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Load Flow Analysis: A Review

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ABSTRACT: Power flow analysis stands out as the foundation of power system preliminary research as well as design. They are really essential for planning, operation, economic scheduling and interchange of power between utilities. The primary facts concerning power flow analysis are to identify the magnitude and phase angle of the voltage at every single bus and the real and reactive power flowing in each transmission system lines. The load flow study in a power system comprises a study of extremely important significance. The analysis uncovers the electrical performance and power flows (real and reactive) for stipulated circumstances whenever the system is functioning under the consistent state. This paper gives an overview of various techniques useful for load flow study under distinctive stipulated conditions.

KEYWORDS:Load Flow Studies, Y-matrix and Z-matrix iteration, Newton-Raphson method, Fast Decoupled method, Fuzzy logic, Artificial Neural Network.

I.INTRODUCTION

Besides giving real and reactive power the load flow study provides information about line and transformer loading *(as well as* losses) throughout the system *and* voltages at different points in the system for evaluation and regulation of the performance of the power systems. Further study and analysis of future expansion, stability and reliability of the power system network can be easily analyzed through this study. Growing demand of the power and complexity of the power system network, power system study is an significant tool for an power system operator in order to take corrective actions in time. The advent of digital computers, load-flow solutions were obtained using network analyzers. The first practical automatic digital solution method appeared in the literature in 1956.

The popular traditional 'Gauss-Siedel' iterative method which require minimal computer storage through Y-matrix. Although the performance is satisfactory on different systems but the main drawback is its converging time. To overcome this deficiency led to the development of Zmatrix methods, which converge more reliably but sacrifice some of the advantages of Y-matrix iterative methods, notably storage and speed when applied to large systems. The other conventional methods like Newton-Raphson method was shown to have powerful convergence properties, but was computationally uncompetitive. Major breakthrough in power system network computation came in the mid-l960. Development ordered elimination [1] and after that it leads in to a preeminent general-purpose load-flow approach which has been adopted by much of industry Currently, with the stimulus of increasing problem sizes, online applications, and system optimization, newer methods are emerging which are also expected to find wide applications. The brief explanation of basic formulation of the load-flow problem is described in [2]-[4]. For review, a balanced three phase power system along with transmission line has been considered. The universally preferred network analysis nodal admittance matrix equation is used and is as shown below

$$I = Y * E \quad (1)$$

Where, matrix Y is square, sparse, and symmetrical (in the absence of phase shifters or mutual couplings represented bynon-bilateral network branches).

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II.CONVENTIONAL METHODS OF POWER STUDY

A. Y-matrix Iterative Lad Flow Methods: The Y-matrix iterative methods of load-flow calculation are based on the iterative solution of the linear equation (1) for thebus voltages, using the relaxation algorithm [5]. J. B. Ward et al. in [6] presented a method for solving on digital computers the power flow problem which is probably the most frequently encountered type of problem in the field of power system network analysis. Digital solution of this class of problem can furnish a valuable tool to supplement the a-c network analyzer. In many system-planning studies, the network analyzer is still the best means for providing quickly and economically results of adequate accuracy. In some studies, such as analysis of losses and incremental losses, the network analyzer does not provide sufficient precision and, in such cases, the digital computer solution gains a distinct advantage. The Y-matrix iterative methods of load-flow calculation are based on the iterative solution of the linear equation (1) for the bus voltages, using the relaxation algorithm discussed in [5]. J. B. Ward et al. in [6] suggested a valuable tool to supplement the a-c network analyzer which is still the best means for providing quick and economic results with adequate accuracy. But the disadvantage is that the network analyzer does not provide sufficient precision. This can be overcome with the digital computer solution that provides a distinct advantage. The procedural development using a medium-sized digital computer, (the International Business Machines Corporation IBM 650), for the calculation of the load flows which are necessary for planning of electric power systems are explained by the authors of [7]. A modification of the well-known Nodal Iterative load flow algorithm is shown to be capable of giving a significant improvement in convergence in routine applications and to give good convergence in a wide range of cases involving series capacitive branches [8]. The modification causes no significant increase in program complexity

B. Z-matrix Load Flow Methods: The major difference in principle between the Y-matrix iterative methods and the Z-matrix methods is that in the latter, the equation (1) is solved directly for E in terms if I using the inverse of Y:

$$E = 1/Y * I = Z*I$$

Authors of [10] developed a new load flow program has been developed which employs the node impedance matrix of a system. A special input routine was developed that allows the line data to be in any order desired. The program has the capacity to control generator voltages within a specified VAR (reactive power) range, and also to incorporate off-nominal auto transformers along with special emphasis on time i.e. the time for solution was less than that required by the usual nodal branch admittance iterative method.Paper [10] presents an extension of the work by the authors of [9] on the Z-matrix load flow. The algorithm originally proposed is derived and further clarified by employing boththe matrix equations with reference ground and those with a bus of the system as reference. Test results are reported on the use of the block-iteration process and the axis-reiteration process and the effect of load incorporation on convergence. Refinements in the basic algorithm are also included, with test results shown verifying the theory.

