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Day-Ahead and Real Time Optimal Power Flow considering Renewable Energy Resources

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ABSTRACT

In practice, the Real Time Optimal Power Flow (RT-OPF) is performed in every 5–15 min intervals, and the Day-Ahead Optimal Power Flow (DA-OPF) is performed in every 1 h intervals with the static snapshot forecast data. During the period between two consecutive schedules, the generators participate in managing power imbalance, based on participation factors from previous Economic Dispatch (ED)/Optimal Power Flow (OPF). In modern power system with considerable Renewable Energy Resources (RERs) that have high variability, this conventional approach may not adequately accommodate the economic implication of the said variability. This paper proposes the evaluation of 'best-fit' participation factors by taking into account the minute-to-minute variability of solar, wind and load demand for RT-OPF, and every 15 min variability for DA-OPF, over a scheduling period. The voltage, reactive power limit and line flow constraints are included for all minute-to-minute sub-intervals for RT-OPF and for every 15 min sub-intervals for DA-OPF. From the system security point of view, voltage stability index is calculated in DA-OPF and RT-OPF approaches. 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. IEEE 30 bus system is used to test the effectiveness of the proposed approach in terms of system security and economical benefit.

Introduction

High on the list of national priorities for national security and economic development is the reduction of the nation's dependence on foreign oil importation. Climate change has also been acknowledged by the present administration as a factor that will greatly influence the future and viability of the nation. Providing solutions to these two challenges is therefore of urgent national interest. Renewable Energy Resources (RERs) such as solar photovoltaic (PV) and wind energy generation have made very rapid progress in the past few years. Optimum application of RERs will help reduce national dependence on the importation of foreign oil, and help reduce the environmental and economic effects of climate change. An important problem associated with the incorporation of RERs is that the future solar irradiation/wind speed is an unknown at any given time. A perfect forecast eliminates uncertainty, but there is still variability. For perfect forecasting cases, the only possibility of imbalance is variability, occurring within the time resolution of the scheduling period. Balancing generation and load instantaneously and continuously is difficult because loads and generators are constantly fluctuating [1].

As a result of varying wind speed and solar irradiation, wind and solar plants generate varying amounts of electricity. The intermittent nature of wind and solar power represents a challenging constraint on power system operators, as supply and demand need to be continuously balanced in real time (RT). The System Operator (SO) needs to not only procure sufficient fast resources, spread over the entire system, but also schedule them appropriately. Hence, compared to managing just the load variability, managing additional, large scale, renewable generation variability, involves considerable generation costs. The operational costs of electricity systems increases, because system operators are required to secure additional operating flexibility on several time scales to balance fluctuations and uncertainties in wind/solar PV power output. Therefore, the presence of any intermittent/renewable source of power, increases balancing requirement and associated costs [2]. Because of wind and solar variability, there has been wide spread interest in quantifying the increase in ancillary services required to integrate wind and solar over various time scales [3].

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Nomenclature

a_i, b_i, c_i	cost coefficients of ith thermal generator
d_j	direct cost coefficient of jth wind farm
e_k	direct cost coefficient of kth solar photovoltaic (PV) plant
G_{ij}, B_{ij}	transfer conductance and susceptance between buses i and j
n	number of buses in the system
N_G	number of generators
N_T	number of transformers
N_{sh}	number of shunts
N_{int}	number of intervals
N_{sub}	number of sub-intervals
P_{Gi}	scheduled power from ith conventional thermal generator (MW) in interval 'T'
P_{Gi}^{T-1}	power output of ith conventional thermal generator (MW) in previous interval '$(T-1)$'
P_{Di}	forecasted real power demand in interval 'T'
P_{Wj}	power output from jth wind farm (MW)
$P_{S,k}$	power output from kth solar PV plant (MW)
$p_{r,j}$	rated wind power from jth Wind Energy Generator (WEG)
$P_{S,k}^{max}$	maximum power output from kth solar PV plant
p	WEG power output
p_s	solar PV power output
Q_{Di}	forecasted reactive power demand in interval 'T'
$R_{Gi}^{up}, R_{Gi}^{down}$	ramp up and ramp down limits of conventional thermal generators (MW/hr)
t	sub-interval (1 min) index for Real Time Optimal Power Flow (RT-OPF)
T	interval (10 min) index for RT-OPF
dt	sub-interval (1 h) index for Day-Ahead Optimal Power Flow (DA-OPF)
dst	sub-sub-interval (15 min) index for DA-OPF
V_{Dk}	load bus voltage magnitude
V_i, V_j	voltage magnitudes at bus i and bus j
δ_i, δ_j	voltage angles at bus i and bus j

