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A REVIEW ON LOAD-FLOW ANALYSIS OF POWER DISTRIBUTION SYSTEMS

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***Abstract*:**

In the literature, there are a number of efficient and reliable load-flow solution techniques, such as: Newton-Raphson method, Fast Decoupled Load-flow method and Gauss-Seidel method. These techniques are well valid for transmission systems. The distribution systems are radial in nature (practically weakly meshed) whereas transmission systems are loop in nature. The distribution networks have a high R/X ratio compared to the transmission networks and hence are ill-conditioned in nature.

Keywords—Load-flow methods, Distribution networks, R/X ratio.

1. INTRODUCTION

The power system networks are complex and interconnected, consist of generation, transmission and distribution systems. Different algorithms are proposed and applied for the load flow analysis of the transmission system, but the load flow analysis for the distribution system is still in its development stage. In present days the study of the distribution network is the major issue because of the characteristics of the distribution system is highly unstable, high R/X ratio. The distributed energy resources are expensive due to their unbalanced condition. The conventional Newton- Raphson (NR) load flow method and fast decoupled load flow methods are not suitable for the Distribution Network (DN). Load flow studies are performed on Power Systems to understand the nature of the existing network. Using the Load flow analysis the static performance of the system can be determined at normal steady-state operation. A power-flow study can be analyzed in a simple manner such as a one-line diagram and per-unit system, and focuses on various forms of AC power (i.e.: voltages, voltage angles, real power and reactive power).

2. FEATURES OF DISTRIBUTION NETWORK

The distribution networks behavior is unsatisfactory because of the following features.

- Radial or weakly meshed networks
- High R/X ratios
- Multi phase, unbalanced operation
- Unbalanced distributed load
- Distributed generation

Due to the above factors the Newton Raphson(NR) and other transmission system algorithms are failed with distribution network. For the distribution network analysis the backward forward sweeping method is introduced. Unlike NR method, Jacobian matrix determination is not necessary in this method.

In this paper, different load flow analysis methods proposed by different researchers is mentioned briefly.

3. OBJECTIVE OF THE REVIEW

In this paper many researchers developed different load flow solutions to the distribution system networks some of which are balanced, unbalanced and weekly meshed networks. There is no unique method for all the cases because methods have some complexity, convergence and time consuming.

The objectives are divided into the following:

1. To use sequential numbering scheme.

2. To reduce data preparation using the radial feature of distribution networks using only the source node of the feeder, lateral(s) and sub lateral(s).
3. To check the loads-flow results using the constant power, constant current, constant impedance, composite and exponential loads.

Stott and Alsac [1] first suggested a simple, very reliable and fast load-flow solution method with a wide range of practical application. It was useful for accurate or approximate off-line and on-line routine and contingency calculations for networks of any size and could be implemented efficiently on computers. In their paper, the detailed performance on a series of practical problems had been presented. The algorithm was simpler, faster and more reliable than Newton's method and had lower storage requirements for entirely in-core solutions. Correlations of general interest between the power-mismatch convergence criterion and actual solution accuracy were obtained.

Bose and Rajicic [2] proposed Fast Decoupled method, which was probably the most popular because of its efficiency. Its reliability for most transmission systems was very high but it had difficulties in convergence for systems with high ratios of branch resistance to reactance. Modifications, that retained the advantages of their method but could handle high R/X ratios, which were of great interest and certain compensation techniques, had been used for their purpose. Both the series and parallel compensation techniques, however, gave mixed results and a new modification was presented here that performed better on several test systems.

Amerongen [3] presented a new version of the fast decoupled load-flow by which a broader range of problems in power systems could be solved. It was shown for normal test systems, so there was hardly any difference in the number of iterations. However, the new algorithm iterated faster if one or more problematic R/X ratio were present. In the paper the advantages of the new version were demonstrated by running on IEEE test systems with both uniformly and non-uniformly scaled resistances and reactance.

Baran and Wu [4] proposed the capacitor sizing problem for the determination of optimal capacitor placement in the radial distribution system to minimize the real power losses for a given load profile. Their problem formulation was in nonlinear form. They presented a new formulation of power flow equations in radial networks which were numerically robust and computationally efficient.

Renato Cespedes [5] mentioned a new method for the solution of load-flow in radial operated distribution networks. The method was based on an electric equivalent and in the elimination of the voltage phase angle in the equations to be solved, which permitted to obtain the exact solution working only with voltage magnitudes.

Nanda [6] proposed a general purpose Fast Decoupled power flow model (GFDPF) that exhibited more or less best convergence properties of both well-behaved and ill-conditioned systems. Simple and efficient compensation technique was proposed to deal with g-limit enforcements associated with bus-type switching at voltage-controlled buses. The results demonstrated that the proposed GFDPF model exhibited more or less stable convergence behaviour for both well-behaved and ill-conditioned situations.

Das [7] explained a novel method for load-flow technique for solving radial distribution networks by computing the total real and reactive power fed through any node. They had proposed an unique node, branch and lateral numbering scheme, which helped to evaluate exact real and reactive power loads fed through any node. Methods were based on the forward-backward sweep process for the solution of ladder networks. The proposed method could easily handle different types of load characteristics. Several Indian rural distribution networks had been successfully solved using the proposed method.

