Reactive Power Loss & Efficiency Calculation Using Load Flow Technique In Distribution System For Pune City

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Abstract - Reactive power compensation is an important issue in electric power systems, involving operational, economical and quality of service aspects. Consumer loads (residential, industrial, service sector, etc.) impose active and reactive power demand, depending on their characteristics. This paper presents an efficient method for solving the load flow problem in distribution systems and which is implemented for Pune city (India) to check the validity of proposed method. A simple algebraic matrix equation to solve the load flow problem is derived by using the complex power balance equations. By adopting the rectangular coordinate, which requires the neglect of only second order terms in the linearization procedure, the proposed method gives better convergence characteristics. Newton-Raphson method is the famous load flow calculation technique, and normally used due to its rapidness of numerical convergence. The proposed method estimates the incremental changes of active power on each generation bus with respect to the total system power loss, efficiency and the estimated value are used to update the slack bus power.

Keywords - Reactive power, load flow, Distribution feeders, $Y_{bus}$ formulation.

1. INTRODUCTION

Reactive power compensation is an important issue in electric power systems, involving operational, economical and quality of service aspects. Consumer loads (residential, industrial, service sector, etc.) impose active and reactive power demand, depending on their characteristics. Active power is converted into “useful” energy, such as light or heat. Reactive power must be compensated to guarantee an efficient delivery of active power to loads, thus releasing system capacity, reducing system losses, and improving system power factor and bus voltage profile.

Load flow analysis has a great importance in future expansion planning, in stability studies and in determining the best economical operation for existing systems. Also load flow results are very valuable for setting the proper protection devices to insure the security of the system. In order to perform a load flow study, full data must be provided about the studied system, such as connection diagram, parameters of transformers and lines, rated values of each equipment, and the assumed values of real and reactive power for each load. [3]

The power flow calculations are the most important and powerful tools in power systems engineering. Newton-Raphson (NR) method, among the various power flow calculation techniques, is normally used due to its rapidness of numerical convergency. In the conventional Newton-Raphson method, however, there is a somewhat unrealistic assumption under which all the system power losses are considered to be supplied by the slack bus generator. The unrealistic feature of the assumption may make little difficulty in general cases of power systems engineering, but in certain cases, especially such as voltage stability studies, it can make the results of load flow solution distorted from those of the real system. In the situations close to voltage collapse, power system has relatively large transmission loss which makes load flow solution often diverges. In those situations, even in convergence case, the results of load flow solution would be more distorted than in the normal, and these distorted solutions can make the results of voltage stability analysis inaccurate [2].

II. MATHEMATICAL FORMULATION

There are several different methods of solving the resulting nonlinear system of equations. The most popular is known as the Newton-Raphson Method. This method begins with initial guesses of all unknown variables (voltage magnitude and angles at Load Buses and voltage angles at Generator Buses)
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Let bus indices 1 to m denote pure load buses, (m+1) to (n-1) denote pure generation buses, and n denote slack bus, then LF problem is to find, m+n-1 unknown variables, bus voltage magnitudes (V) and n-1 bus voltage angles (δ), from the following nonlinear simultaneous equations.

\[
\begin{align*}
\Delta P_i &= \sum_{j=1}^{n} (V_i V_j G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij}), \quad i \in (L+G) \\
\Delta Q_i &= \sum_{j=1}^{n} (V_i V_j G_{ij} \sin \delta_{ij} - B_{ij} \cos \delta_{ij}), \quad j \in L
\end{align*}
\]

Where,

- \(P_i, Q_i\) = Active, Reactive pure injection power at bus \(i\).
- \(G_{ij}, B_{ij}\) = conductance, susceptance between bus \(i\) and \(j\).
- \(L = \{l, \ldots, m\}\) : index set of load bus
- \(G = \{m+1, \ldots, n-1\}\) : index set of generation bus (slack bus excluded).

