An Overview of Load Flow Analysis Methods for Electrical Distribution Networks

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Abstract

Generally in electrical systems loads can exist in different forms such as linear and non-linear and each type of load is going to have a definite impact upon the quality of power. Thus an electrical power supply after being in operation with above referred loads may result in degradation of power quality in terms of voltage dips, surges, spikes and harmonics. If the adequate compensation on the demand side is not applied the existing power system may encounter many serious challenges which include line overloading, equipment outages, voltage collapse and extended blackouts. A proper load flow analysis and devices such as OLTC, AVR’s and FACTS are obvious solution for such power quality problems. The paper elucidates various load flow methods including forward and backward sweep method in different electrical distribution networks to improve the voltage regulation and system line losses keeping in view the reliability and economy of the entire power system. The proposed approach can be tested on IEEE-15 and IEEE-33 bus system.

Keywords: Load flow analysis, Voltage dips, Electrical distribution networks, Non-linear loads

I. INTRODUCTION

The main information obtained from the load flow study are voltage magnitude and phase angle at each bus, real and reactive power flowing in each element. All traditional load flow methods use iterative algorithm for solving various non-linear algebraic equations as the electrical networks in the distribution side are usually complex in nature. Load flow studies are significant for planning and designing future expansion of existing power system. The iterative methods range from linear convergent Gauss Siedel to quadratic convergent Newton Raphson load flow method.

The efficiency and utility of various load flow methods cannot be gauged in general rather the behavior of different load flow methods depends upon types and sizes of problems to be solved as well as exact details of execution. Load flow studies aids in ascertaining the various parameters of power system operation such as voltage sagging, violation of stability margins, overloading of lines and generators, type of compensation to be applied, effect of contingencies etc.

In different applications choice of load flow methods is a compromise between various attributes of load flow analysis and to some extend it is not incorrect to point out that among existing methods not a single method possesses all the attributes viz, high speed, reliability for ill-conditioned system, accuracy, slack bus sensitivity and computation time for number of iterations.

II. TYPES AND COMPARISON

<table>
<thead>
<tr>
<th>Load Flow methods in Distribution System</th>
<th>Merits</th>
<th>Demerits</th>
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<tbody>
<tr>
<td>Gauss Siedel</td>
<td>Programming is easy. Small number of arithmetic operations to complete one iteration.</td>
<td>Linear Convergence. Least accurate.</td>
</tr>
<tr>
<td>Newton Raphson Method</td>
<td>Sensitivity to slack bus is least. Most accurate method.</td>
<td>Time per iteration is more than GS and increase with increase in number of buses. Elements of Jacobian need to be calculated in every iteration.</td>
</tr>
<tr>
<td>FDLF</td>
<td>It requires 2 to 5 iteration for practical accuracies. Require least arithmetic operations and more reliable than NR.</td>
<td>Moderately accurate. Sensitivity to slack bus is moderate.</td>
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<tr>
<td>Genetic Algorithm based</td>
<td>Execution of algorithm is easy. It is suitable for offline application.</td>
<td>Time per iteration increases with the increase in complexity of network. Sensitive to slack bus and controller parameters.</td>
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<tr>
<td>Artificial neural networks</td>
<td>It is suitable for online application. Least time per iteration is required</td>
<td>Limited input parameter range is specified. Other methods are required to find accurate solutions.</td>
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III. Fast Decoupled Load Flow

FDLF was developed by B. Scott in 1974 in a process of further simplification of NRLF method. In this method certain calculations namely off diagonal elements of Jacobian matrix were eliminated by physically justifiable assumptions and method became fast in terms of reducing computations, time and memory requirement. As a result of which a constant Jacobian was produced whose inversion was required only once. Physically justifiable assumptions are:

1) Resistances are ignored in comparison to reactances.
2) Power angle (δ’s) are small and angle δ is usually operated at linear portion of p-δ curve where its value is small.
3) Conductance can be ignored as compared to susceptance.

\[
\begin{bmatrix}
\Delta P \\
\Delta Q
\end{bmatrix} = \begin{bmatrix}
H & 0 \\
0 & L
\end{bmatrix} \begin{bmatrix}
\Delta \delta \\
\Delta V/V
\end{bmatrix}
\]

With these assumptions the elements of H & L sub-matrices are considerably simplified.

IV. Forward/Backward Sweep Method

The computational procedure which is aimed to calculate steady state operating characteristics of power system for a number of bus bar loads is a basic criterion for a load flow or power flow studies. Overall emphasis is to keep the voltage profiles within specified limits (0.95 p.u to 1.05 p.u) for different distribution networks existing in power system. Once the system is operating for achieving optimization of various parameters, different techniques are explored to maintain the voltage in stipulated limits and keeping the system losses at minimal amount.

Some of the traditional load flow methods such as GS, NR turn inefficient for distribution networks due to radial structure of network, ill-conditioned system with high R/X ratio, unbalanced distribution loads, improper operation and distributed generation.

Most of the authors agree with the fact that for distribution load flow analysis backward /forward sweep method and ladder network theory are commonly employed because of computational efficiencies and system accuracies.

The backward /forward sweep algorithm consists mainly of two steps namely backward sweep and forward sweep. In backward sweep, voltage and currents are computed using KVL and KCL from the farthest node to root node. In case of forward sweep downstream voltages are calculated by employing linear principle method from the root node or source node. The parameter data required are active power, reactive power, numbering of different roots & terminal nodes and sequence impedance models for different branches.

After performing a backward sweep, the mismatch of calculated and specified voltages at different bus bar loads is verified and algorithm repeats until the convergence criterion is achieved at different bus bars.

For Backward sweep we have

\[ J_{f}^{(b)} = -J_{lr}^{(b)} + \sum J_{lr}^{(b)} \]

For Forward sweep we have

\[ V_{lr}^{(f)} = V_{ls}^{(b)} - Z_{l}(b) J_{f}^{(b)} \]
V. FLOW CHART FOR BACKWARD /FORWARD SWEEP METHOD

```
START
READ LINE DATA & LOAD DATA
SET ITERATION COUNT WITH FLAT VOLTAGE (1 P.U.)
SET CONVERGENCE CRITERIA ΔV = |Vmill - Vinit| ≤ 0.0001
COMPUTE REAL AND reactive POWER FLOWS USING BACKWARD SWEEP FOR NODE CURRENT Ii = (S/V)
USING FORWARD SWEEP UPDATE UPSTREAM CURRENTS I0 = |Ii - 1| WHERE CURRENTS ORIGINATING FROM NODES i+1
USING FORWARD SWEEP COMPUTE NODE VOLTAGIS FROM ROOT NODE TO TERMINAL NODE Vi = Vi+1 - I (i+1) * Z(i, i+1)
HAS CONVERGENCE BEEN ACHIEVED ΔV = 0.0001
YES
STOP
NO
COMPUTE SYSTEM LOSSES & PRINT VOLTAGE, REAL AND reactive POWER
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REFERENCES