A brief literature survey on load flow calculation methods and FACTS devices is presented in this chapter.

Brain Stott presented a paper [14] on review of load flow calculation methods, that have received widespread practical application; the analytical bases, computational requirements and comparative numerical performances are discussed in this paper.

The Y-matrix iterative methods were well suited to the early generations of the computers since they require minimal storage and convergence process is slow. The incentive to overcome this deficiency led to the development of Z-matrix methods which converge more reliably but sacrifice some of the advantages of Y-matrix, iterative methods, notable storage and speed when applied to large systems. The Newton-Raphson method was shown to have very powerful convergence properties.

The conclusions of this review are:

1. When speed is still important the fast decoupled load flow method can be used.

2. The importance of sparse matrix techniques in the exploitation and further development of load flow algorithms. Modern methods using sparse matrix factorization need great attention to programming efficiency, if they are to fully realize their considerable advantages over previous methods.

The authors in [15] have presented a method which improved the solution of the power flow considerably in speed and in accuracy.
They have applied two fundamental ideas: the use of Newton’s method and solution of the resulting set of linear equations by means of optimally ordered Gaussian elimination with a compressed storage scheme.

The methods used for solution of power flow problem are all iterative

1. The nodal iterative method, using the admittance matrix and an iterative procedure similar to the Gauss-Seidel iterative solution of linear equations.

2. The impedance matrix iterative method using the impedance matrix. It is equivalent to the direct solution of the linearized system with given node currents whose values are changed from step to step to get the scheduled power values.

3. Newton method using a Jacobian matrix where in each step a system of linear equations was solved and the matrix changes after each step.

Newton’s method has proved to be a standard technique for solving non linear equations. This method appears to be faster, more accurate, and more reliable than any other known method for any size or any kind of problem. Using this method both polar and rectangular formulation gave identical convergence properties.

Rectangular formulation might prove more advantageous when computer memory is not critical. Newton’s method takes only 5
iterations each equivalent to about 7 of widely used Gauss-Siedel method are required for an exact solution.

B.Stott O.Alasc [16] developed an extremely fast load flow solution method which is very simple and reliable with a wide range of practical applications. It is attractive for accurate or approximate off and online routine and contingency calculations for networks of any size and can be implemented efficiently on computers with restrictive core store capacities. The method was developed employing the MW-θ/MVAR-V decoupling principle, and its precise algorithmic form was determined by extensive numerical studies.

Authors in [17] addressed the practical problem of power flow cases which have no real solution. Such cases often represent the most severe threat to the system operation. An efficient method has been developed to provide optimal control recommendations to mitigate these cases. The method uses the minimum Euclidean distance in parameter space to quantify the unsolvability of the case. The sensitivity of this measure to different system controls is calculated. These sensitivities are used to determine the best way to mitigate the contingency. The dynamic consequences of losses of solution are also discussed in this paper.

J.X.Luo A.Senlyen [18] discussed a fast and efficient method for load flow solutions of weakly meshed networks. It uses real variables P, Q rather than complex ones and enables us to handle the PV buses in an exact manner as loop break points. This not only eliminates the convergence difficulty due to the PV buses but also
reduces to half the computational effort of handling the PV buses. Applying modified network tree labeling makes it possible to construct the sensitivity matrix by a graph based approach which reduces the computational effort to a minimum.

The CPU required for backward-forward sweeps is dominant in each iteration of the solution phase. Savings of CPU time have been achieved by using a single sweep instead of converged sweeping. Results have shown that the method is fast, efficient, robust and eminently suitable for large scale systems with a small number of loops. This method has the potential of being applied to 3 phase unbalanced load flow problems in weakly meshed networks.

The authors of reference [19] proposed two small adjustments to the standard FDLF method. The handling of the resistances when building the $B^1$ and $B^{11}$ matrices, and the iteration scheme that is used in the FDLF method converges if the resistances are ignored when forming $B^1$. For the normal cases there is hardly any difference in the number of iterations, but as soon as the $R/X$ ratios are increased, the new form will converge much faster than the old one. However, in a small number of such cases, a certain type of cycling behavior occurs and the number of iterations needed to solve the load flow raises far more than could be expected.