In general, \(P_i, V_i\ (i \in G), V_n, \delta_n\ (n: slack bus), P_j, Q_j\ (j \in L)\) are considered as preliminarily specified in the conventional LF formulations. In some literature, \(P_i, V_i\ (i \in G), V_n, \delta_n\) are called controlled variables. NR Method then finds the unknown variables \(V_i, \delta_i\ (i \in L+G)\) (these are called state variables basically with iterative updating scheme from a given initial point \((V^0, \delta^0)\), based on the 1st order Taylor approximation of eq. (1)(4)

**Unknown variable updating scheme**

The iterative scheme commonly used can be explained in brief with the following equations;

\[
\begin{bmatrix}
\Delta \delta \\
\Delta V
\end{bmatrix} =
\begin{bmatrix}
H & M \\
N & L
\end{bmatrix}^{-1}
\begin{bmatrix}
\Delta P \\
\Delta Q
\end{bmatrix}
\]

Where,

- \(\Delta P\) = Active power mismatch
- \(\Delta Q\) = Reactive power mismatch
- \(\Delta \delta\) = Voltage angle difference
- \(\Delta V\) = Voltage magnitude difference

\[H = (\partial P/\partial \delta), \ M = (\partial P/\partial V) V, \ N = (\partial Q/\partial \delta), \ L = (\partial Q/\partial V) V,\]

Then, newly updated magnitude and angle of bus voltage are obtained:

\[
\begin{align*}
V_{\text{new}} &= V^0 + (\Delta V/V) V^0 \\
\delta_{\text{new}} &= \delta^0 + \Delta \delta
\end{align*}
\]

If \(V, \delta\) are converged after a few iterations then the final values are accepted as the solution of the LF calculation.[5]

**Calculation of line power flows and slack bus power**

Given the solution the power flow of each transmission line and slack bus power are obtained with following expressions:[7]

\[
\begin{align*}
P_{ij} &= V_i V_j (G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij}) - V_i^2 G_{ij} \\
Q_{ij} &= V_i V_j (G_{ij} \sin \delta_{ij} - B_{ij} \cos \delta_{ij}) + V_i^2 (B_{ij} - \frac{b_{ij}}{2})
\end{align*}
\]

Where,

- \(b_{ij}\) = shunt susceptance of the line between bus \(i\) and \(j\)
- \(P_{ij}, Q_{ij}\) = Active, reactive power flow from bus \(i\) to \(j\)

And

\[
\begin{align*}
P_n &= \sum_{j=1}^{n} V_n V_j (G_{nj} \cos \delta_{nj} + B_{nj} \sin \delta_{nj}) \\
Q_n &= \sum_{j=1}^{n} V_n V_j (G_{nj} \sin \delta_{nj} - B_{nj} \cos \delta_{nj})
\end{align*}
\]

\[
V_i \sum_{j=1}^{n} V_j = P_i^{sp} - j Q_i^{sp}, \quad i=1, \ldots, N, i \neq s
\]

Where \(s\) denotes the slack bus

With an appropriate solution guess \(V_0 = [V_{10}, V_{20}, \ldots, V_{n0}]\), the above equation can be rewritten as

\[
(V_i^{0} + \Delta V_i) \sum_{j=1}^{n} V_j = P_i^{sp} - j Q_i^{sp},
\]

Fig. 1: Single Line Diagram of Radial Distribution Network
By neglecting the second order terms, we can obtain the following linearized equation:

\[ V^* \sum_{i=1}^{N} Y_{ij} \Delta V^i + \left( \sum_{j=1}^{N} Y_{ij} V^j \right) \Delta V^j \approx (P_{i}^{sp} - jQ_{i}^{sp}) V^* \]

(9)

From Eq. (1), we can obtain the following approximated relation:

\[ \sum_{j=1}^{N} Y_{ij} V^j = \frac{(P_{i}^{sp} - jQ_{i}^{sp})}{V^*} \]  

(10)

Substituting (10) into (9) and dividing both sides by \( V^* \),

\[ \sum_{j=1}^{N} Y_{ij} \Delta V^j + \frac{(P_{i}^{sp} - jQ_{i}^{sp})}{V^*} \Delta V^i \approx \Delta I^i \text{, } i=1, 2, ..., N & I \neq s \]

(11)

In the above equation, the current mismatch \( \Delta I^i \) is determined by

\[ \Delta I^i = \frac{(P_{i}^{sp} - jQ_{i}^{sp})}{V^*} \text{, } i=1, 2, ..., N & I \neq s \]

(12)

Where, \( \Delta P = P_{i}^{sp} - P_i \)

\[ \Delta Q = Q_{i}^{sp} - Q_i \]

The above equation can be rewritten in a matrix form as follows:

\[ Y_{BUS} \Delta V + D \Delta V^* = \Delta I \]

(13)

Where, \( \Delta V = [\Delta V_1, \Delta V_2, ..., \Delta V_N]^T \)

\[ \Delta I = [\Delta I_1, \Delta I_2, ..., \Delta I_N]^T \]

\[ D = \text{diag}\{(P_{i}^{sp} - jQ_{i}^{sp})/(V^*)^2\} \]

