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Regression Analysis in Load Flow

Daniel T Varghese[1], B Krishnachandran[2], Beena K H[3] and Reshmasree M R[4]

[1] M.Tech Scholar
Trivandrum, India
danibethelveedu@gmail.com

[2] M.Tech Scholar
Kottayam, India
b.krishnachandran@ee.ajce.in

[3]M.Tech Scholar
Kollam, India
beenakh@ee.ajce.in

[4]M.Tech Scholar
Palakkad, India
reshmasree@ee.ajce.in

ABSTRACT— ***Electricity is the most preferred form of energy used in industries, homes, business, and transportation. In the present situation, meeting the power demand is not the major issue, rather it is important to provide stable and quality power to the consumers. Thus analyzing the power system network is very much important. For this we have classical methods such as Gauss Siedel, Newton Raphson and other computer aided software programming techniques as well. All the existing technologies have the major setback that they require large computational time and extensive iterative numerical analysis. Even a simple three bus network requires substantial calculation. It is suggested that for a general class of problems covering ring bus systems, an approximate, fairly accurate solution can be obtained. The method is purely heuristic one. It is an experienced based solution technique for load flow analysis in power systems. The result is a simpler form of load flow analysis involving linear computation time.***

Keywords— Curve Fitting, Heuristic, Load flow, Regression

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1. INTRODUCTION

ELECTRICITY is the most preferred form of energy used in industries, homes, business, and transportation. At present the demand for electricity is soaring, leading to the operation of power system at its extreme limits. Thus the need for a reliable, stable and quality power is imperative in power sensitive industries like information technology, communication, electronics etc. Therefore in the present situation, meeting the electric power demand is the basic criteria but with added responsibility of the power system engineers to provide a stable and quality power to the consumers.

An electrical power system is made up of many components connected together to form a large complex system that is capable of generating, transmitting and distributing electricity over large areas. To meet the ever increasing load demand, either new power systems have to be built or the existing power systems need to be expanded by adding new generators and transmission lines. Detailed analysis must be performed to design and study the performance of the system and plan for expansion. Some of the analysis performed to study the system condition, feasibility and performance are (a) Load flow analysis, (b) Fault analysis/short circuit studies, (c) Stability studies, (d) Contingency analysis. Throughout the paper the emphasis will be on load flow analysis.

Considerable research has already been carried out in the development of computer programs for load flow analysis of large power systems. However, these general purpose programs may encounter convergence difficulties when a radial distribution system with a large number of buses is to be solved and, hence, development of a special program for radial distribution studies becomes necessary.

The solution of a load flow analysis provide information regarding bus voltage magnitudes and angles, active and reactive power flows in the individual transmission units, losses and the reactive power generated or absorbed at voltage controlled buses. Also based on the difference between power flow in the sending and receiving ends, the losses in a particular line can also be computed. Furthermore, from the line flow we can also determine the over and under load conditions. The steady state power and reactive power supplied by a bus in a power network are expressed in terms of non-linear algebraic equations. It is therefore required to have iterative methods for solving these equations.

The load flow problem is formulated in its basic analytical form with the network represented by linear, bilateral and balanced lumped parameters. However the power and voltage constraints make the problem nonlinear and the numerical solution must therefore be iterative in nature.

The mathematical model for the study of load flow analysis involves a set of non-linear algebraic equations that basically express power conservation at a bus. These equations can be expressed as a set of real equations with the voltages either in rectangular or polar form. The mathematical techniques used to solve the non-linear set of algebraic equations are Gauss-Siedel Method, Newton Raphson Method, Decoupled load flow and Fast Decoupled load flow

All the above techniques are iterative starting from an initial guess. The Gauss-Siedel method takes a large number of iterations depending on the system size while Newton's method converges in three to four iterations. In this paper, Newton's method is adopted for load flow analysis. Even though we have got these many mathematical techniques for the analysis of the power system, there are some drawbacks. The current problems faced in the development of load flow are an ever increasing size of systems to be solved.

New methods have been developed to overcome the problem. Some of them include calculation of load flow using genetic algorithm, constrained genetic algorithm load flow method etc. Even then all these methods would result in too many calculations.