Shlrmohammadi and Cheng [8] presented a three-phase power flow solution method for real-time analysis of primary distribution systems. The method proposed here was capable of addressing these modelling challenges while still maintaining a high execution speed required for real-time application in distributed automation systems. The paper also included test results from the application of a computer program developed based on the proposed method for large primary electric distribution systems.

Zimmerman and Chiang [9] proposed a novel power flow formulation and an effective solution method for general unbalanced radial distribution system. In their paper the authors exploited the radial structure and the decoupling numerical property of a distribution system to develop a Fast Decoupled Newton method for solving unbalanced distribution system problems. The modelling included unbalanced three phase, two phase and single phase branches of bus system, constant power, constant current, and constant impedance loads connected in star or delta formations, shunt capacitors, line charging capacitance, co- generators, switches and three phase transformers of various connection types. The proposed solution algorithm was evaluated on three-phase unbalanced 292-bus and 394-bus test systems with very promising results.

Zhang and Cheng [10] presented a modified Newton method for radial distribution systems in which the Jacobian matrix was in UDUT form, where U was a constant upper triangular matrix depending solely on system topology and D was a block diagonal matrix. With the formulation, the conventional steps of forming the Jacobian matrix, LU factorization and forward/backward substitution was replaced by back/forward sweeps on radial feeders with equivalent impedances. The proposed method could be applied to other applications, such as state estimation, solution of systems with loops, dispersed generators and three phase (unbalanced) representation.

Ghosh and Das [11] proposed a method, which involved only the evaluation of a simple algebraic expression of receiving-end voltages. They presented a load-flow technique based on nodes beyond branches, which was very efficient computationally. It had good and fast convergence characteristics. Loads in the formulation had been presented as constant power. The speed requirement of the proposed method had also been compared with other existing methods and they had not reduced the network.

Bompard [12] proposed a study on the convergence characteristics of the backward/forward sweep method, which was one of the most effective methods for the load- flow analysis of the radial distribution systems. In their research the convergence conditions and the evolution of the iterative process were investigated in detail for different load models, taking into account different line R/X ratio and different types of voltage-dependent loads.

Mok [13] presented an efficient method of power flow analysis for solving balanced radial distribution systems. The radial distribution system was modelled as a series of interconnected single feeders. Using Kirchhoff‟s laws, a set of iterative power flow equations were developed to conduct the power flow studies. For the purpose of power flow study, the radial distribution system was modelled as a network of buses connected by distribution lines or switches connected to a voltage specified source bus. Each bus might also had a corresponding bus load, compensating load (shunt capacitor or inductor), lateral load and/or co-generator connected to it. This paper also compared the power flow results of a distribution system for the different voltage-dependent load models. The radial topology of distribution networks had been fully exploited such that a unique branch and node numbering scheme was utilized to achieve storage and computational economy.

Haque [14] proposed a very simple and efficient method of load-flow analysis for a general distribution system having a mesh network with more than one feeding node. The network conversion process created some break points and dummy buses. The characteristics of the original system were preserved by injecting appropriate complex power at the break points in the equivalent system. The injected powers were computed and updated during the iteration process through a reduced order impedance matrix. The performance of the proposed method was investigated on three different test systems with various modifications.

Aravindhababu [15] proposed a novel technique to obtain the solution of load-flow in radially operated distribution networks in which the loads could be represented by any model. The method was simple, easily programmable and based on the formation of a constant sparse upper triangular matrix, which was for the determination of the bus voltages. The proposed method was tested through test results of IEEE 34 and IEEE 123 bus systems.

Augugliaro [16] presented an efficient method for radial distribution network solution. The efficiency of the presented strategy made it suitable for distribution automation applications. It used a simple matrix representation for the network topology and branch current flow management.

Zhu and Tomsovic [17] analysed an adaptive distributed power flow solution method based on the compensation-based method. The numerical properties of the compensation-based power flow method was compared and analysed under different situations, such as load unbalance, sudden increase of single phase loads, degree of meshed loops, number of generator nodes and so on. They exploited in their research an adaptive compensation-based power flow method that was fast and reliable while maintaining necessary accuracy and appropriate for simulation of slow dynamics.

Mekhamer [18] presented a new development for solving the load-flow problem for radial distribution feeders, without having to solve the well-known conventional load-flow equations. They exploited the table of solution variables such as voltage, injected powers at each node of the feeder and line losses. They compared their method with the original method from [4] and as well as the standard conventional load-flow methods.

Ranjan and Das [19] proposed a simple and efficient algorithm for solving problems in radial distribution network. In their research they mentioned simple algebraic recursive expression of voltage magnitude and all the data were stored in vector form. Their algorithm used basic principle of circuit theory and could be understood easily. They had reduced the network for the load-flow analysis of the networks.

