Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 11 Issue 12, December 2022

Review of Solution Techniques for Load Flow Studies

Saeed S. Al-Hajri, Ibrahim Omar Habiballah
King Fahd University of Petroleum & Minerals;
Dhahran, Saudi Arabia

1. *Abstract:*

At a common power system, the power flows are obtained from generating plants to downstream power distribution stations through various sections of the networks. The flow of active and reactive power is known as load flow or power flow. Load flow analysis is an important technique utilized by power staff for operating, planning, and determining the steady state of any power system.

Globally, several new techniques studies have been developed for Load flow analysis, along with the traditional techniques, such as Gauss-Seidel (GS), and Newton- Raphson (NR), which currently couldn't be performed, due to the high diffusions of circulated energy networks. This review paper concludes some of the existing published techniques on Load flow analysis that can be applied on dynamic power networks.

2. INTRODUCTION:

Commonly, the power flow Solutions are mainly relying on Ohm's Law, which is addressing the consequential relation between voltages and currents. For a system, it can be expressed in matrix notation in nodal form as follows:

$$[I] = [Y]\,[V] \qquad (1)$$

Where: [I] is an array of bus current injections (positive value when generation, and negative value when load), [V] is an array of bus voltages, [Y] is the bus admittance matrix. The nodal equation can be written in a generalized form for an n bus system.

$$I = \sum_{j=1}^{n} Y_{ij} V_j \text{ , for } (i) = 1\,,2\,,3\,..\,\text{n} \qquad (2)$$

The complex power delivered to bus $[i]$ is

$$P_i + jQ_i = V_i (I_i)^* \qquad (3)$$

$$I = \frac{P_i\ - Q_i}{{V_i}^*} \qquad (4)$$

Substituting for I_i in terms of P_i *and* Q_i, the equation gives,

$$\frac{Pi\ - Qi}{Vi^*} = V_i \sum_{j=1}^{n} Yji - \sum_{j=1}^{n} Yij\,Vj\ , \qquad (5)$$

$$j \neq i$$

The set of equations define a non-linear system because the complex injected power or current is a non-linear function of the complex bus voltages. The solution requires the descriptions of two out of four values at each bus. Hence, generators regulate the voltage at their controlled buses, if the generator's reactive power limits, Q_{max} *and* Q_{min}, have not been reached. For that, if any generator reaches its maximum or minimum VAR limit, the generator reactive power will be held at the respective limit, and the scheduled voltage becomes the unknown parameter for that bus. [1]. Therefore, several solution techniques for load flow studies had been created based on that concept. Herewith, some of the traditional solution techniques have been specified as following:

2.1. Gauss-Seidel Method (GS):

The Gauss-Seidel method is developed based on the Gauss method. It is an iterative method used for solving set of nonlinear algebraic equations. The method applied for an initial guess for value of voltage, to obtain a calculated value of a particular variable. The initial guess value is swapped by a calculated value. After that, the process will be repeated until the iteration solution converges. The convergence is quite sensitive to the starting values assumed, but this method suffers from poor convergence characteristics. [1]. GS method is very useful for very small systems. It is easily adapted; it can be generalized, and it is very efficient for systems having a smaller number of buses. However, GS LFA fails to converge in systems with one or more of the features as under:

- Systems having large number of radial lines
- Systems with short and long lines terminating on the same bus
- Systems having negative values of transfer admittances
- Systems with heavily loaded lines, etc.

GS method successfully converges in the absence of the above problems. However, convergence also depends on various other set of factors such as: selection of slack bus, initial solution, acceleration factor, tolerance limit, level of accuracy of results needed, type and quality of computer/ software used, etc. [22]

2.2. Newton-Raphson Method: -

The Newton-Raphson method is an iterative method which estimates a group of non-linear synchronized equations to a group of linear synchronized equations using Taylor's series expansion and the terms are limited to the first approximation. Newton-Raphson is the most iterative method used for the load flow because its convergence characteristics are relatively more significant compared to other alternative processes and the reliability of Newton-Raphson approach is comparatively respectable since the Newton-Raphson method can resolve cases that lead to discrepancy with other popular processes [3]. There are two methods of solutions for the load flow using Newton Raphson Method. The first method uses rectangular coordinates for the variables while the second method uses the polar coordinate form. Out of these two methods the polar coordinate form is used widely.