This paper proposes an elegant method to reduce the cumbersome calculations in check. It can be implemented quite easily to large power systems as well. The method improves with experience and is essentially driven by heuristics. Hence it is titled "Space Crawling of Solution Space of a Power System".

1.1 HEURISTICS

It refers to experience based techniques for problem solving, learning, and discovery that give a solution which is not guaranteed to be optimal. Heuristic methods are used to speed up the process of finding a satisfactory solution via apparently disjoint shortcuts to ease the cognitive load of making a decision because the exhaustive search is impractical.

Several heuristic tools have evolved in the last decade that facilitates solving optimization problems that were previously difficult or impossible to solve. These tools include evolutionary computation, simulated annealing, particle swarm, etc. Recently, these new heuristic tools have been combined among themselves and with more traditional approaches such as statistical analysis, to solve extremely challenging problems. The advantages of these tools in developing solutions are development time is much shorter than when using orthodox approaches and the systems are very robust, being relatively insensitive to noisy and missing data.

The proposed model is also a heuristic approach for finding the load flow solution of a power system. Thus in effect we can conclude that for analyzing any power system network whether large or small, load flow analysis is a must. Until now there exist many methods for the conduction of load flow studies. These are glossed over in section 2.

2. COVENTIONAL POWER FLOW METHOD

Load flow analysis uses simplified notation for solving the power system network. The power flow equations are non-linear algebraic models for which explicit solutions are not possible. The equations are solved using iterative techniques [1].

The first algorithm for power flow problem, employing the Gauss- Siedel method, using Ybus is still used when the system size is not very large Newton's method using Gauss elimination and the concept of optimally ordered elimination for the solution of large, sparse systems in 1970s. Later on optimally ordered Gaussian elimination and special programming techniques were introduced. These methods gain favor for system having 200 buses or more [2].

In 1963, Brown et al. developed a method which uses the system bus impedance matrix Zbus for power flow solution. This method has got good convergence characteristics. However, it suffers from the disadvantage that the bus impedance matrix Zbus is a full matrix and requires very large computer memory [2]. However this disadvantages becomes insignificant in view of the large computer storage capacities in vogue.

In 1972, B. Stott suggested approximations in the Newton-Raphson method by decoupling MW-frequency and

MVAR-voltage loops. A simplified version of decoupled method known as fast decoupled method, with faster convergence characteristics, was suggested by B. Stott and O. Alsac in 1974 [3].

2.1 GAUSS-SIEDEL METHOD

Gauss-Siedel method was one of the most common methods used in load flow studies. Its advantages [4] are: Simplicity, small computer memory requirement, less computational time per iteration. The disadvantages include slow rate of convergence, increase in number of iterations with increase in number of buses effect on convergence due to choice of slack bus. Thus Gauss-Siedel method is used only for systems having small number of buses. Similarly all other analytical methods have some drawbacks [5]. With the developments in power engineering, newer techniques for conducting load flow studies have been developed. Some of them are listed below.

2.2 CONSTRAINED GENETIC ALGORITHM LOAD FLOW

This is a new approach in which a genetic algorithm based load flow algorithm is developed. It is based on the concept of genetic algorithms and the methods of constraint satisfaction for satisfying the specified powers of the PQ nodes and the specified voltage magnitudes of the PV nodes [6]. When the loading condition is such that the load flow equation set is unsolvable, the insolvability is indicated by CGALF in the form of voltage magnitude violation at the PV nodes. Methods for satisfying the power balance requirement and the voltage magnitude constraint are then developed and incorporated into the genetic algorithm method to form a constrained genetic algorithm load flow algorithm for solving the load flow problem. The new load flow algorithm is enhanced by using dynamic population method [6]. Three mechanisms, the dynamic population technique, the solution acceleration technique and the sequencing method for nodal voltage updating, have also been developed and incorporated in constrained genetic algorithm load flow (CGALF) to enhance its performance and computational speed.

2.3 SOLVING LOAD FLOW PROBLEM USING GA

Recently, owing to the problem of static voltage instability, attempts have also been made to establish methods for finding multiple load flow solutions. A numerical method for tracking the multiple solutions has been proposed [7]. A method based on genetic algorithms has been reported [8]. However, these method are not reliable as its repeatability is not high. Moreover, the accuracy of the solutions obtained by it is also not high because of the binary-bit coding method employed introduces discretization errors in the solutions and there is no method to handle the constraints in the load-flow problem.

