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A Review on Load Flow Analysis of Ring Main System

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***Abstract* - Load flow analysis of the complex power system is very much essential for operation, planning and sharing of power to the electrical power utilities and power engineers. In an interconnected Ring mains system, the bus voltages and complex power comprising of active and reactive components have to be assessed. Various methods are available to evaluate the system under normal and abnormal conditions. In this paper, a review of various methods available and the recent advancements in the techniques of load flow analysis has been made and presented. In particular iterative methods has been proposed to be applied to 132 KV Nagpur Ring Main System with the data of seven bus system. The overview of the performance of the said system to be tested in MATLAB Simulink environment for all the proposed methods of load flow in normal and abnormal conditions shall be presented in further work**

Keywords: Load Flow Studies, Newton-Raphson method, Gauss-Seidal method, Fast Decoupled method, Fuzzy logic, Artificial Neural Network.

I. INTRODUCTION

Load flow analysis is an important tool used by the power engineers for planning and determining the steady state operation of a power system. The flow of active and reactive power is known as load flow or power flow. Load flow studies helps in determining the various bus voltages, phase angles, active and reactive power flows through different branches, generators, transformer settings and load under steady state conditions [1].

The main information obtained from the load flow or power flow analysis comprises magnitudes and phase angles of load bus voltages, reactive powers and voltage phase angles at generator buses, real and reactive power flows on transmission lines together with power at the reference bus; other variables being specified [2]-[3]. The resulting equations in terms of power, known as the power flow equations become non-linear and must be solved by iterative techniques using numerical methods.

In the past three decades, the most commonly used iterative methods are Gauss-Seidel, Newton-Raphson and Fast Decoupled method [4].Also with the growing industrial developments, the power system is becoming more complex in operation. With such huge development, any numerical mathematical method cannot converge to a correct solution. Thus power engineers have to seek more reliable methods. The problem that is faced by power industry is to determine which method is most suitable for a power system analysis. In the analysis of Load flow, high degree accuracy and a faster solution time are the basic requirements to determine the best method to be used for a particular problem.

But accurate calculations of load flows would be impractical without the use of computer programs. The use of digital computers to calculate load flow started from mid 1950s. There have been different methods used for load flow calculations. The development of these methods is mainly led by the basic requirement of load flow calculation such as convergence properties, computing efficiency, memory requirement, convenience and flexibility of the implementation [4]-[7]. With the accessibility of fast and large size digital computers, all kinds of power system studies, including load flow, can now be carried out appropriately and conveniently

[8]. The numerical method provides an approach to find solution with the use of computer, therefore there is need to determine which of the numerical method is faster and more reliable in order to have best result for load flow analysis.

The first practical automatic digital solution method appeared in the literature in 1956. The popular traditional „Gauss-Seidal" 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.

This drawback is overcome by the development of Z-matrix 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.

At present, with the increase in problem sizes, on- line 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 nodal admittance matrix can be solved using the following equation

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

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

II . CONVENTIONAL METHODS OF POWER STUDY

D. Y-matrix Iterative Load Flow Methods:

This method of power flow calculation is based on the iterative solution of the linear equation 1 for the bus voltages, using the relaxation algorithm [5].

A method for solving the power flow problem on digital computers in the field of power system network analysis is proposed and presented [6]. A modified Nodal Iterative load flow solution has been described that requires significantly shorter time and has good convergence in a wide range of cases involving series capacitive branches [8]. The modification does not increase in program complexity.

B. Z-matrix Load Flow Methods:

The basic difference in principle among the Y-matrix iterative method and the Z-matrix method is that in the later, the equation 1 is solved directly for E in terms of I using the inverse of Y:

$$E = 1/Y * I = Z^*I \quad (2)$$

Where; Z is an Impedance Matrix and Y is an Admittance Matrix.

A new load flow program has been developed which uses the node impedance matrix of a system. The program has the capacity to control generator voltages within a specified VAR (reactive power) range, and also to incorporate off-nominal autotransformers along with special emphasis on time i.e. the time required for the solution was less than that required by the usual nodal branch admittance iterative method [8].