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix}=\begin{bmatrix}J_1 & J_3\\ J_2 & J_4\end{bmatrix}\begin{bmatrix}\Delta\delta\\ \Delta|V|\end{bmatrix} \qquad (6)$$

Only the polar form is used in practice since it produces fewer equations than the total number of equations in rectangular form.

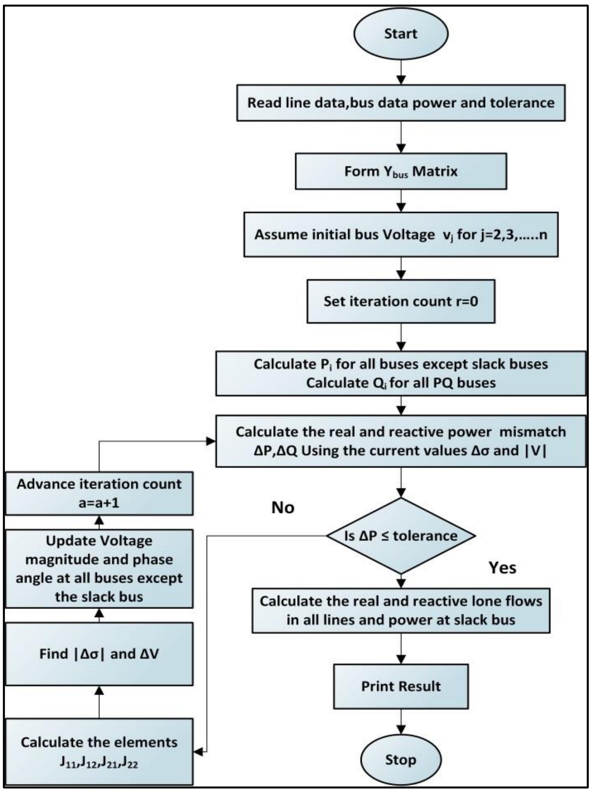


Figure 1. Newton Raphson Flow Chart

In this method if the assumed value is near the solution, then the result is obtained very quickly, but if the assumed value is farther away from the solution, then the method may take longer to converge [4]

2.3. Fast Decoupled Method: -

The Fast Decoupled Method is the same as of the Newton- Raphson method, proposes calculation simplifications, fast convergence and reliable results which became a widely utilized method in load flow analysis. However, fast decouple for some cases, where high resistance-to-reactance (R/X) ratios or heavy loading (low voltage) at some buses are present, does not converge well because it is an approximation method and make some assumption to simplify Jacobian matrix. For these cases, many efforts and developments have been made to overcome these convergence obstacles. Some of them targeted the convergence of systems with high R/X ratios, and others with low voltage buses. [5][6]. This method is a modification of Newton-Raphson, which takes the advantage of the weak coupling between $P-\delta$ and $Q-V$ due to the high X:R ratios. The Jacobian matrix is reduced to half by ignoring the element of J_2 and J_3.

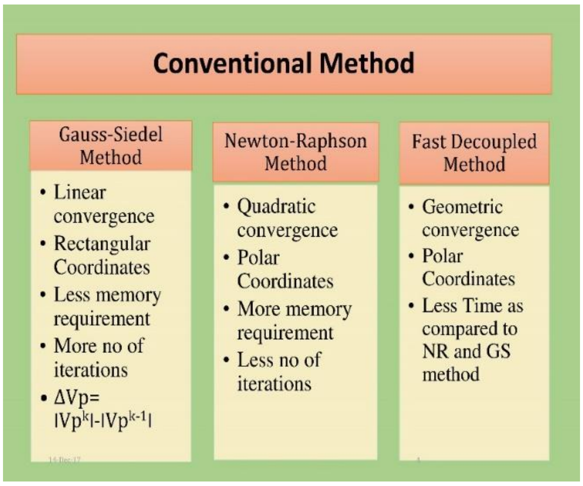
$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix}=\begin{bmatrix}J_1 & J_0\\ J_0 & J_4\end{bmatrix}\begin{bmatrix}\Delta\delta\\ \Delta|V|\end{bmatrix} \qquad (7)$$