This is a reliable genetic based algorithm for solving the load flow problem. In this algorithm, the floating point coding method is employed [8]. A method for dealing with the power balance equations and the voltage magnitude constraints in the load flow problem is also developed. The developed algorithm can solve for the normal operation solutions and the abnormal operation solutions using appropriate fitness functions. In this algorithm, the load flow problem is taken as an optimization problem in which the objective is to minimize the total mismatch in the nodal powers and voltages. A method for treating the nodal power balance constraint and the constraint on the specified nodal voltages has been developed. The incorporation of the method into GALF has two advantages [9].It provides a mechanism to ensure that the constraints are satisfied as much as possible and also assists the solution process of GALF to minimize the mismatch and hence improves the convergence characteristic.

Case studies reveal that this approach has great future to find a new technique for load flow analysis using soft computing techniques. There are also various computer software that has been developed for doing the load flow analysis which are Mi-Power, E-Tap, PSAT and MATLAB.

However even with all the plethora of techniques there is no unique method by which we can analyse the power system. All the above mentioned methods are iterative in nature with corresponding large computational times [10]. In this paper a simple method is being proposed with which we can conduct load flow studies, without using any complex equations or any complicated numerical techniques.

3. STUDY ON LOAD FLOW ANALYSIS

In order to find the solutions of the power flow equation which is a set of simultaneous non-linear algebraic equations, it is required to adopt the method of systematic initial guessing of the unknown variables. In power flow studies, the solution is approached in the following manner:

(i) An initial solution, Vi is guessed.

(ii) This solution is used to compute a new and better first solution for Vi

(iii) The first solution is used for finding a second one, and so on.

This repetitive process of converging on the solution is referred to as an iterative method. The different methods of power flow solutions utilize somewhat different schemes in computation. Thus for the study of power system network, load flow is very necessary. It is the backbone of the power system network. So before going further let us analyse our power system using one of the analytical methods (Newton-Raphson).

If there are limits on the controllable B sources at PV buses, Q is computed each time and if it violates the limits, it is made equal to the limiting value and the corresponding PV bus is made a PQ bus in that iteration. If in the subsequent computation, Q does come within the prescribed limits, the bus is switched back to a PV bus.

If there are limits on the voltage of a PQ bus and if any of these limits is violated, the corresponding PQ bus is made a PV bus in that iteration with voltage fixed at the limiting value. Thus by using the above algorithm load flow analysis are carried out for various power system network. During case study NR method is being followed for load flow calculations.

3.1 ADVANTAGES

(a) This method is faster, more reliable and results are accurate.

(b) Requires less number of iterations for convergence

(c) The number of iterations is independent of the size of the system.

(d) Suitable for large systems.

3.2 DISADVANTAGES

(a) The programming logic is more complex than G-S method.

(b) The memory requirement is more.

(c) Numbers of calculation per iteration are higher than GS method.

A faster solution is obtained using the Newton-Raphson method and is suitable for large scale problems. Here partial derivatives are used to construct the Jacobian matrix. The Newton-Raphson solution approach is much faster than the other approaches. For an n bus system, the size of the matrix is:

$$(2n-ng-2)$$

Where, ng is the number of generator buses, and n is the total number of buses.

One of the main issues with the Newton-Raphson method is the need for evaluating and inverting the Jacobian matrix. Further, the Jacobian matrix must be recalculated and inverted for each iteration, so the time is considerably longer. For typical large systems, the time per iteration in the Newton-Raphson method is roughly equivalent to 7 times that of the Gauss-Siedel method.

The Newton-Raphson method which has quadratic convergence characteristics and is the best among all methods from the standpoint of convergence. In addition, the number of iterations for the Gauss-Siedel method increases directly as the number of buses of the network, whereas the number of iterations for the Newton-Raphson method remains practically constant, independent of system size. The Newton-Raphson method needs 3 to 5 iterations to reach an acceptable solution for a large system [11]. In the Gauss-Siedel method and other methods, convergence is affected by the choice of slack bus and the presence of series capacitor, but the sensitivity of the Newton-Raphson method is minimal to these factors which cause poor convergence. Therefore, there is a need for simplified approaches to solve the power flow problem.