Non divergent constant Jacobian Newton power flow methods were discussed by P.R Bijwe S.M.Kelapure [20]. The non divergence feature of these methods was achieved through application of optimal multiplier theory for step size adjustment control. Both coupled and
decoupled Jacobian versions were developed. These methods are extremely useful in situations like real time power flow solutions where both speed and reliability of convergence are of paramount importance. Results have clearly confirmed potential of optimal multiplier based algorithms in divergence control and substantial reduction in the number of iterations at higher loading.

Vander Menengoy Nelson Martins[21] presented a sparse Newton-Raphson formulation for the solution of power flow problem, comprising 2n current equations written in rectangular coordinates, for both PQ and PV buses. A new dependant variable (ΔQ) is included for each PV bus together with an additional equation imposing the constraint of zero deviations in the bus voltage.

The Jacobian has the same structure as the (2n*2n) nodal admittance matrix in which each network branch is represented by a (2*2) block. Except for PV buses the off diagonal (2*2) blocks of the proposed Jacobian equations are equal to those of nodal admittance matrix.

The main advantage of this formulation lies in the calculation of the Jacobian matrix because its off diagonal elements are constant and equal to the terms of nodal admittance matrix, except for PV buses. This method does not require at all the usage of transcendental functions during the iterative process.

The advantage of this formulation showed a 20% average speed up when benchmarked with a state of the art production grade Newton-Raphson power flow.
Ying Chen and Chen Shen [22] developed an adaptive preconditioner that does not need estimations of the Jacobian or its Eigen values, which is devised for solving coordination equations in distributed simulations of power systems. The idea is to utilize the projections on the Krylov subspace produced by the Arnoldi process directly to perform corrections of preconditioners. The intrinsic relations between these projections guarantee that the preconditioner can approximate the inverse of the Jacobian matrix effectively. The results show that the adaptive preconditioner can enhance convergence of Newton-GMRES iteration schemes greatly and has stronger robustness compared to other preconditioner methods. Moreover the proposed method has strong parallelism and scalability which makes it feasible to solve distributed simulation problems of power systems.

A critical evaluation of three Newton load flow methods based on step size optimization is carried out by Luciana Mcbraz, Carlos A Castro[23]. These methods are based on the computation of a scalar multiplier at each iteration which multiplies by the voltage correction vector so as to minimize a power mismatch based quadratic function. Attention was paid for evaluating the performance of these methods for Ill-Conditioned heavily loaded and over loaded systems. The possibility of using them as general load flow tools is also discussed. These methods can also play an important role in voltage stability analysis for the determination of the load margins to voltage collapse.
S.C Tripathy G.Durga Prasad O.P Malik G.S Hope [24] used K.M. brown’s method to solve load flow problems. This is particularly effective for solving Ill-Conditioned algebraic equations. The proposed technique has quadratic convergence characteristics. The method is relatively simple and can be easily incorporated in the existing Newton-Raphson algorithm. The transformers with on load tap changers and phase shifters can be taken into account while developing programs.

The storage requirement of Brown’s method is slightly more than that of Newton’s method. Brown’s load flow algorithm converges to the solution of Ill-Conditioned system in few iterations, where as the standard load flow methods either show poor convergence or diverge.

Zhiping Yang [25] proposed a new STATCOM model appropriate for power flow analysis derived directly from the dynamic model of the STATCOM. The proposed model can therefore account for the high-frequency effects and power electronic losses and more accurately predict the active and reactive power outputs of the stator. In order to consider the loss of the connection transformer, a modified model is presented: a new PV bus, bus j, was added to represent the STATCOM’s output terminal, while the connection transformer is replaced by its leakage reactance and resistance: $R_t + jX_t$. The losses of the transformer are then calculated iteratively within the standard load flow. Although the power losses of a STATCOM are small compared to its capacity , the losses play a significant role in the
STATCOM’s mathematical model and the accuracy of the corresponding simulation are calculated.

U.P. Mhaskar, A.B. Mote [26] addressed the solution of load flow equations for a power system with series flexible ac transmission systems (FACTS) devices. A novel formulation of equations using dual state variables (current magnitude and angle) and dual control variables (series injected real power and series voltage in quadrature with current) for series devices was proposed. These specifications can be related to transmission line loading and device limits. Specifications like power flow through a series device can also be handled using this formulation. The load flow equations were solved using Newton-Raphson technique. A decoupled formulation was also proposed.

T.H. Weber [27] has proposed exact derivation of the necessary control values for the FACTS devices, which was presented with generally valid equations especially for long lines and weakly meshed power systems. The important influence of the available reactive power was also discussed for these cases. Finally various transeuropean transit scenarios were examined in a model of the eastern European power system. Nonconducted power transits were compared with the direct and the indirect conduction method and the results of load flow calculations allow an assessment of these methods of conducting power transits.