$$\Delta P = J_1\Delta\delta = \left[\frac{\partial P}{\partial\delta}\right]\Delta\delta \qquad (8)$$

$$\Delta Q = J_4\Delta|V| = \left[\frac{\partial P}{\partial|V|}\right]\Delta|V| \qquad (9)$$

$$\frac{\Delta P}{V_i} = -B'J_4\Delta\delta \qquad (10)$$

$$\frac{\Delta Q}{V_i} = -B''\Delta|V| \qquad (11)$$



Conventional Method

Gauss-Siedel Method	Newton-Raphson Method	Fast Decoupled Method
• Linear convergence • Rectangular Coordinates • Less memory requirement • More no of iterations • ΔVp= |Vp^k|-|Vp^{k-1}|	• Quadratic convergence • Polar Coordinates • More memory requirement • Less no of iterations	• Geometric convergence • Polar Coordinates • Less Time as compared to NR and GS method

3. MODERN TECHNIQUES DISCUSSION:

Currently, a significant penetration of energy sources which had been presented on the existing power systems surround the world. As an influence, it became challenging, during planning stage, to perform load flow analysis due to the doubts in buses data which makes it even more challenging to perform load flow using traditional technique. However, a lot of different techniques had been introduced lately to deal with these concerns perfectly, which some of them will be conclude at this review paper.

3.1. A Dynamized Power Flow Method Based on Differential Transformation:

At this technique the extends of power flow model into a fictitious dynamic system by adding a differential equation on the loading parameter. As a result, the original solution curve tracing problem is converted to solving the time domain trajectories of the reformulated dynamic system. A non-iterative algorithm based on differential transformation is proposed to analytically solve the dynamized model in form of power series of time. This paper proves that the nonlinear power flow equations in the time domain are converted to formally linear equations in the domain of the power series order after the differential transformation, thus avoiding numerical iterations. Case studies on several test systems including a 2383-bus system show the merits of the proposed method [21].

3.2. Differential Evolution Approach:

At this technique, the differential evolution (RMODE) algorithm is used to solve the limited reactive power management (RPM) problem, which is a non-linear, multi objective optimization issue. Reducing of total active power loss and improvement of voltage profile are considered as the aims of the RPM problem. For RPM, generator bus voltage magnitudes, transformer tap settings and reactive power of capacitor & reactor are carried as the outcome variables. In the suggested RMODE algorithm, the multi-objective differential evolution (MODE) algorithm has been applied frequently using the available Pareto-optimal solutions and re-initializing the remaining population. Thus, for each next cycle of the RMODE, the better values of best compromise solution have been obtained. The proposed method in [**3.2.**], was compared with other proposed methods and it has the capability of converging regardless of the system conditioning. In addition, PF results were obtained even forum solvable test cases. [12].

3.3. Non-Linear Iterative Solver using Graph Computing:

The proposed a nonlinear iterative solver (NLIS) based on Bulk Synchronization parallel computing model (BSP), by restructuring GS using PageRank algorithm on a graph computing platform. The method was performed on IEEE 118-bus test system, 1500 nodes system of one province in China, and MatPower 10790 system.

The proposed method was compared with Mat Power, even though the convergence criteria for the proposed method is 0.00025 and for MatPower is only 0.05, it was shown that the proposed method is four times faster.

3.4. Decoupled Extended Power Flow:

At this technique, the extended power flow formulation, suggested, produces the concept of switchable branches for power flow analysis. In this formulation, the active and reactive power flows combined with the switchable branches are considered as state variables. This method avoids numerical obstacles while a closed & opened switch state is considered excluded the presence of excessive impedance values in the formulation. The new power balance equations modified considering the two sets of branches are as follows:

$$P_k = \sum_{m\in\Omega_k} P_{km}(V_k\,, V_m\,, \theta_k\,, \theta_m) + \sum_{l\in\Gamma_k} t_{kl} \tag{12}$$

$$Q_k = Q_k^{sh}(V_k) + \sum_{m\in\Omega_k} Q_{km}(V_k\,, V_m\,, \theta_k\,, \theta_m) + \sum_{l\in\Gamma_k} u_{kl} \tag{13}$$

where Γ_k is the set of buses adjacent to bus k, which linked to switchable branches. This attempt achieves of this explanation to model circuit breakers, reclosers and network switches in distribution grids. [20]. After that, additional entire image of the power grid present over the traditional bus-branch modelling. Power flow analysis can be achieved across various topological designs excluding requirement to revise the network data. [19].

