NEW EFFICIENT TECHNIQUES FOR POWER SYSTEM ANALYSIS AND OPTIMIZATION

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by

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CERTIFICATE

This is to certify that the dissertation entitled '**New Efficient Techniques for Power System Analysis and Optimization**', being submitted by **Mr. Abheejeet Mohapatra** for the award of the degree of **Doctor of Philosophy** is a record of bonafide research work carried out by him in the Department of Electrical Engineering at Indian Institute of Technology Delhi, New Delhi.

Mr. Abheejeet Mohapatra has worked under our supervision and has fulfilled the requirements for the submission of this dissertation, which to our knowledge has reached the requisite standard. The results obtained here have not been submitted to any other University or Institute for the award of any degree.

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ABSTRACT

The research work presented in this dissertation discusses various complex issues associated with the day-to-day operation and planning of the power systems. The existing approaches in this respect need significant revision and, thus the work in this thesis primarily aims at developing new efficient approaches to serve this need. To this end, one of the important contributions in this dissertation is the new Optimal Power Flow (OPF) model. Linear programming techniques and Interior Point methods (IPM) have been extensively used for solving OPFs. Both have their merits as well as limitations. There are situations in which, when merits of both are combined, is desirable. Also, in view of the extremely large size of practical OPF problems, there has always been a need for improving the speed of the solution, without sacrificing its accuracy. This new, nonlinear, compact, efficient model of the OPF serves this purpose which is in incremental variables. Successive applications of this model shall lead to the same solution as in the original OPF problem. This model shall also allow for the speed-accuracy trade off, which may be useful in real time applications. It also removes the step size restrictions, so common in linear programming applications, due to the nonlinear incremental formulation.

Another important challenge in the history of OPFs has been the issue of efficient and optimal handling of discrete variables in OPFs of transmission as well as distribution systems. This thesis, thus, presents an approach for handling discrete variables, i.e. transformer taps and shunt capacitors, in OPFs. For transmission systems, power flow sensitivity based approach has already been proposed for this purpose. However, these are not so reliable under stringent operating conditions. Rather, sensitivities based on the Hessian of OPF are more meaningful in these situations. The proposal for handling

discrete variables in OPFs of a transmission system is, thus based on the use of Hessian based sensitivities obtained from the popular IPM. In the context of distribution systems, an efficient hybrid approach for Volt/ Var Control (VVC) with switching limits on taps and shunts has also been proposed. Since the problem is non-deterministic polynomial hard and combinatorial with huge solution space, meta-heuristic techniques, have been extensively used. These, however, are computationally expensive. The proposed approach combines the strengths of a gradient technique and a meta-heuristic technique. The primary aim, here has been to reduce the number of power flow executions required for each chromosome in the meta-heuristic technique, by developing two simple yet important bounds on the control combinations.

Another type of discrete variable in the context of Unit Commitment (UC) is the binary unit status of the generations. Consequently, an efficient approach for the solution of the UC problem through the use of classical OPF based sensitivities has also been presented. Traditional methods for UC have been the meta-heuristic algorithms, Lagrange relaxation, dynamic programming or the mixed integer programming techniques. These, however, have been computationally expensive and generally provide sub-optimal solutions. The proposed approach shall be extremely efficient and will provide optimal solution to the UC problem.

Line and generator outages pose security threats for a power system. Coordinated preventive and corrective rescheduling actions attempt to make the system correctively secure with respect to these detrimental contingencies. This is an iterative process and is also computationally onerous. The research work in this dissertation, thus attempts to reduce this computational burden in a twofold manner: firstly, by developing an OPF index based method for the quick identification of the infeasible post contingencies and secondly, by reducing these indices for the identified infeasible contingencies in a preventive rescheduling manner. Hence, a non-iterative Primal-Dual IPM (PDIPM) based OPF approach, requiring only one common pre-contingency Hessian factorization in all the critical contingencies, is proposed for the fast identification of infeasible outages. The preventive OPF, thus performed shall also be efficient as indices for identified infeasible contingencies are used as constraints and full OPF solutions for all critical post contingencies are completely avoided.

Different types of uncertainties exist in the system data. OPF, being an important tool in system planning and operation, is also no exception. The data required for such a study, is rarely available with complete certainty. The nature of the uncertainty in the cost characteristics of the generators, network parameters, load model coefficients, and limits on bus voltages, line flows and real and reactive generations, is generally of non-probabilistic type. Boundary value representation has been useful in such situations. These represent extreme bounds of a variable, in the fuzzy set. This thesis, thus also attempts to find boundary OPF solutions of the critical variables and functions of concern, corresponding to multiple input data uncertainties. Since, the boundary OPF greatly depends on Hessian based sensitivities, a detailed sensitivity analysis of the OPF has also been presented. Such boundary solutions could be of immense value to the planners and the market players.

Another contribution in this dissertation has been an efficient novel Hessian based sensitivity approach for assessment of impact of these above discussed uncertainties in the Multi-objective Optimization (MO). The approach aids in robust decision making. The MO problem considered, here is the environmental economic dispatch problem. The two objectives, i.e. emission and economic cost, are continuous convex functions. The uncertainties considered are those in system parameters such as loads (or injections) and limits on line flows, bus voltage magnitudes etc. These uncertainties are assumed to be of fuzzy type, more specifically in an interval. The results obtained provide interesting insights on how the uncertainties can affect decision making in a MO framework.

Line or generator outages, errors in load forecasts and the forecasts of the renewable energy source generations are generally represented as probabilistic uncertainties. Load model coefficients and the network parameters, on the other hand, are best represented as interval uncertainties. Irrespective of the nature of these uncertainties, all of them need to be considered in an integrated manner for proper system analysis. This thesis also tries to fulfill this precise need in the context of handling multiple types of uncertainties in a power flow. By utilizing the proper synergy of the boundary and probabilistic power flow algorithms, development of the efficient line outage simulation and the use of constant Jacobian approach, the computational burden have been kept to a manageable level. It is also applicable for both transmission and distribution systems.

The proposed methodologies have been extensively tested on multiple test systems and the detailed discussions on results from various case studies have been presented. The results on these test systems illustrate the effectiveness and the efficacy of the proposed approaches and provide insights into the nature of the problem.

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