block form it is

$J = \begin{bmatrix} H & N \\ M & L \end{bmatrix}$, where H contains $\partial P / \partial \delta$ terms, N contains $\partial P / \partial |V|$ terms, M contains $\partial Q / \partial \delta$ terms, and L contains $\partial Q / \partial |V|$ terms.

For a small system the Jacobian can be formed directly from analytical derivatives. In larger systems, sparse matrix storage and factorization are normally used because the network admittance matrix and Jacobian are sparse [1], [5].

Step 7 — Solve the correction equation and update variables

The linear system $J\Delta x = \text{mismatch}$ is solved for the correction vector. The state variables are updated according to $x(k+1) = x(k) + \Delta x$. The process is repeated using the new voltage magnitudes and angles.

Step 8 — Check convergence

Convergence is declared when the maximum absolute mismatch is less than the selected tolerance. In this study, a tolerance of 10^{-10} p.u. is used for the numerical demonstration. If the tolerance is not satisfied, the algorithm returns to the power-calculation and Jacobian steps.

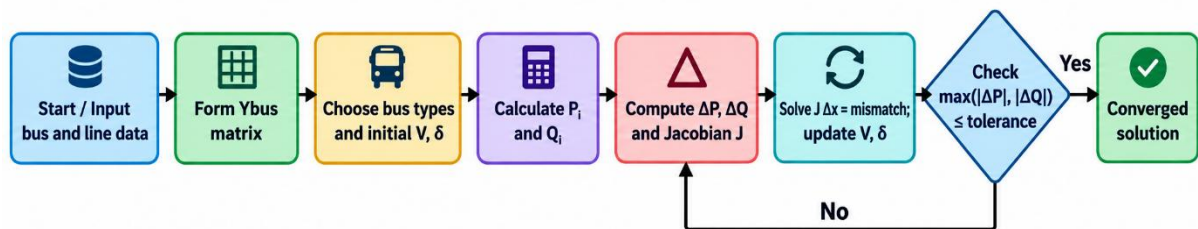


Figure 2. Step-by-step Newton–Raphson load-flow algorithm.

Results

The three-bus system was solved using the conventional polar-coordinate Newton–Raphson formulation. The flat-start solution converged in

four iterations. Table 2 shows the maximum mismatch at each iteration. The mismatch decreases rapidly, which is consistent with the strong local convergence characteristic of Newton-based power-flow methods [1], [6].

Table 2. Newton–Raphson mismatch reduction during the solution

Iteration	$ \Delta P_2 $	$ \Delta P_3 $	$ \Delta Q_3 $	Max. mismatch
1	3.827e-01	4.708e-01	1.375e-01	4.708e-01
2	1.865e-03	5.137e-03	1.149e-02	1.149e-02
3	4.588e-07	8.728e-06	1.730e-05	1.730e-05
4	3.185e-12	2.263e-11	4.041e-11	4.041e-11

The final voltage solution is $|V_1| = 1.0500$ p.u. at 0° , $|V_2| \approx 1.0400$ p.u. at 0.3366° , and $|V_3| \approx 0.9965$ p.u. at -2.7358° . The calculated slack-bus generation is $P_1 \approx 0.2154$ p.u. and $Q_1 \approx 0.3427$

p.u. The small change in the PV-bus voltage magnitude is only a numerical consequence of the calculation and the specified set point is maintained to the stated precision.

Table 3. Final converged bus results.

Bus	Type	$ V $ (p.u.)	Angle (deg.)	P (p.u.)	Q (p.u.)
1	Slack	1.0500	0.0000	0.2154	0.3427
2	PV	1.0400	0.3367	0.4000	-0.0466
3	PQ	0.9965	-2.7358	-0.6000	-0.2500

The total active-power loss calculated from the three line-end flows is approximately 0.0154 p.u., while the total reactive-power loss is approximately 0.0461 p.u. These losses represent

the difference between the sending- and receiving-end complex powers on the network branches.

Table 4. Calculated branch powers and losses (p.u.).

Line	P_{ij}	Q_{ij}	P_{ji}	Q_{ji}	P loss	Q loss
1-2	-0.0436	0.1899	0.0443	-0.1878	0.0007	0.0021
1-3	0.2590	0.1528	-0.2525	-0.1331	0.0066	0.0197
2-3	0.3557	0.1412	-0.3475	-0.1169	0.0081	0.0244

Conclusion and Discussion

The Newton–Raphson method provides a systematic and computationally efficient approach for AC load-flow analysis. The methodology begins with network data and the Ybus matrix, defines bus types and initial conditions, evaluates nonlinear power equations, constructs the Jacobian, solves for state-variable corrections, and repeats the process until the power mismatches satisfy the convergence criterion.

For the three-bus test system, the algorithm converged in four iterations from a flat start. The final solution provides bus voltage magnitudes and angles together with line flows and total losses. The calculation demonstrates why the Jacobian is central to the NR method: it converts the nonlinear power flow problem into a sequence of linear correction problems. The method is especially attractive for transmission-system studies because its local convergence is rapid and its formulation can be extended to large sparse networks [1], [5].

The main practical limitations are the need to construct and factorize a Jacobian at each iteration and the possibility of convergence difficulties for poorly initialized or heavily stressed systems. Research on improved starting procedures [2], modified Newton formulations [4], parallel computation [5], higher-order methods [6], and alternative coordinate systems [7] shows that the conventional method can be enhanced for specific applications. Nevertheless, the classical NR formulation remains an important reference algorithm for validating

power-flow implementations and for teaching the numerical structure of steady-state power-system analysis.

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