4. EXPERIMENTAL SETUP

For conducting the quantitative analysis an approach was taken to arrive at the solution. The test system taken for conduction load flow analysis using Newton-Raphson was:

- Consider a three bus system. Each of the three lines has a series impedance of 0.02+j0.08 pu and a total shunt admittance of j0.02 pu. The specified quantities at the bus are tabulated below

Table 4.1 Bus details [3]

Bus	Real Load Demand	Reactive Load Demand	Real Power Generation	Reactive Power Generation	Voltage Specification
1	2	1	Unspecified	Unspecified	1.04<0 Slack bus
2	0	0	0.5	1	Unspecified(PQ bus)
3	1.5	0.6	0	?	1.04(PV bus)

Results after doing Newton-Raphson manually and analyzing the same problem using PSAT can be summarized as shown in Fig4.2.

Table 4.2 Tabulated Values 3 bus

Variables	Calculated	PSAT	Error
V2	1.089	1.089	-0.0006
δ2	-0.023	-0.0267	-0.0037
δ3	-0.0654	-0.0799	-0.0145
P2	0.7385	0.5	0.2385
P3	-1.6189	-1.5	0.1189
Q2	1.9725	1	0.9725

Table 4.2 shows the tabulated results of the load flow problem considered. The first column indicates the variables that are to be found out using power flow analysis. The second and the third is the result obtained by doing Newton-Raphson technique manually and using software PSAT respectively. The last column denotes the error values which was calculated using Eq.4.1

$$\left|\sum totalerror\right| = \left|\sum error_{calc}\right| - \left|\sum error_{psat}\right| \tag{4.1}$$

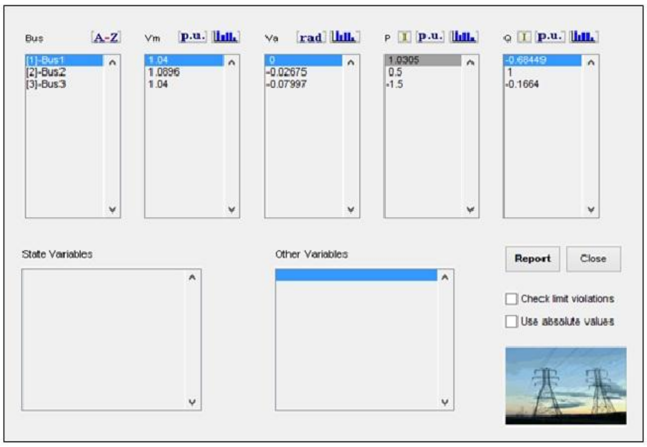


Fig 4.3 PSAT simulated values 3 bus

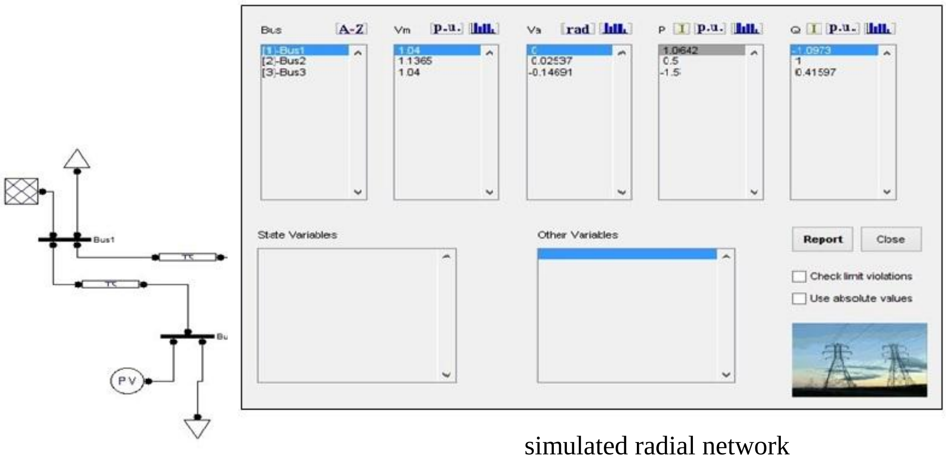
Similarly the results for 5 bus systems can be summarized as follows,

