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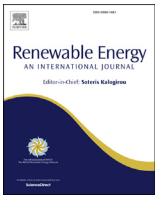

A heuristic methodology to economic dispatch problem incorporating renewable power forecasting error and system reliability

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ABSTRACT

With the constant increment of wind power generation driven by economic and environmental factors, the optimal utilization of generation resources has become a critical problem discussed by many authors. Within this topic, determination of optimal spinning reserve (SR) requirements is a key and complex issue due to the variable and unpredictable nature of renewable generation besides of generation unit reliability. Cost/benefit relationship has been suggested as a way to determine the optimal amount of power generation to be committed by taking into account renewable power forecasting error and system reliability. In this paper, a technique that combines an analytical convolution process with Monte Carlo Simulation (MCS) approach is proposed to efficiently build cost/benefit relationship. The proposed method uses discrete probability theory and identifies those cases at which convolution analysis can be used by recognizing those situations at which SR does not have any effect; while in the other cases MCS is applied. This approach allows improving significantly the computational efficiency. The proposed technique is illustrated by means of two case studies of 10 and 140 units, demonstrating the capabilities and flexibility of the proposed methodology.

1. Introduction

Besides of their remote and isolated location, insular systems have high operating costs due to their fuel consumption and the costs related to its transportation. In most of cases, power generation is based on steam turbines (STs), combined cycle gas turbines (CCGTs), diesel engines (DEs), open cycle gas turbines (OCGTs), and renewable sources (REN); a representative example is the case of Canary Islands, at which STs represent 22.4%, CCGTs represent 28.8%, DEs represent 17.7%, OCGTs represent 20%, REN represent 10%, while cogeneration and other power sources represent 1% of the total installed capacity [1]. However, most of these systems have good potential for exploitation of renewable energy sources like solar and wind energy; a representative situation is the case of Cyprus, where grid parity for installation of photovoltaic (PV) generation has been reached due to the high selling prices of energy and the considerable reduction in the prices of PV panels [2]. Under these circumstances, it is expected a strong growth of renewable generation in the next years; however, the variability and uncertainty related to renewable generation is an important factor, which limits the integration of these sources to the grid. Variability of renewable generation impacts spinning reserve (SR) requirements and the utilization of renewable generation. In the case of mainland power grids; by one hand, primary reserves could increase between 0.3% and 0.8%, while all other reserves could increase between 6% and 10% of the corresponding installed wind power generation. On the other hand, conventional generators could reduce their efficiency up to 9% [3]. A way for solving this problem consists on improving the flexibility of the system by adding an energy storage system (ESS); however, its successful integration since an economic point of view strongly depends on capacity tariffs, wind power potential and investments costs [4]. Another option consists on implementing a demand response (DR) program; a reference case is the Canary Islands, where cost savings related to the implementation of DR program are estimated up to 30% [5]. However, the success of any DR program depends on awareness and knowledge of the consumers as well as the automation of household appliances. Other inexpensive option consists