An extension of the work done in [7] on the Z-matrix load flow is presented in [8]. The algorithm originally proposed is derived and further simplified by employing both the matrix equations with reference ground and those with a bus of the system as reference. Modifications in the basic algorithm are also included, with test results shown verifying the theory.

C. Newton Raphson Method:

It is an iterative method which estimates a set of non-linear simultaneous equations to a set of linear simultaneous equations using Taylor‟s series expansion and the terms are limited to the first approximation. Due to its best convergence characteristics this method is used for the load flow. This is relatively more powerful compared to other alternative methods and is more reliable. This method is quick in operation if the assumed value is near the desired value, but may take longer to converge if the value is far away from it. The problem is constructed as the Jacobian matrix equation

$F(X) = - J^*\Delta X$ (3) Where, ΔX is the correction factor.

A novel approach for solving the Load flow problem based on nodal current injections and a highly sparse augmented Jacobian is proposed [9]. The augmented formulation is equivalent to the conventional Newton-Raphson power flow regarding convergence characteristics, and allows an easier incorporation of more realistic modelling of power system components, such as SVC, TCSC and voltage control through multiple reactive sources.

An improvement on the representation of control adjustments of N-R power flow by using a sparse 4n×4n formulation for the solution of power flow problem is described [10], comprising of 2n current injection equations presented and has been stated that it is best suited to the incorporation of flexible AC transmission system devices and controls of any kind.

A detailed comparison of the Newton method is done [11] and also the Back/Forward sweep method usually used in the distribution network is described, bringing forward an improved method of Newtonian-Raphson method, which is Broyden method. It is seen that this power flow algorithm with the core of Broyden method could improve the operating speed and overcome the numerical instability that often appears in the Newton- Raphson method in distribution network. From an overall perspective, this approach has good stability, which is a superior load flow algorithm in the distribution network.

A method combining Down-hill and Newton method, termed as Newton-Downhill algorithm is presented [12]. It has good convergence and there is no need of the requirement of initial iteration value calculation. But in some cases, Newton-Downhill method also fails to convergence when meeting singular Jacobian matrix.

Development of GUI Load Flow Analysis tools based on Newton Raphson Method by using MATLAB software is presented [13]. The analysis tool has been tested with three test systems. Comparisons with the load flow solution in Power World simulator tool and VBA Excel has verified the solution produced by the GUI. Thus, this tool helps student and lecturer to learn and verify their manual calculation and at the same time reduce their calculation time.

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

$$\Delta P/V = A * \Delta \grave{e} \qquad (4)$$

$$\Delta Q/V = C.\Delta V \qquad (5)$$

Where, A and C are negated Jacobian matrices.

A decoupled load flow concept has been presented in which the mathematical decoupling of bus bar-voltage angle and magnitude calculations in Newton load-flow solutions has many computational attractions [14].

A fast and reliable method for solving the load flow problem in electrical power systems is presented [15]. It is called the voltage vectors method which has ability to solve the load flow problem very quickly, faster than any present method. The method incorporates complex off-nominal transformers into the model without any problems.

A quick, reliable and new method for solving the load flow problem in electrical power systems is presented [16]. This method is called the decoupled voltage vectors. The method has advantages over Newton‟s method in terms of computer storage, speed and it is more reliable, convergent and accurate as the voltage vectors method.

Using the same principles employed for developing the fast decoupled method, an approximate solution of the load flow equations is developed and presented. This needs less time to calculate than one iteration of the fast decoupled method and gives a good representation of the V-D profile of a power system [17].

An improved FDLF method for improving the decoupling of real and reactive powers is presented [18]. Two algorithms has been developed and tested and results shows that both algorithms shows better convergence characteristics compared to other fast decoupled load flow methods.

A fast FDLF algorithm is presented in which unnecessary computation is exempted in the algorithm by the procedure of Gauss elimination [19]. This method needs a little more running time than the one using sparse matrix techniques, but it is much faster than the one without sparse matrix techniques.