3.5. Data-Driven Power Flow:

At this technique, the author delivered the doubts of power generation in SGs and used a data-driven PF technique based on accurate linear degradation which contains dual phases to achieve an answer for PF problems in SGs. The initial phase is offline learning stage, and another phase is online calculating phase. In offline knowledge phase, Rigid Regression (RR) is used to resolve a built learning model based on past records established as a mapping matrix, while in online knowledge phase, the past records with similar existing topology are performed to find the solution excluding algebraic iterations. This method had been examined on various IEEE check systems. The suggested method has no convergence concerns, without algebraic iterations. In addition, it was recognized that findings can be achieved even if the topology of the system varies on a repeated base. [19].

3.6. Newton-Raphson based Predictor Corrector (NR-PC):

At this technique, method of (NR-PC) is applied to solve the load flow (LF) difficulty of well and ill-conditioned power systems. In the suggested LF method, the Predictor-Corrector mechanism is developed to reach convergence rate of order $1+\sqrt{2}\approx 2.4$ instead of 2 for the standard Newton Raphson (NR). The proposed NR-PC LF method I confirmed on different trial systems; IEEE 30-bus, 57-bus, 118- bus and 300-bus systems as well-conditioned trial cases, 13-bus and 20-bus systems as naturally ill-conditioned trial systems, 1354-bus, 2869-bus, and 9241-bus systems as accurate very large-measure trial systems. The sensitivity of the suggested method with different R/X transmission line ratios and loading conditions is proven and evaluated with well-known methods. The simulation outcomes appear that the suggested LF method has well convergence characteristics and low calculation time compared with standard methods. [21]. The suggested method was compared with multiple techniques like NR, FD, IM and RK4, which indicated that it remained the best in terms of calculation time as well as number of iterations. Furthermore, it could achieve a solution even when the test system is ill-conditioned.

3.7. Modelling C-UPFC in load flow analysis:

At this technique, A recent developed flexible AC transmission system (FACTS) device is C-UPFC, which performs an important role in managing several factors in transmission lines, such as voltage magnitude and power flow. This technique suggested indicating the C-UPFC with inserted load as a role of control variables to prevent the modification of the JM. In addition, the maximum limitations of the C-UPFC are considered resulting in the release of certain values which revised in each iteration. The method was verified on IEEE 30-bus and IEEE 118-bus test systems. [19] The simulation outcomes for this proposal indicated strength over conventional methodologies that deal with C-UPFC constraints. Also, the calculation period is decreased as no adjustments are needed to the JM.

4. CONCLUSION:

This review paper has attempted to summarize the research developments in distribution power flow from the research papers which the authors went through. Initially, the categorized techniques of distribution system power flow solution under two different frames called phase and sequence frame approaches. Moreover, several algorithms utilized based on each reference frame were discussed in detail with referring to balanced or unbalanced system, radial or weakly meshed or meshed network, with or without DG and mismatch principle. Finally, the conclusions are reviewed for the algorithms utilized in both frames of approach along with their capability to deal with various systems. Scientists and experts can gain from this review on the distribution power flow studies to improve enhanced tools of intelligent distribution system concepts.

ACKNOWLEDGMENTS:

The authors acknowledge the support of King Fahd University of Petroleum and Minerals in conducting this research work.

REFERENCES:

[1] Olukayode A. Afolabi, Warsame H. Ali, Penrose Cofie, John Fuller, Pamela Obiomon, Emmanuel S. Kolawole.H “Analysis of the Load Flow Problem in Power System Planning Studies “ - 2015

[2] Aroop, B., Satyajit, B., and Sanjib,) Power “Flow Analysis on IEEE 57 bus System Using Mathlab” H. (2014International Journal of Engineering Research & Technology (IJERT), 3.