S. Chung [28] presented a new genetic algorithm (GA) method to solve optimal power flow (OPF) in power system incorporating flexible
AC transmission systems (FACTS). As a powerful and versatile FACTS device, UPFC (unified lower Flow controller), is considered in the paper: Unlike other FACTS devices, UPFC has a great flexibility that can control the active power, reactive power and voltage simultaneously. In the solution process, GA, coupled with full AC power flow selects the best regulation to minimize the total generation fuel cost and keep the power flows within their security limits. The optimization process with GA was presented with case study examples using IEEE test system to demonstrate its applicability. The results were presented to show the feasibility and potential of this new approach.

Y.E.Pen [29] presented a new method to incorporate flexible AC transmission system (FACTS) devices in optimal power flow (OPF) problem. Through power injection model of FACTS devices; their control to power system is expressed as additional power equations at the nodes and the branches where FACTS devices are located. These additional power equations are convenient in combination with OPF algorithm based on nonlinear interior point (IP) programming. A two-part calculation structure was introduced in order to make full use of the existing OPF algorithm and related software in EMS. Digital simulations of the modified IEEE 30-node system located with multiple FACTS devices are presented to test the effectiveness and efficiency of this work. The study also shows that FACTS devices are capable of providing economically and technically attractive solution to power systems congestion problems.
The increasing energy demand and tighter interconnection between systems, the loop flow problem should be solved for the purpose of reliable system operations, which was addressed by Wei Wu Chikong Wong [30]. FACTS devices, such as UPFC, have the ability to control the power flow, which makes it possible for them to prevent loop flows in interconnected systems. From economic considerations, the FACTS devices can be installed in a suitable location in MV networks, instead of directly being installed in HV network where loop flows occur. The modeling of UPFC in power flow calculation is introduced. A real case in South China, which focuses on solving loop flows by UPFC in MV network, is presented. Since the party getting benefited from the interconnection is subjected to loop flows and takes on the network loss caused by loop flows, the Economic feasibility of implementing FACTS devices is discussed.

Ying Xiao[31] focused on developing an approach to steady-state power flow control of Flexible AC Transmission systems (FACTS) device-equipped power systems. Based on a power-injection model of FACTS devices and an optimal power flow model, a novel versatile power flow control approach is formulated, which is capable of implementing power flow control incorporating any FACTS device flexibly. Different from existing FACTS device control approaches, the active and (or) reactive power injections are taken as independent control variables. Therefore, using this method, Jacobian matrix need not be changed, although various FACTS devices possess different physical models and different control parameters. Furthermore, it
enables the integration of FACTS devices into the existing power system analysis and control Programs efficiently. Physical limits of the FACTS devices are also considered in the model. Numerical results on a reduced practical system and a 1500-bus practical system with various FACTS devices are presented to illustrate the vigorousness of the proposed approach.

Advanced load flow models for the static VAR compensator (SVC) are presented by H.Ambriz –Prez [32]. The models are incorporated into existing load flow (LF) and optimal power flow (OPF) Newton algorithms. Unlike SVC models available in open literature, the new models depart from the generator representation of the SVC and are based instead on the variable shunt susceptance concept. In particular, a SVC model which uses the firing angle as the state variable provides key information for cases when the load flow solution is used to initialize other power system studies e.g., harmonic power flow analysis. The SVC state variables are combined with the nodal voltage magnitudes and angles of the network in a single frame-of-reference for a unified, iterative solution through Newton methods. Both algorithms, the LF and the OPF exhibit very strong convergence characteristics, regardless of network size and the number of controllable devices. Results are presented which demonstrate the prowess of the new SVC models.

S.C.Srivastava [33] presented an optimal power flow (OPF) model to minimize the curtailment of the contracted powers in a power market having bilateral, multilateral as well as firm contracts. A
strategy has been suggested for allocation of transmission losses among various market participants. Role of flexible AC transmission system (FACTS) devices on reducing the transmission congestion and curtailment of the contracted power has also been studied.