C. Newton Raphson Method: In brief it is a successive approximation procedure based on an initial unknown estimate and the use of Taylor series expansion. Comparison between two consecutive solutions is needed to see whether their difference is within the tolerance limit or not. The problem is constructed as the Jacobian matrix equation

$$F(X) = - J*\Delta X$$Where ΔX is the correction.

J. E. Vann Ness in [11] reported that purpose to take one particular problem having to do with the flow of power in an electric network and to study the convergence of the solution when this problem is solved by the node method. The general method is that presented by J. B. Ward and H. W. Hale. The author considered several parts of this problem, while the contribution is restricted to the problem of convergence of the solution.Authors of [12] have adopted the elimination method to the power-system equations. The result is a method that is much faster and which will solve some problems that cannot be solved by the iteration method.Report of the author of [13] about the standard areainterchange control method for load flow inhibits the convergence of whatever numerical technique is being used.

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A simple revision of the system of equations being solved allows Newton's method to calculate load flows with area control but with the same convergence rate as studies in which area control is not included.Author of [14] developed a procedure for modifying the equations which model a load flow while retaining the same basic (Newton's Method) algorithm; this results in a program of increased power and efficiency. X. Zhang et al in [15] have considered three sequencedecoupled models with the well-known Newton-raphson algorithm, the so-called Sequence-Decoupled NewtonRaphson Method used for three phase load flow study is conducted and the computation accuracy, computation speed and convergence character of this method is then investigated and the specialty of this method is high accuracy, high speed, and reliable convergence.

Another advantage verified and reported of this method is that its suitability for parallel processing. This method can be extended to the three phase harmonic load flow study.The authors of [16] have made improvements on the representation of control adjustments of N-R power flow by describing a sparse 4n×4n formulation for the solution of power flow problem, comprising 2n current injection equations. It is best suited to the incorporation of flexible AC transmission system devices and controls of any kind.In paper [17] presented a new procedure for the solution of power flow problem by using the current injection equations in rectangular coordinates and observed that same convergence characteristics of the Conventional power flow expressed in terms of power mismatches when expressed in polar coordinates.

D. Fast Decoupled Method: Power system transmission lines have a very high reactance to resistance ratio. For such a system real power is more sensitive to change in phase angle rather than voltage magnitude and for the reactive power just the reverse of it. So in this method the elements of J2 and J3 of the jacobian matrix are set to zero. The decoupled Newton equations are

$$\Delta P/V = A * \Delta\theta \text{ and } \Delta Q/V = C.\Delta V$$

WhereA and C are negated Jacobian matrices. B.Stott in [18] had developed the decoupled load flow concept. In Newton load-flow solutions the mathematical decoupling of bus bar-voltage angle and magnitude calculations has several computational and conceptual attractions. A fast and reliable method for solving the load flow problem in electrical power systems is presented by authors of [19]. It is called the voltage vectors method. The main feature of the method is its ability to solve the load flow problem very quickly, faster than any present method. Rapid and reliable convergence is its other important feature. The mathematical model of the method is very simple. It is defined by two systems of simultaneous linear equations, which can be solved by the use of optimally ordered Gaussian elimination as well as special programming techniques. The method incorporates complex off-nominal transformers into the model without any difficulty. A numerical example is also given and solved byNewton's method in order to show that the voltage vectors method has some advantages over Newton's method at present;the latter method is now considered to be the quickest method of solving the load flow problem. Authors of [20] presented a fast approximated method for solving the ac power flow problem for line and generator outages.