Table 4.3. Tabulated Values 5 bus

Variables	Calculated	PSAT	Error
V2	1.105	1.0871	0.0179
V4	1.0903	1.09	0.0003
δ2	-0.046	-0.0681	0.0221
δ3	-0.105	-0.1367	0.0317
δ4	-0.104	-1.366	1.262
δ5	-0.122	-0.16293	0.04093
P2	0.7385	0.5	0.2385
P3	-1.6189	-1.5	-0.118
P4	0.7385	0.5	0.2385
P5	-1.7414	-1.5	-0.2414
Q2	1.9715	1	0.9715
Q4	1.9715	1	0.9715

Every load flow methods have basic problem of convergence in large system as well as in radial type of power system networks. The variables for the load flow analysis of distribution systems are different from that of transmission systems. This is because distribution network is radial in nature having high R/X ratio, whereas, the transmission system is loop in nature having high X/R ratio.

The conventional Gauss-Seidel and Newton-Raphson method do not converge for the distribution networks. Thus studies were conducted on radial type of systems. Various forms of radial type network were considered for the analysis. The PSAT results for radial network and the Simulink diagrams are shown in Fig.4.5 and Fig.4.6.



simulated radial network

$$\sum error_{n+2} = k \sum error_{n}$$

Table 4.3. Tabulated Values for radial network.

Variables	Calculated	PSAT	Error
V2	1.1381	1.1365	-0.0016
δ2	0.0188	0.02537	-0.0065
δ3	-0.117	-0.14691	-0.0299
P2	-0.12051	0.5	0.3795
P3	-0.00303	-1.5	1.497
Q2	-4.906	1	0.5094

4.1 OBSERVATION

The above studies provided an idea to precede further to find a new technique. So in order to frame the solution two approaches were adopted. Both of them have their own respective mathematical backgrounds. The two heuristic based approaches introduced here are: (i) Method of Errors (ii) Method of curve fitting

4.1.1 METHOD OF ERRORS

From the observations of the calculated and PSAT values we could find that a G.P existed between the sums of the total errors. The error was calculated as follows:

$$\left|\sum totalerror\right| = \left|\sum error_{calc}\right| - \left|\sum error_{psat}\right| \qquad (4.2)$$

The error value increased as the bus size increases. Thus by a relation we could predict the gross error of any system. This is illustrated as shown below.

Total error of 3 bus system: 1.3487

Total error of 5 bus system: 4.1548

Let K= (Total error of 5 bus system) / (Total error of 3 bus system) ie K= 3.0802 approx 3

The ratio between consecutive bus numbers almost remained a constant which is 1.5. Hence from the observation we are able to predict the total error of the 7 bus system from the equation Therefore: The total error of 7 bus system is: 12.46299.The above results was checked and proofed using PSAT values of & bus system. A new set of equation was framed as follows,

$$New_{val} = \frac{\sum individ_{error}}{total_{error}} + Assum_{val} \tag{4.4}$$

With the above equations load flow studies were again conducted but results were not that satisfactory. As the bus size increased the variation in the values became larger and larger. After some point of analysis it was found that by proceeding with error values of system it is difficult to obtain a method or any technique to find the load flow solution so curve fitting was the next thing explored

4.1.2 METHOD OF CURVE FITTING

In general, curve fitting is the process of constructing a single function by capturing the trends in the given data across the entire range. In order to infer the values of functions where no data are available, fitted curves can be used as an aid for data visualization. This method can be used to summarize the relationships among two or more variables. By using curve fitting a polynomial equation was framed with which the load flow analysis could be conducted. Graphs were plotted as follows:

(i) PSAT vs CALC

(ii) PSAT vs ERROR

(iii) CALC vs ERROR

The above graphs were plotted for both five bus and three bus. Plots with and without phase angle values were considered during the analysis. Among the above graphs, the plot between PSAT vs CALC was the most acceptable. From this the framings of equations were more realistic with its own practical relevance. The results are as shown below:

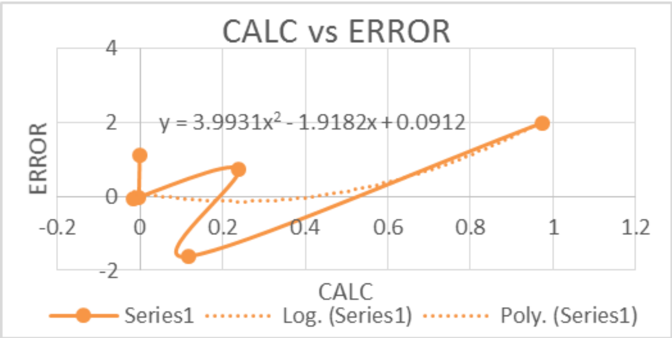


Fig 4.7 Error plot

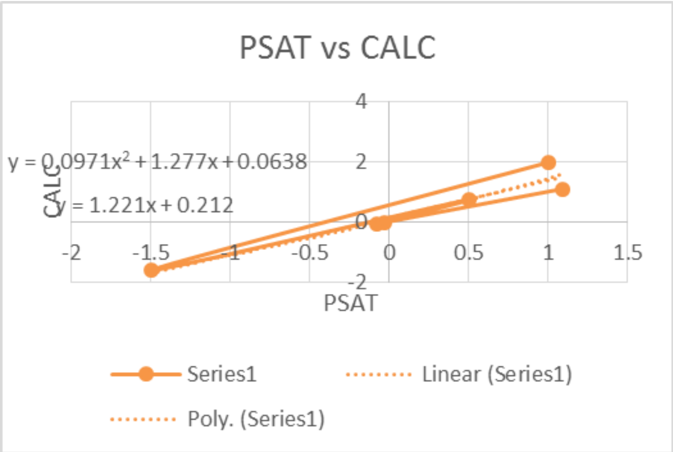


Fig 4.8 Three bus plot

From the above studies the equation can be framed as:

$$y = 1.221x + .212 \quad \text{(linear)} \qquad (4.5)$$

$$y = 0.097x^2 + 1.277x + 0.0677 \quad \text{(polynomial)} \qquad (4.6)$$

It can be reframed as:

$$calc_{value} = 1.221 Psat_{value} + 0.212 \qquad (4.7)$$

$$calc_{value} = 0.097 Psat^2{}_{value} + 1.277 Psat_{value} + 0.0677 \qquad (4.8)$$

With the above equations it is possible to conduct the load flow studies and find the values required for power system analysis which includes bus voltages, angle, reactive power etc. Furthermore the above equations were verified and proved by adopting genetic algorithm technique [4]. The values obtained by using this method coincided with the required values.

The studies of radial type network also reveals the same observations hence the convergence problem that persist in the existing methods can be eliminated if the above mentioned technique is used.

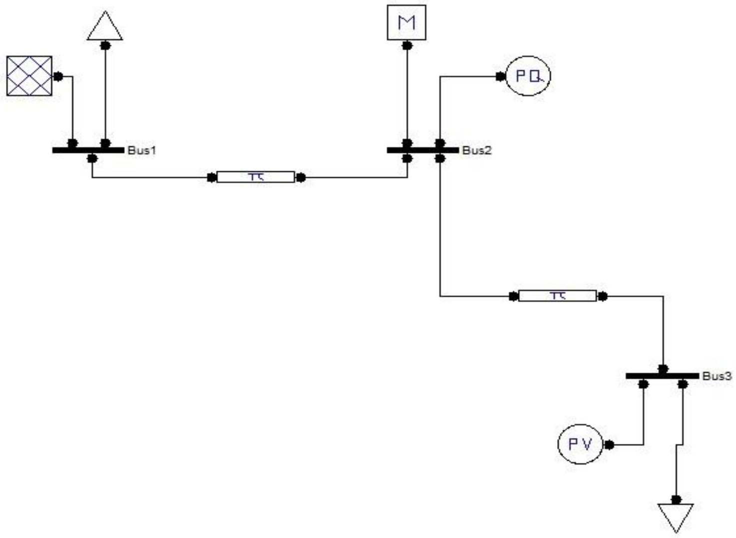


Fig 4.10 Radial type network

Like any other work some unrealistic observations were found in the case of radial type power system network as those values exceeded the limits in voltages, reactive power etc. The Simulink diagram of that special case is shown in Fig 4.10