Roy Billinton [34] examined the impact of a unified power flow controller (UPPC) on power system reliability. The UPPC is employed in the system to adjust the natural power sharing of two different parallel transmission lines and therefore enable the maximum transmission capacity to be utilized. The results of the investigations show a significant improvement in the system reliability by utilizing the UPPC. The improvement is measured using three reliability risk indices, namely, the loss of load expectation (LOLE), the loss of energy expectation (LOEE), and the system minutes (SM). The paper also presents a comparison between the effects of the UPFC and a Thyristor controlled series capacitor on the system reliability.

A systematic study of the operating constraints of I-converter FACTS devices based on series voltage and shunt current injection is presented by M.Kazerani. Then, the power ratings of the series voltage and shunt current injection devices performing the same job of reactive power compensation or power flow control are compared and the conditions under which each approach becomes more economical are derived. The results can be generalized to FACTS devices with more than one converter such as UPFC.

Sami Ammari [37] deals with an interaction phenomenon between dynamic loads and FACTS controllers in power systems.
Different power system configurations have been studied (power system with without dynamic loads, uncertainty and variation of dynamic load parameters. Two methods have been proposed to solve this problem. The first one based on sensitivity and residues techniques, takes into account the uncertain character of dynamic loads to compute the most efficient phase compensation for low frequency oscillation damping. The second approach consists of designing a robust damping controller by LMI (Linear Matrix Inequalities) techniques with the aim of guaranteeing a certain degree of stability and performance of the FACTS controller in the presence of dynamic loads uncertainties.

C.R.Furete –E.Acha [38] presented a new and comprehensive load flow model for the Thyristor Controlled Series Compensator (TCSC) . In this model the state variable is the TCSC’s firing angle, which is combined with the nodal voltage magnitudes and angles of the entire network in a single frame-of-reference for a unified iterative solution through a Newton-Raphson method. Unlike TCSC models available in the open literature, this model takes account of the loop current that exists in the TCSC under both partial and full conduction operating modes. Also, the model takes proper care of the resonant points exhibited by the TCSC fundamental frequency impedance. The Newton-Raphson algorithm exhibits quadratic or near-quadratic convergence characteristics, regardless of the size of the network and the number of TCSC devices.

**Reasons for development of the proposed method**
The Studies for the load flow calculations started with ward & Hale method in 1956 and currently the Newton-Raphson method which have the attractive property of quadratic convergence, they tend to take a large amount of CPU time to find a solution due to factorization of the power flow Jacobian at each iteration. On the other hand, after a single, simpler factorization the fast decoupled methods have the desirable property of requiring only an inexpensive forward elimination and backward substitution on a smaller matrix at each fast decoupled half iteration. The disadvantage of using the fast decoupled approach is due to its weaker convergence properties. For bus voltage magnitudes near 1 p.u. and small angle separations across network branches, the fast decoupled method can be a powerful solution algorithm. However, the fast decoupled method may fail to converge for lines with high R/X ratios or stressed operating conditions. Conventional power flow methods are known to have difficulties in solving cases for ill conditioned systems. The ill conditioning relates to the nature of the power flow Jacobian matrix. A system is said to be ill conditioned if the condition number of the Jacobian is very high.

Therefore, there are situations when a power system engineer must resort to using a Newton-Raphson method to solve the power flow equations. This thesis will present certain recent techniques to load flow solutions for well conditioned and ill conditioned power systems incorporating FACTS controllers.

The advent of Flexible AC Transmission Systems (FACTS) devices has given a system operator additional leverage to control a power system. With the help of FACTS devices, it is possible to regulate real and reactive power flows in the network. In this context there is need to develop analytical tools in order to gauge the effectiveness of these devices. In particular existing programs for load flow need to be modified to incorporate these devices. The approaches based on Optimal multiplier theory, Runge-Kutta method and modified Newton-Raphson techniques proposed by
“G.Durga Prasad, AK Jana and SC Tripathy” such as 2 step and 3 step algorithms are used to tackle the problems with ill conditioned power systems incorporating FACTS devices. In a conventional Newton power flow method, at each iteration, the non linear set of equations is linearised at the current solution point and the updates are obtained by solving these equations. The key idea in Optimal Multiplier based power flow method is to improve the convergence of the basic method by using an optimal multiplier to modify the iterations. The Runge-Kutte method shows that there is a formal analogy between the Newton’s method and a set of autonomous ordinary differential equations. This analogy is intriguing, since it allows unifying the standard Newton-Raphson method and the most robust techniques proposed in the literature in a unique frame work. In case of Optimal Multiplier method, the Jacobian is factorised once per iteration, while, in case of Runge-Kutte method 4 times per iterations.