

**IMPROVEMENTS IN ENERGY AND
ANCILLARY SERVICES OPTIMIZATION IN
ELECTRICITY MARKETS**

by

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CERTIFICATE

This is to certify that the thesis entitled, “**Improvements in Energy and Ancillary Services Optimization in Electricity Markets**” being submitted by **Mr. Surender Reddy S** 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 of Indian Institute of Technology Delhi.

Mr. Surender Reddy S has worked under our guidance and supervision and has fulfilled the requirements for the submission of this thesis, which to our knowledge has reached the requisite standard. The results obtained here in 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 thesis discusses various complex issues associated with energy and ancillary services markets in deregulated power systems. The aim is to provide some improvements, accommodate new-market related dimensions to the market clearing procedures. One of the important improvements handled in this thesis is the voltage dependent load models. Use of realistic voltage dependent load models is important in power system analysis and optimization. The importance of voltage dependent load models on energy, reactive power and demand-side reserve markets has been established in this thesis. It emphasizes the need for selecting judiciously, a combination of objectives best suited for a given operating condition.

The integration of stochastic weather-driven power sources has resulted in larger uncertainties that need to be met by dispatchable generation. The concerns brewing up over fossil fueled generating plants and their part of play in global warming has pushed energy based research towards utilization of green energy around the globe. With the greater integration of renewable electricity generation like wind and solar photovoltaic power into existing grids, research efforts must be devoted to formulate generation scheduling problems taking into account the intrinsic variability and non-dispatchable characteristics of these resources. The random nature and large scale integration of renewable sources into power system poses challenges to system operators and planners. Further, future load is also uncertain and can not be predicted accurately. This thesis addresses some of the challenges posed by such generation to the system and market operation.

System Operators are responsible for ensuring a secure, reliable and efficient electricity system, and in that context, for ensuring the availability of all necessary ancillary services. Spinning reserve is one of the most important ancillary service used by the system operators to respond to sudden generation/ line outage, load increase or both. In recent years, a massive focus has been made on fostering demand response programs aimed at ancillary service provision. Whilst providing large amount of reserve hedges the system

against a larger spectrum of contingencies, this is unpractical, since the reserve comes at a cost, and this ideally should be kept at a minimum. System operators should therefore balance the costs of providing reserve, versus the risk of having to shed load as a consequence of contingency. This thesis proposes energy and spinning reserve market clearing mechanism for wind-thermal power system, considering uncertainties in wind power and load forecasts. For this, two different market models are investigated. One model includes reserve offers from the conventional thermal generators, and the other includes reserve offers from both conventional thermal generators, and demand/consumers.

Subsequently, the thesis proposes a market clearing mechanism which explicitly takes into account the impact of uncertainties in wind power generation and load forecast. Since, the market clearing is a multi-settlement process: day-ahead and real time, a strategy is proposed that provides ‘best-fit’ day-ahead schedule, which minimizes the twin (both day-ahead and real time adjustment) costs/maximizes social welfare, under all possible scenarios in real time. This two stage optimization strategy consists of a genetic algorithm based day-ahead market clearing and a two point estimate based probabilistic real time optimal power flow. The former generates sample schedules with respect to which, the latter provides mean adjustment costs.

Further, the thesis proposes an optimal dynamic reserve activation plan after the occurrence of an emergency situation (generator/ transmission line outage, load increase or both). An optimal plan is developed to handle the emergency situation, using coordinated action of fast and slow reserves, for secure operation, with minimum overall cost. It considers the reserves supplied by generators (spinning reserves) and loads (demand-side reserves). The optimal backing down of costly/fast reserves and bringing up of slow reserves in each sub-interval, in an integrated manner, is proposed.

Real time economic dispatch is performed every 5 to 15 minutes with the static snapshot forecast data. During the period between two consecutive schedules, generators participate in managing power imbalance, based on participation factors from previous economic dispatch. In modern power system with considerable renewable energy sources

that have high variability, this conventional approach may not adequately accommodate the economic implication of the said variability. This thesis proposes evaluation of ‘best-fit’ participation factors by taking into account the minute-to-minute variability of solar, wind and load demand, for a scheduling period. Since ‘best-fit’ participation factors are evaluated only once, i.e., at the start of scheduling interval, the dimensionality of optimization problem remains the same as that of conventional approach. The proposed approach is suggested for sequential as well as dynamic variants.

The market clearing methods proposed in this thesis require optimal power flow (OPF) to be carried out. To make it efficient, an appropriate optimization algorithm is required for adjustment of control variables in OPF. The main drawback of evolutionary based OPF is the excessive execution time due to large number of power flows required in the solution process. In this thesis, an efficient approach for evolutionary algorithm based OPF is proposed.

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

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