A hybrid DLF method is proposed which uses a hybrid procedure to solve the power flow equations, in which the direct method is used to solve the active power equations, and the indirect method is used to solve the reactive power equations [20]. It models zero-impedance branches accurately and avoids solution divergence that is usually caused by zero or small impedance branches in conventional methods. It is observed that the proposed method is much faster than both the Gauss-Seidel and Newton-Raphson algorithms, and has better convergence than the fast decoupled algorithms.

Screening and ranking of the contingency analysis is done by FDLF method using performance index [21]. Ranking is based on overall performance index (PI). It is observed that contingency analysis can be done by using performance index and AC load flow solution is most appropriate by fast decoupled method.

III. NON-CONVENTIONAL METHODS OF POWER FLOW STUDY

A. Fuzzy Logic Method:

A logic that can identify more than simple true or false value and can represent the proposition with degrees of truthfulness and false hold is called a fuzzy logic. It is a very powerful tool for the solution of nonlinear algebraic equations.

A new approach using fuzzy logic to adjust variable parameters is conducted so as to meet constraints during load-flow study [22]. 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 mainly aimed at assisting convergence in load flow programs and the parameters to be adjusted are decoupled from the main body of the load-flow formulation.

Application of fuzzy logic to power flow problem is presented in which the repetitive solution of the proposed fuzzy load flow (FLF) method needs only 2m calculations per iteration, where m is the number of buses of the system [23]. In the FLF method, the real and reactive power mismatches per voltage magnitude at each node of the system. Hence the solution was achieved in a very short computing time on systems of various sizes. The FLF method is also able to incorporate all modern control strategies of load flow designed by means of fuzzy logic control.

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 [24]. Thus considering the given range of uncertain variables, a range of dependent variables and functions is provided by the proposed approach.

A fuzzy logic based Load flow method has been proposed which helps in computing voltage magnitudes and angles at various buses of power systems [25]. It is seen that by using Gaussian function in place of triangular membership function, the overall CPU time requirement was reduced.

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.
Due to the advantage of increase in speed of ANN over conventional PF methods, multilayer perceptrons neural networks trained with the second order Levenberg/Marquardt method have been used for obtaining voltages magnitudes and angles of the PF problem [26]. The proposed ANN methodology using the IEEE-30 bus system has been successfully verified. A new method for stochastic load flow analysis using artificial neural networks is proposed [27] in which Back propagation and quick prop algorithms have been applied. It is clear from this that the proposed method using ANN is very much suitable for solving the stochastic load flow for power systems in an extremely fast way and also provides a very useful technique for power system planning and operation.

Another application of Artificial Neural Networks (ANNs) by determining the bus voltages of a radial distribution system for any given load without executing the load flow algorithm is presented [28].

An artificial neural network method based on Lagrangian multiplier to solve the problem of economic load flow in a power system is presented [29]. Convergence speed is then increased by using the momentum technique.

A new method for stochastic load flow analysis by applying the standard back propagation technique for training the neural network is provided [30]. The results are good Quick and instantaneous and the proposed method can be applied to large power systems.

C. Other Miscellaneous Methods:

A new second order power flow methodology by using current injection equations is presented in which voltage rectangular coordinates are used instead of traditional rectangular power flow equations [31]. From the results obtained it is clear that the proposed method leads to a faster second order power flow solution, when compared to the conventional method expressed in terms of power mismatches and written in rectangular coordinates.

A new step size optimization factor to be used for solving unbalanced three-phase distribution current injection power flow is presented [32]. This optimization factor increases the performance of the iterative process namely at higher loading level and R/X ratio.

A methodology for conducting load flow studies of a multi area system with constraints on power settings/power limits on the tie lines linking different areas is presented [33]. Two algorithms are proposed and implemented on the test systems including a typical regional grid of an Indian power system.

A new approach for solving optimal power flow (OPF) is proposed which consists of two parts in which the former one employs the genetic algorithm (GA) to obtain a possible solution subject to desired load convergence, while the later one employs GA to obtain the optimal solution [34]. OPFGA has the advantage not to calculate differential equations neither the Jacobean matrix unlike classical methods. The proposed method that combines concept of co-evolution, repairing procedure, exclusive strategy helps in obtaining very reasonable results.

