ON POWER FLOWS AND OPTIMAL POWER FLOWS OF INTEGRATED POWER SYSTEMS

By

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this thesis is

dedicated

to my

beloved parents

Sri.V.Krishna Murty garu and Smt.V.Sitha Maha Lakshmi garu

- *BAPI*

C E R T I F I C A T E

This is to certify that the thesis entitled " **ON POWER FLOWS AND OPTIMAL POWER FLOWS OF INTEGRATED POWER SYSTEMS** " which is being submitted by Sri **VINNAKOTA BAPI RAJU** to the **INDIAN INSTITUTE OF TECHNOLOGY, DELHI**, for the award of the degree of **DOCTOR OF PHILOSOPHY** in Electrical Engineering, is a record of bonafide research work carried out by him. He has worked under our joint supervision and guidance and has fulfilled the requirements for the submission of this thesis. The thesis, in our opinion, has attained the standard required for a **Ph.D.** degree of this institute. The results contained in this thesis have not been submitted elsewhere in part or full for the award of any degree or diploma.

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ABSTRACT

This Thesis deals with few important problems of power system studies viz. power flows, optimal power flows and environmental aspects.

Many power flow models have been proposed in the past. With the advent of sparsity techniques and optimal ordering of busses, the Newton-Raphson (NR) technique has relegated other power flow models to the back-ground. Original Newton model has undergone several changes to provide for faster and storage efficient models. One such method to speed up the solution process is to maintain the Jacobian constant throughout the solution process. However, these models also suffer from poor convergence when Q-limit enforcements are being done and requires re-factorization of the Jacobian due to bus-type switchings which is computationally expensive. Round about ways of Q-limit enforcements using compensation techniques have been tried out with little success as these indirect techniques are resulting in substantial increase of number of iterations for the adjusted solutions to converge thereby rendering these constant Jacobian power flow models less attractive. This problem is circumvented by Chang et al. using partial matrix re-factorization technique which is quite involved and requires higher degrees of programming skills to implement without which its full potential can not be realized. Moreover, if there are too many bus-type

switchings, the partial matrix re-factorization technique is not suitable and requires total re-factorization of the Jacobian.

In view of the problems mentioned above, an attempt is made to develop a simple and efficient compensation technique suitable for power flow models with Jacobian held constant. Due to this new compensation technique, the structure of the Jacobian is preserved throughout the iterative process irrespective of any number of bus-type switchings.

Also, an attempt is made to develop an efficient power flow model wherein the Jacobian is formed in the complex form unlike the usual real variable Jacobian without resorting to any decoupling principles. This model is shown to be memory efficient. In this model, another compensation technique is developed to enforce Q-limits at PV buses. This compensation technique preserves the structure of the complex Jacobian irrespective of any number of bus-type switchings.

Among the decoupled versions of power flow models, the most notable is the Fast Decoupled Load Flow (FDLF) developed by Stott and Alsac. Even though, this model is proved to be quite fast and memory efficient, it greatly suffers from poor convergence and some times does not converge for those systems having high r/x ratio branches. This is a serious limitation of the model. Several researchers have tried to understand the convergence properties of the FDLF model through analytical and experimental techniques without any major break through to make the classic FDLF model a general purpose one. This is due to the lack of understanding about the role played by the several network parameters such as line series resistances, line charging shunts and external shunts etc. involved in the formulations of [B′] and [B″] matrices. In this context, an attempt is made through an extensive experimentation to bring out clearly the role played by the several network parameters upon the convergence behaviour of the FDLF model. Subsequently, a general purpose Fast Decoupled Power Flow model is suggested suitable for both well-behaved and ill-conditioned networks.

Amongst various optimization techniques used for solving economic/optimal load dispatch problems, classical techniques are simpler and provide faster solutions. Classical co-ordination equations using B-coefficients are still widely used for economic load dispatch problems. Attempts have been made by Nanda et al. to extend the concepts of economic dispatch based on co-ordination equations to reactive power optimization also. They have used simpler new loss formulae where the loss coefficients are evaluated based on a perturbation technique exploiting the sensitivity properties of the Jacobian available at the end of a base case power flow. They however, did not consider transformer taps along with their operating constraints in their reactive power optimization model. These are very vital control parameters in reactive power optimization. In this context, an attempt is made to extend the Nanda et al.'s reactive power optimization model based on a set of co-ordination equations to take into account the transformer taps also along with their operating constraints. A new OPF model is proposed to minimize the total cost of generation and to minimize the total real power transmission loss so as to enhance the overall computational efficiency of the model. In this new model, the change in transformer tap is simulated by a fictitious Q-source and the exact quantity of Q-injection needed to control the bus voltage magnitude is computed a priori from the reactive power optimization problem. Eventually, these new optimal Q-injections are used to back compute the required optimal tap settings so as to necessitate for appropriate changes in Y-bus.

Linear Programming (LP) techniques applied to power system problems are gaining more attention in recent times due to their inherent good features of simplicity, ability to handle any number of system constraints effectively and speed of solution as compared to non-linear programming techniques. Most of the works based on LP techniques are either to solve the optimal power dispatch problems or to solve the optimal reactive power problem but not both at a time. Possibly only two published works - one by Chamorel and Germond and the other by Contaxis et al. have attempted to solve the twin problems of Optimal Power Flow (OPF) using the LP technique. The OPF model suggested by Contaxis et al. is computationally less efficient as it involves large number of intermediate power flow solutions and uses rigorous loss formulae requiring evaluation of loss coefficients which is quite involved and time consuming. They have also not considered transformer tap settings in their model which are so vital for any OPF solution. Moreover, the generalized generation distribution factors are used to express the line flow constraints which do not reflect accurate distribution of generations to various line flows due to several assumptions involved. In view of this, an attempt is made to overcome some of the deficiencies mentioned above and an iterative scheme is proposed with which the overall computational efficiency of the Contaxis model is enhanced without sacrificing the accuracy of the solution.

Keeping this in view, a new OPF model is proposed based on LP technique wherein a set of new simplified loss formulae are used. A set of New Generalized Generation Distribution Factors (NGGDF) are developed which are more accurate and no assumptions are involved. The new loss coefficients and the NGGDF are evaluated based on a perturbation technique exploiting the sensitivity properties of the Jacobian available at the end of a base case power flow.

In recent times, due to increased awareness and concern over the environmental pollution caused by fossil based electric power generating stations, operating at absolute minimum generation cost is no longer the only criterion to be followed in optimal real power dispatch. Hence, the problem area of OPF has taken a subtle twist to deal with environmental pollution aspects also. But, unfortunately very little work is being reported in the area of economic emission load dispatch problems (i.e. economic load dispatch considering pollution aspects also). Gent and

Lamont were possibly the first to report their work on minimum emission dispatch. Most of the works, even though few in number, are based on usual programming techniques based on a single objective approach. Nanda et al. tackled this problem by multi objective model using goal programming techniques. From the literature, it is not yet established with clear vision whether multi objective models or the conventional single objective models are best suited for the economic emission load dispatch problem even though minimization of cost and minimization of emission both conflict with each other.

In the light of the above, an attempt is made to explore the feasibility of developing a set of co-ordination equations with which the emission levels could be minimized and eventually to develop an OPF model dealing with environmental aspects also along with the loss minimization. Similarly an OPF model based on LP technique is presented which considers the environmental aspects also along with minimization of system loss on the lines of Contaxis et al. formulation. An attempt is made to develop another version of OPF model based on LP to deal with emission aspects wherein a set of simplified loss formulae are being used. Also the line flow constraints are expressed by a set of new generalized generation distribution factors which are proposed in this thesis.

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