The power outputs from RERs can change significantly within short amount of time. Introducing dynamic dispatch can better manage the ramp capability of dispatchable resources for the volatility of renewable generations. Day-ahead Dynamic Economic Dispatch (DED) determines the optimal settings of generator units with predicted load demand over the scheduling period. The objective is to operate an electric power system most economically while the system is operating within its security limits. The DA-OPF under vertically integrated power system is a tool to schedule online generators in order to meet the forecasted demand and reserve requirements at least cost. In unbundled system, the objective would be profit maximization, and the DA-OPF results can be used for building successful bids. In deregulated environment, the GENCOs are not obliged to meet the demand and can sell lesser quantities if higher profits can be realized. Traditionally, real time Security Constrained Economic Dispatch (SCED) provided by the Independent System Operators (ISOs) solves energy dispatch and/or ancillary service clearing for one target interval. Real time SCED inputs include demand forecast, net scheduled interchange and forecast of intermittent resource outputs, such as wind and solar, for the target interval.

A new hybrid methodology for solving DED is deployed in [4] in such a way that a simple evolutionary programming is applied as a based level search, which can give a good direction to the optimal global region, and a local search sequential quadratic programming is used as a fine tuning to determine the optimal solution at the final. A fuzzy-optimization approach to DED, considering the uncertainties in deregulated energy and reserve markets is presented in [5]. A Real-Time Economic Dispatch (RTED) algorithm suitable for on-line generation control and for study programs is presented in [6]. This method is based on the rules of linear programming and the classical method of merit order loading. A novel approach that combines abductive reasoning network and a technique for order preference by similarity to ideal solution decision approach to achieve real-time economic emission power dispatch, and the best compromise solution is described in [7]. An Optimum RTED/RT-OPF approach should consider all the operational costs involved, as accurately as possible, without making the optimization unduly complex, and computationally inefficient from implementation point of view. With the present state of art, in real time, energy, reserve and regulation markets are cleared simultaneously or sequentially, typically at 5 min intervals, depending on the individual market structures [8].

The characteristic of the predicting accuracy of wind power that decreases with the lapse of time will seriously impair the reasonableness of day-ahead scheduling, and bring about heavy burden for regulation services which are provided by automatic generation control (AGC). It is necessary to consider linking up day-ahead scheduling and AGC on the time scale by more meticulous generation dispatch modes [9]. A new framework using adaptive robust optimization for the economic dispatch of power systems with high level of wind penetration is presented in [10]. In [11], wind energy generators are being considered in multi-objective day-ahead dynamic economic emission dispatch problem which minimize total fuel cost and emission, simultaneously.

To the best of authors knowledge, all the approaches for RT-OPF and DA-OPF consider frozen static snapshots of power system at 5–15 min intervals and 1 h sub-intervals, respectively. The variable generation cost between two consecutive scheduling intervals is ignored in this optimization. The motivation in this paper is to accommodate these aspects at suitable discrete sub-intervals (say 1 min for RT-OPF and 15 min for DA-OPF) for which the load and renewable power generation forecast information/data is available.

During the RT-OPF scheduling interval (say 10 min) and DA-OPF scheduling interval (say 1 h), the regulating generators share the power imbalance as per their participation factors (PFs) evaluated at the base point generations. This paper proposes a method that considers security and variability cost of RERs between two consecutive scheduling intervals. In the proposed approach, the evaluation of these 'best-fit' PFs is based on the security and total cost of energy over the entire RT-OPF interval, consisting of 1 min discrete sub-intervals, and over the entire DA-OPF interval, consisting of 15 min discrete sub-intervals. All the relevant constraints including generation rate constraint (GRC) are considered in both DA-OPF and RT-OPF approaches. All the DAED and RTED approaches proposed in the literature, do not considers the voltage, reactive limit and line flow constraints in the every 15 min and minute-to-minute time domains, respectively, because of computational difficulties. The highlight of the proposed approach is that the optimization is done only once at the start of scheduling interval, and the 'best-fit' PFs are evaluated from this optimization. Therefore, the dimensionality of optimization problem, and the implementation remains the same as that of conventional approach.