The method is significantly more accurate than any linear approximation and significantly faster than the Newton Raphson method for an approximate solution. The method has applications in system planning and operations where approximate ac power flow solutions are acceptable. The method is applicable to system planning for rapid location of design criteria violations and it is particularly well adapted for system operation use as an on-line security monitor. Efficiency is achieved through decoupling of real and reactive power equations, sparse matrix methods, an experimentally determined iteration scheme and the use of the matrix inversion lemma to simulate the effect of branch outages. A quick, reliable and new method for solving the load flow problem in electrical power systems is presented by author of [21]. It is called the decoupled voltage vectors and Newton's method. The method has advantages over Newton's method in terms of computer storage, speed and reliable convergence. It also has advantages over all other known methods in terms of computer storage, and is as reliable convergent and accurate as the voltage vectors method. A numerical example is given and solved by Newton's method, by the voltage vectors method, by voltage vectors and Newton's method and by Decoupled Newton's method in order to show that the decoupled voltage vectors and Newton's method has some advantages over Newton's method and the other mentioned method. B.Stott*et al* in [22] describes a simple, very reliable and extremely fast load-flow solution method with a wide range of practical application. It is attractive for accurate or approximate off- and on-line routine

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and contingency calculations for networks of any size, and can be implemented efficiently on computers with restrictive core-store Capacities. The authors of [23] have given some important observation on fast decoupled load flow suggested by authors of [7] especially on its convergence. The authors of [24] also described a strengthened fast decoupled model and a novel approach for the adjusted load flow analysis without any need for refractorization. G. Leonidopoulos[25] presents an approximate solution of the load flow equations is developed using the same principles employed for developing the fast decoupled method. The approximate decoupled solution takes less time to calculate than one iteration of the fast decoupled method and gives a good approximate picture of the V-D profile of a power system. In paper [26] the authors have described a simple method for strengthening the decoupling of real and reactive powers that leads to an improved general purpose version of the state of-the art approach for fast decoupled load flow solution the basic idea is that suitably combined real and reactive power equations rather

III.NON CONVENTIONAL METHODS OF POWER FLOW STUDY

A. Fuzzy Logic Method: It is a type of logic that can recognize more than simple true or false value and can represent the proposition with degrees of truthfulness and false hold. It is a very powerful tool for the solution of nonlinear algebraic equations. K. L. Lo et al in [27] have conducted a new approach using fuzzy logic to adjust variable parameters so as to meet constraints during load-flow study. Parameters to be adjusted include transmission-line impedance, phase angle and transformer tap position, and the constraints are transmission line power flow and bus-voltage magnitude. The proposed approach is particularly aimed at assisting convergence in load flow programs. The parameters to be adjusted are decoupled from the main body of the load-flow formulation. J. G. Vlachogiannis[28] shows the application of fuzzy logic to power flow problem. There Fuzzy logic is used to solve the load flow problem, so decreasing computing time. Consequently, the repetitive solution of the proposed fuzzy load flow (FLF) method requires only 2m calculations per iteration, where m is the number of buses of the system. In the FLF method, the real and reactive power mismatches per voltage magnitude at each node of the system are chosen as the crisp input values, which are fuzzified into the fuzzifier. The process logic uses a rule base to explode the fuzzy output signals, which are defuzzified and the crisp values are chosen as the corrections ofvoltage angle and magnitudes at each node of the system. The authors of [29] have made an attempt is made to obtain fuzzy power flow solution considering reactive power limit violations at voltage controlled buses, uncertainties in voltage dependent load models, load forecast and system parameters. Corresponding to the given range of uncertain variables, a range of dependent variables and functions is provided by the proposed approach. A fuzzy logic based power flow method has been proposed in [30] which compute voltage magnitudes and angles at different buses of power systems. In place of triangular membership function, Gaussian function was used. This reduced the overall CPU time requirement.

B. Artificial Neural Network Method: This method is same as previous one with the addition of the concept of neural network. This is also a powerful tool for solving nonlinear equations.V. L. Paucar et al in [31] the superior speed of ANN over conventional PF methods, multilayer perceptrons neural networks trained with the second orderLevenberg/Marquardt method have been used for computing voltages magnitudes and angles of the PF problem. The proposed ANN methodology has been successfully tested using the IEEE-30 bus system. A. Arnagiriet et al in [32]have reported an application ofArtificial Neural Networks (ANNs) to determine bus voltages of a radial distribution system for any given load without executing the load flow algorithm. In paper [33] has proposed an artificial neural network approach based on Lagrangianmultiplier to solve the problem of economic load flow in a power system. Convergence speed is further increased by employing the momentum technique. Authors of [34] have provided a new method for stochastic load flow analysis by applying the standard back propagation technique for training the neural network. The results are good fast and instantaneous and the proposed method can be applied to large power systems. Paper [3] presents a new method of stochastic load flow analysis using artificial neural networks. Artificial neural networks are extremely fast and directly give the confidence limits of the output quantities.

C. Other Miscellaneous Methods: Authors of [36] troughs a basic concept for a modified power flow analysis with a sense of the economic loaddispatch to remove the concentrated burden of the slack bus. the proposed method eliminates not only the burden of a slack bus, but also maintains ‘an equal incremental cost’ in the economic load dispatch sense in this paper. Both the IEEE 14- bus and IEEE 39-bus systems are used to verify the usefulness of the proposed technique.Paper [37] presents a new second order power flow methodology by using current injection equations expressed in voltage rectangular coordinates instead of using traditional rectangular power flow equations.