[3] Hadi, S. “Power System Analysis”. (2010) 3rd Edition, PSA Publishing, North York.

[4] Glover, J.D. and Sarma, M.S. “Power System Analysis and Design”. (2002) 3rd Edition, Brooks/Cole, Pacific Grove.

[5] Stott, B. “Review of Load-Flow Calculation Methods”. (1974) Proceedings of the IEEE, 62, 916-929.

[6] Adejumobi, I.A., et al.” Numerical Methods in Load Flow Analysis “: (2014) An Application to Nigeria Grid System. International Journal of Electrical and Electronics Engineering (IJEEE),

[7] -D. Srinivasan “Review of power flow studies on distribution network with distributed Generation “National University of Singapore 346 PUBLICATIONS 14,339 CITATIONS.

[8] Shirmohammadi, D., Hong, H.W., Semlyen, A., Luo,G.X.: “A compensation-based Power flow method for weakly Meshed Distribution and Transmission Networks”’, IEEE Trans. On Power Systems,1998, 3, (2), pp.753-762

[9] Cheng, C.S., Shirmohammadi, D.: “A three phase power flow method for real time distribution system analysis”, IEEE Trans. Power Syst., 1995, 10, (2), pp 671-679

[10] Sarika Khushalani, Jignesh Solanki, M., Noel Schulz, M.:” Development of Three-Phase Unbalanced Power Flow Using PV and PQ Models for Distributed Generation and Study of the Impact of DG Models”, IEEE Trans. Power syst., 2007,22, (3), pp. 1019-1025

[11] Zhu, Y., Tomsovic, K.: “Adaptive Power Flow Method for Distribution” IEEE Trans. Power Syst 2002

[12] Laxmi Srivastava, Himmat Singh “Recurrent multi-objective differential evolution approach for reactive power management” October 2015

[13] Tsai-Hsiang Chen, Moshing chen, Kab-Ju Hwang, Paul Kotas, Elie Chebli, A.:’ “Distribution System Power Flow Analysis –A Rigid approach”, IEEE Trans. On Power Delivery,1991,6, (3), pp 1146-1152

[14] Fan Zhang and Carol Chang, S.:” A modified Newton Method for Radial Distribution System Power Flow Analysis”, IEEE Trans Power Systems,1997 ,12, (1), pp.389-397

[15] Jen-Hao Heng, Chuo-Yean Chang: “A novel and Fast Three-Phase Load Flow for Unbalanaced Radial Distribution Systems”, IEEE Trans.Power Syst., 2002,17, (4), pp.1238-1244

[16] Paulo Garcia, A.N., Jose Luiz, Sandoval Carneiro, Vander Costa da, M., Nelson Martins: “Three-Phase Power Flow Calculations Using the Current Injection Method”, IEEE Trans on Power Systems, 2000,15, (2),508-514

[17] Mesut Baran, E., and Felix Wu, F.:” Optimal Sizing of Capacitors Placed on A Radial Distribution System”, IEEE Trans. Power Delivery,1989,4, (1), pp.735-743

[18] Hieu Le Nguyen: “Newton-Raphson Method in Complex Form”, IEEE Trans. Power Syst., 1997,12, (3), pp.1355-1359

[19] Abdulaziz Othman Almasoudi, Electrical Engineering Department King Fahad University of Petroleum & Minerals (KFUPM) Dhahran 31261, Saudi Arabia Dr. Ibrahim O. Habibullah Electrical Engineering Department King Fahad University of Petroleum & Minerals A “Review on Load Flow Analysis Modern Techniques” International Journal of Engineering Research & Technology (IJERT) 2021.

[20] Marcos Tostadoa, Salah Kamelb, Francisco Juradoa “Developed Newton-Raphson based Predictor-Corrector load flow approach with high convergence rate” February 2019 International Journal of Electrical Power & Energy Systems

[21] ANEEL KUMAR AKHANI “LIMITATIONS OF GAUSS SEIDEL METHOD FOR LOAD FLOW ANALYSISBY ENGR”. - SEPTEMBER 19, 2015

[22] YANG LIU, KAI SUN, , AND JIAOJIAO DONG “A Dynamized Power Flow Method Based on Differential Transformation” IEEE