Bhutad [20] presented the distinguishing features of distribution system to the transmission system. In their research they proposed certain features of the distribution system which made it different and somewhat difficult to be analysed than to the transmission system. Analysing un-transposed lines, single-phase and two-phase laterals were some of those difficulties. They mentioned in their paper, the distribution system needed to be analysed on the three-phase basis instead of the single-phase basis. Various load-flow methods for distribution systems were reviewed and hence applied on a sample 8-bus system. The performance of these methods was compared for various parameters.

Aravindhababu [21] proposed a new, robust, and fast technique to obtain the load-flow solution in distribution networks. The proposed method was based on the Newton-Raphson"s technique using equivalent current-injection and rectangular coordinates. This method was simple, insensitive to R/X ratios of the distribution lines and used a constant Jacobian matrix. It was solved similar to Fast Decoupled power flow method.

Eminoglu and Hocaoglu [22] illustrated in their paper a simple and efficient method to solve the power flow problem in radial distribution systems. The proposed method considered voltage dependency of static loads and line charging capacitance. The method was based on the forward and backward voltage updating by using the polynomial voltage equation for each branch and backward ladder equation (Kirchhoff"s Laws). Convergence ability and reliability of the method was compared with the Ratio-Flow method, which was based on classical forward–backward ladder method for different loading conditions, R/X ratios and different source voltage levels, under the wide range of exponents of loads.

Kumar and Selvan [23] proposed a simple approach to load-flow analysis of a radial distribution network. In their approach, computation of the branch current depended only on the current injected at the neighbouring node and the current in the adjacent branch. The approach started from the end nodes of sub lateral line, lateral line and main line and moved towards the root node during branch current computation. The node voltage evaluation began from the root node and moved towards the nodes located at the far end of the main, lateral and sub lateral lines. The proposed method found to be computationally efficient.

Sivanagaraj [24] explained about distinctive load-flow solution technique for the analysis of weakly meshed distribution systems. The special topological characteristics of distribution networks had been fully exploited to make the solution possible. A branch-injection to branch-current matrix was formed (BIBC). This matrix was obtained by applying Kirchhoff‟s current law for the distribution network. Using the same matrix a solution for weakly meshed distribution network was proposed. Bus voltages were found by the forward - sweep of the network. Test results of 33-bus and 69-bus systems were given to illustrate the performance of the presented method.

Ghosh and Sherpa [25] proposed a new and accurate method for load-flow solution for radial networks with minimum data preparation where the node and branch numbering in bus systems was not to be sequentially only like other methods. Their proposed method used the simple equation for voltage magnitude computation. Their method was capable to handle composite load modelling. Their method was effective and compared with other methods using examples through detailed study and different load-modelling pattern.

Wu and Zhang [26] suggested theoretical formulation of the forward/backward sweep with compensation power flow method. Subsequently, a novel solution of unbalanced three-phase power systems based on the loop-analysis method was developed. The proposed method had clear theory foundation and took full adva ntage of the radial (or weakly meshed) structure of distribution systems.

Eminoglu and Hocaoglu [27] proposed load-flow algorithms based on the forward/backward sweeps. Their convergence ability was quantitatively evaluated for different loading conditions, R/X ratios and sub-station voltage levels. Moreover, the effects of static load modelling on the convergence characteristics of algorithms were also investigated.

Ghosh [28] proposed a simple method for solving load-flow problem of radial distribution networks. In the paper the algorithm easily computed the power flow through any branch exploiting the radial feature of the distribution networks. The proposed algorithm was efficient for less data preparation and could handle arbitrary node numbering scheme very easily. The method was effective and easily computable.

Ghosh and Singh [29] proposed the effect of charging capacitance of the line had been incorporated into load-flow solution. A computer algorithm was developed in such a way that there was no need to adopt any sequential node numbering scheme for the solution and the angle of the receiving-end voltage was also computed along with the magnitude of the voltage. The comparison of speed and memory requirement of the proposed method with the other methods had been verified to show its efficiency.

Hamouda and Zehar [30] presented an improved method to solve load-flow problem in balanced radial distribution systems with laterals. Their method was based on electric circuit laws with iteration and allowed the evaluation of both, voltage (rms) values and phase-angles. A simple technique of determining nodes beyond each branch was given through load-flow where speed convergence was increased by an appropriate choice of initial voltages. The method required a small number of iterations and less computational time.

Abul'Wafa [31] successfully analysed and solved network-topology-based method to the load-flow problem of radial distribution networks. The proposed technique was based on network graphical information and power flow equation formulation which was in matrix form to satisfy the need of distribution automation. In the technique a directed graph of a radial network represented by a nodes-by-nodes sparse matrix (S) allowed detection of the path of power flow from the reference node to the leaf end. The proposed method also allowed dynamic building of the two matrices: bus injection to bus current (**BIBC**) and branch current to bus voltage (**BCBV**) matrix which were used to find out the load-flow solution.

4. CONCLUSION

From the above review researchers developed different load flow solution methods observed as

- Simple algebraic equations such as KCL and KVL (Kirchhoff‟s Laws).
- Some authors used optimal capacitors placement to reduce real power losses.
- Backward/forward sweep algorithms in which convergence criteria is different.
- Matrix methods which include bus injection

to bus current (**BIBC**) and branch current to bus voltage (**BCBV**).

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