A new method of two-stage GA based algorithm is described which works better with smaller population size than other evolutionary algorithm in solving the power flow problem [35]. The proposed load flow is very rugged and can be mainly used for solving ill conditioned systems, including the problem of the determination of the loadability limit. The proposed load flow clearly cannot compete with conventional methods in terms of speed, but in critical situations when conventional methods fail, the proposed load flow undoubtedly can be the choice. The proposed algorithm can also handle FACTS devices efficiently.

A Chaotic PSO based robust load flow method is presented in which the number of required generations for convergence decreases with the increase of population size [36]. The performance of the proposed method is better than the NRLF method under critical conditions such as high R/X ratios and heavy loading situations. The CPSO based load flow algorithm shows its robustness when the conventional methods fail.

A Selection Enabled PSO is presented in which a better population of particles is selected by applying reduction factor after suitable number of iterations called sorting frequency [37]. The results obtained are found to be as accurate as that obtained by Newton Raphson method and also converge faster than the conventional PSO. However, these times are much more than as compared to the time taken by NR method.

A methodology which helps in determining control variable settings, such as the number of shunts to be switched, for real power loss minimization in the transmission system is proposed [38]. The proposed approach uses the PSO algorithm for the optimal setting of optimal power flow (OPF) based on loss minimization (LM) function by installing the shunt compensator.

A probalistic OPF method is presented in which uncertainty of the undetermined load is modelled by Gaussian distribution and OPF problem is defined with several constraints [39]. Probabilistic OPF can expand the possibility of responding to uncertain load states and unexpected situations such as power quality disturbances and interruptions if more complex constraints are considered.

A Probabilistic Load Flow method, which considers the load and generation uncertainties, is presented [40]. The results obtained shows that if the varying nature of the distribution network is taking into account in the load flow studies, the stochastic behaviour of the distribution network will provide a more accurate profile of the voltages An improved Backward-forward sweep load-flow algorithm, which is suitable for three-phase radial distribution system is proposed and the voltages at each upstream bus in the backward sweep are calculated using KVL [41]. It is seen that proposed method is superior to the two commonly used methods in the computational efficiency, while the solution accuracy is maintained.

A modified forward backward load flow algorithm for unbalanced radial distribution systems is proposed [42]. The proposed algorithm modifies branch current calculation approach in backward sweep by using three matrices which are used in identifying downstream buses and also in calculating branch current or power flow in an easy manner. The performance of the proposed method is validated on a 25-bus unbalanced radial distribution networks and the results show that it takes less iterations to converge as compared to a conventional forward-backward sweep load flow algorithm.

An efficient method for solving the power flow problem of radial or weakly meshed distribution network is proposed [43]. Test results have verified the feasibility and validity of the proposed method as it converges in 2 to 4 iterations irrespective of the size of the system and is 5 to 6 times faster than the current injection method. Thus the proposed method is simple, accurate, robust and time-efficient. Hence, it is suitable for online system studies of large scale distribution systems. This method finds potential applications in distribution network reconfiguration, reactive power compensation studies and optimal incorporation of renewable energy sources.

A hybrid approach with AC and DC power flow models for power flow analysis is presented [44] and it is mentioned that this approach has a fast solution without compromising accuracy in areas of interest and the test results show the hybrid approach is more accurate than using the DC model.

Genetic algorithm has been proposed for sequential load flow analysis of AC/DC system in which IEEE-9 Bus system is used for testing purpose [45].

A novel sequential power flow model for hybrid AC-DC system is presented [46]. Four control Strategies for integrated AC-DC power flow analysis are studied and it was also observed that the power-flow convergence pattern for integrated AC-DC systems depends on the control strategy adopted for the DC link.

IV. CONCLUSION AND FUTURE SCOPE

Literature review on load flow analysis has been made thoroughly. Different methods are available to solve the nonlinear and complex load flow problems. In further study, various methods and algorithms shall be utilized to investigate the performance for the Ring main system as a specific industrial problem. 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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