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The results presented show that the proposed method leads to a substantially faster second order power flow solution, when compared to the conventional method expressed in terms of power mismatches and written in rectangular coordinates.

H.M.Smith,JR, Shih-Yung Tong[38] have shown that power transmission load flow studies are generally based on the assignment for each bus of either voltage or reactive voltamperes. Reduced system loss may be obtained by more critical voltage adjustment.Authors of [39] presented a new step size optimization factor to be used for solving unbalanced three-phase distribution current injection power flow. This optimization factor improves the performance of the iterative process namely at higher loading level and R/X ratio. In addition, they also proposed to extend the concept of this optimization factor to calculate the multiple unbalanced three-phase power flow solutions.Authors of [40] presented a methodology to conduct load flow studies of a multi area system with constraints on power settings/power limits on the tie lines linking different areas.Two algorithms are proposed and implemented on the test systems including a typical regional grid of an Indian power system.Gradient methods are applied to load-flow studies by the author of [41].It is shown that these are more relevant to the problem statement than the known methods. Steepest-descent and conjugate-gradient methods are adapted, but the main point made is that the load-flow can be reformulated as an optimization problem, thereby permitting recourse to other optimization methods. The numerical results obtained imply that such reformulation may reduce the required computer time.

Newton's method is altered in [42] to obtain a faster convergence than with the normal approach. The method is derived by comparison with the non-linear programming approach to the solution of the load flow problem. A control of the convergence process is an additional feature of the proposed algorithm. By means of this control, the method converges for cases when the normal Newton's method diverges. Numerical examples show evidence of these characteristics. The alteration is simple to implement on existing Newton programs.Authors of [43] shown a method presented the load flow equations are divided into two groups. An algorithm is developed where the first group is handled by a Point Jacobi method and the second group by Newton's method. Experimental evidence indicates that the algorithm achieves significant savings in storage and computation requirements over the use of Newton's method on both groups of equations.H. E. Brown [44] developed a method suitable for on-line evaluation of contingencies that requires a relatively small computer. The effect on critical lines, produced by removing a line from service or by changing the generation schedule, can be determined as an on-line function of a computer that is installed in the system operator's office. The method can also be used by system planning personnel to reduce the number of detailed power flow cases that must be made in an expansion study.

Author of [45] describes a method for evaluation of power flow which takes into consideration uncertainty of node data. The essence of the method is that the net loads are given as a set of values together with additional information on the frequency of its accuracy.J. F. Dopazoet et al in [46] presented a method for calculating the effect of the propagation of data inaccuracies through the load flow calculations, thus obtaining a range of values for each output quantity that, to a high degree of probability, encloses the operating conditions of the system. The method is efficient and can be added to any existing load flow program.A. M. L. da Silvaet al in [47] paper has presented a new PLF algorithm by combining Monte Carlo simulation techniques and linearised power flow equations for different system load levels.andmultilinearised power flow equationswhich uses a criterion based on the total active system load to determine different linearisation points. This approach has reduced the errors introduced in the state vector (i.e., angles and voltages), and consequently in the output network quantities (i.e., power flows).

In paper [48] developed a globally convergent optimization algorithm for solving large nonlinear optimal power flow (OPF) problems. An application of the Byrd-Omojokun trust region technique to solve nonlinear OPF Problems has been presented here which is efficient in dealing with inconsistent constraints that may appear in trust region sub problems.C. S. Indulkar et al in paper [49] conducted load-flow analysis of a five-bus test system containing voltage sensitive loads for a typical five-bus seven-line sample power system.Generalized equations that are suitable for the voltage sensitive loads and applicable to the Newton-Raphson method are developed. As compared with the load flow solution for constant power load, it is shown that the constant current and constant impedance loads require additional iterations to obtain the solution.The load flow solutions with voltage sensitive loads are more accurate than those for the constant power load.

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In paper [49], authors have applied Genetic Algorithm that is one of the heuristic methods to the load flow problem of integrated AC/DC power systems.Jen-HaoTeng[50] has proposed a robust and efficient method for solving unbalanced three phase distribution load flow problems by a simple matrix multiplication of the bus injection to branch-current matrix and branch-current to branch-voltage matrix.

IV.CONCLUSIONS

The discussion shows the different methods involved in solving the nonlinear load flow problems. Further research work can be done for finding more powerful methods to solve the power flow equations with more efficiency in terms of time, computer memory storage as well as robustness.

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