III. RESULT AND RESULT ANALYSIS

12 node Line data

| Branch | Sending-end | Receiving-end | r(pu) | x(pu) |
|--------|-------------|---------------|-------|-------|
| 1      | 1           | 2             | 0.0192| 0.0575|
| 2      | 2           | 3             | 0.0452| 0.1652|
| 3      | 3           | 4             | 0.0570| 0.1737|
| 4      | 4           | 5             | 0.0132| 0.0379|
| 5      | 5           | 6             | 0.0472| 0.1983|
| 6      | 3           | 7             | 0.0581| 0.1763|
| 7      | 7           | 8             | 0.0119| 0.0414|
| 8      | 8           | 9             | 0.0460| 0.1160|
| 9      | 5           | 10            | 0.0267| 0.0820|
| 10     | 10          | 11            | 0.0120| 0.0420|
| 11     | 7           | 12            | 0.0   | 0.2080|

12 node Load data

| Nodes | \( P_{Li} \) at RE (kW) | \( Q_{Li} \) at RE (KVARr) |
|-------|--------------------------|---------------------------|
| 1     | 0                        | 0                         |
| 2     | 21.7                     | 12.7                      |
| 3     | 2.4                      | 1.2                       |
| 4     | 7.6                      | 1.6                       |
| 5     | 94.2                     | 19.0                      |
| 6     | 0.0                      | 0.0                       |
| 7     | 22.8                     | 10.9                      |
| 8     | 30.0                     | 30.0                      |
| 9     | 0.0                      | 0.0                       |
| 10    | 5.8                      | 2.0                       |
| 11    | 0.0                      | 0.0                       |
| 12    | 6.1                      | 1.6                       |

Result Table

| Bus | Type | \( P_{Li} \) | \( Q_{Li} \) | Efficiency |
|-----|------|--------------|--------------|------------|
| 1   | 1    | 0            | 0            | 0          |
| 2   | 3    | 21.7         | 12.7         | 63         |
| 3   | 3    | 2.4          | 1.2          | 66.67      |
| 4   | 3    | 7.6          | 1.6          | 82.6       |
| 5   | 3    | 94.2         | 19.0         | 83.2       |
| 6   | 3    | 0.0          | 0.0          | 0          |
| 7   | 3    | 22.8         | 10.9         | 67.6       |
| 8   | 3    | 30.0         | 30.0         | 50         |
IV. CONCLUSIONS

In this study, a simple and efficient load flow solution has been proposed for determining system power loss & efficiency for distribution system in Pune city (INDIA).

A simple algebraic matrix equation has been derived from conventional complex power balance equation. Since only second order terms are required to be neglected in the linearization procedure, the proposed method gives better convergence characteristics. Only diagonal elements of matrix and current mismatch vector are updated each iteration in the proposed algorithm, which remarkably improves the computation speed with use of the sparsity technique and near-optimal ordering.

The proposed method can be applied to any city with fast calculation speed & it can be well applied to the distribution system with a wide range of R/X ratios.

REFERENCES

[1] Young-Hyun Moon, Byoung-Kon Choi Byoung-Hoon Cho, “Fast and Reliable Distribution System Load Flow Algorithm Based on the Ybus Formulation”, 1999, IEEE.

[2] Joong-Rin Shin, Han-Suck Yim, “AN EXTENDED APPROACH FOR NR LOAD FLOW WITH POWER LOSS CORRECTION METHOD”, 1993, IEEE.

[3] Avani Jigar Pujara, Gitanjali vaidya, “Voltage stability index of radial distribution network”, 2011, IEEE.

[4] Abdellatif Hamouda, Khaled Zehar, “Efficient Load Flow Method for radial Distribution feeders”, journal of Applied Sciences 6(13): 2741-2748, 2006.

[5] D. Das, D.P. Kothari and A. Kalam, “Simple and Efficient Method for Load Flow Solution of Radial Distribution Networks”, International Journal of Electrical Power & Energy Systems, Vol. 17, No. 5, pp. 335–346, 1995.

[6] S. Ghosh and D. Das, “Method for Load Flow Solution of Radial Distribution Networks”, IEE Part C (GTD), Vol. 146, No. 6, pp. 641 – 648, 1999.

[7] Nagrath Kothari, power System Analysis, Tata McGraw-Hill, 1994. ISBN 0-07-462299-4, Tata McGraw-Hill Publishing Company Ltd.