4.2 EXPERIMENTAL RESULTS

A simple equation for conducting the load flow analysis has been framed using method of curve fitting, which are Eq.4.6 and Eq.4.7 respectively. Then load flow analysis was conducted using the new set of equations and the results are tabulated in Table 4.5. The equations reliability was verified using optimal solution check using genetic algorithm technique. C++ coding was done for the conversion of floating point numbers to binary digits. This was done inorder to generate population that was required for fitness evaluation in genetic algorithm. Results were further verified by doing the above procedure for random set of population that was generated. Genetic algorithm was used as it was the most efficient classical tool available to verify or consolidate the findings and also it is less complex in its structure compared with other optimization techniques. Moreover it is a probabilistic transition tool [12].

Table 4.5 Tabulated result 5 bus

Variables	New Solution	PSAT
V2	1.102	1.087
V4	1.0956	1.09
δ2	-0.059	-0.0681
δ3	-0.1099	-0.1367
δ4	-0.121	-1.366
δ5	-0.123	-0.16293
P2	-0.621	0.5
P3	-1.595	-1.5
P4	0.621	0.5
P5	-1.595	-1.5
Q2	0.987	1
Q4	0.987	1

4.2 INFERENCES

An initial qualitative study reveals that the proposed method can be used for load flow studies only if the power system network is an odd bus network. And also the number of PV and PQ bus in the case of closed network should be equal. Hence a constrained formulation is necessary. It is framed as follows:

$$[N]_{PQ} = [N]_{PV} = \frac{n-1}{2} \tag{4.9}$$

With the above mentioned minimal constrain the load flow analysis can be done for both radial and closed type of power system networks. From the Table 4.5, the degree of accuracy of the actual value which is being calculated to the true value is very high. Hence the reliability of the new framed solution can be trusted. The above framed equation also yielded admissible results for a 7 bus network. As the configuration of the networks increases the convergence rate gradually declines. Thus from the above analysis it can be concluded that the new technique which have been introduced is an efficient tool for doing the load flow analysis of small network topologies.

5. CONCLUSION

In this work a new method of load flow technique, a heuristic based solution techniques is proposed for conducting the load flow studies. The major advantages of the proposed method are:

- The method is a simple mathematical technique that can be used for the analysis of load flow studies
- With this the tediousness that is felt during the manual calculation of the load flow studies can be reduced to very large amount
- Also the computational time required for the proposed method is reduced drastically to a large extent
- The major advantage of the proposed method is even the person with very basic knowledge in mathematics can perform the load flow studies of very large power system within a short span

Further developments in the proposed work are possible. Works can be done to eliminate the odd constrained imposed on this method and to obtain a more acceptable solution technique for radial type of power system network. Finding an acceptable solution technique which is beneficiary for both radial and ring type network is also a future scope. Overall the proposed solution technique is a simple quantitative mathematical solution technique for conducting the load flow analysis.

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Daniel T Varghese received the B.Tech. degree in Electrical and Electronics Engineering from Mar Baselios College of Engineering and Technology, Kerala, India, in 2013, and the M.Tech degree in Power Electronics and Power Systems from Amal Jyothi College of Engineering, in 2015, respectively. Her research interests is in Renewable Energy and Power system.

Beena K H received the B.Tech. degree in Electrical and Electronics Engineering from UKF College of Engineering and Technology, Kerala, India, in 2013, and the M.Tech degree in Power Electronics and Power Systems from Amal Jyothi College of Engineering, in 2015, respectively. Her research interests is in Power Electronics and Power system.

B.Krishnachandran received the B.Tech. degree in Electrical and Electronics Engineering from Adi Shankara Institute of Engineering and Technology, Kerala, India, in 2012, and the M.Tech degree in Power Electronics and Power Systems from Amal Jyothi College of Engineering, in 2015, respectively. Her research interests is in Renewable Energy and Power Electronics.

Reshmasree M R received the B.Tech. degree in Electrical and Electronics Engineering from Sengunthar College of Engineering and Technology, Kerala, India, in 2013, and the M.Tech degree in Power Electronics and Power Systems from Amal Jyothi College of Engineering, in 2015, respectively. Her research interests is in Power Electronics and Power system.