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Nomenclature

s	Index for discretization levels of normal standard PDF $s\varepsilon[1,S]$
q	Index for discretization levels of wind power PDF $q\varepsilon[1,Q]$
p	Index for discretization levels of thermal power PDF $p\varepsilon[1,P]$
n	Index for generation units $n\varepsilon[1,N]$
m	Number of failure events of a determined unit $m\varepsilon[1,M]$
a	Index for discretization levels of FCC PDF $a\varepsilon[1,A]$
h	Index for discretization levels of initial power generation
t	Index for time step
M	Number of MCS trials
f_W	Discretized Weibull PDF
f_R	Discretized Wind power PDF
f_G	Discretized PDF of power generation loss (Convolution)
f_M	Discretized PDF of power generation loss (MCS)
$f_{IPG,n}$	Discretized PDF of initial power generation of unit n
f_C	Discretized PDF of FCC
F_N	Standard normal CDF
F_W	Weibull CDF
F_G	Discretized CDF of power generation loss (Convolution)
$F_{IPG,n}$	Discretized CDF of initial power generation of unit n
ΔWP	Discretization step of wind power PDF
ΔTPG	Discretization step of thermal power PDF
ΔFCC	Discretization step FCC PDF
WS_s	Value of discretization levels of Weibull PDF
TPG_p	Value of discretization levels of thermal power PDF
FCC_a	Value of discretization levels of FCC PDF
WP_q	Value of discretization levels of wind power PDF
TPG^{max}	Maximum thermal power production
TPG^{min}	Minimum thermal power production
FCC^{max}	Maximum value of FCC
FCC^{min}	Minimum value of FCC
$WPG(\cdot)$	Function to estimate the power production of wind farm
v	Value of a determined wind speed velocity
R_p	Rated power of a single wind turbine of the wind farm
N_t	Number of wind turbines of the wind farm
α, β, σ	Parameters of the function $WPG(\cdot)$
v_i	Cut-in wind speed of wind turbine
v_r	Rated wind speed of wind turbine
v_o	Cut-off wind speed of wind turbine
FOR_n	Failure outage rate of unit n
$E\{\cdot\}$	Function to estimate expect value of a determined variable
λ	Intermediate discretization parameter
μ_s	Intermediate distribution of the transformation process
$\emptyset_s$	Value of discretization levels of normal standard PDF
ω_s	Central value of discretized level WS_s
ξ_h	Discretization interval of CDF of initial power generation
$IPG_{n,h}$	Initial power generation of unit n and interval ξ_h
I_n	Intermediate variable for $E\{ENS_t\}$ and $E\{FCC_t\}$ calculation
Φ_h	Weight associated with the values $IPG_{n,h}$; $n\varepsilon[1,N]$
L_t	Load demand at time t
$G_{t,q,n,h}$	Thermal power of unit n at time t considering WP_q and $IPG_{n,h}$
$G_{min,n}$	Minimum generation of unit n
$G_{max,n}$	Maximum generation of unit n
UR_n	Ramp-up limit of unit n
DR_n	Ramp-down limit of unit n
$WPD_{t,q,h}$	Wind power dispatched at time t considering WP_q and $IPG_{n,h}$
$NL_{t,q,h}$	Net load at time t considering WP_q and $IPG_{n,h}$
$l_{t,q,h}$	Maximum power of thermal units at time t considering WP_q and $IPG_{n,h}$
$ENS_{t,q,h}$	ENS at time t considering WP_q and $IPG_{n,h}$
η_q	Weighted values of ENS according to wind generation
τ_h	Weighted values of ENS according to initial power generation
θ_h	Weighted values of FCC according to initial power generation
ENS_t	ENS at time t
FCC_t	FCC at time t
$VOLL$	Value of loss load
TGC	Total generation cost
FCC	Fuel consumption cost
ENS	Energy not supplied

on improving the quality of renewable power forecasting in order to reduce total generation costs, reduce renewable power curtailment, and reduce the commitment of OCGTs [6]. Nevertheless, it is not possible predicting renewable power generation perfectively; besides of this, improvements on forecasting tools has a limited enhancement on power system performance [7]; so that, incorporation of mathematical models for renewable power generation to solve economic dispatch (ED) and unit commitment (UC) problems to estimate the amount of SR required is a critical necessity.

SR requirements could be determined by using a traditional approach based on the solution of deterministic UC problem, solving stochastic UC problem taking into account failures and contingencies of generating units; as well as, wind power forecasting error, incorporating a probabilistic constraint on UC problem based on estimating the probability of load curtailment as a consequence of any contingency, and analysing the cost/benefit relationship [8]. In the traditional approach, SR requirements are adjusted so that the system be able to face the failure of the generation unit with highest capacity among the committed generators plus a determined margin based on the amount of wind power forecasted [9]. Then, deterministic UC problem constrained to the SR requirements aforementioned is solved typically using mixed-integer linear programming (MILP) optimization approach, some formulations widely suggested in the literature can be found in Refs. [10–12]. Another way consists on represent the uncertain nature of any contingency and wind power generation by means of a representative set of scenarios relaxing the constraint related to the SR requirements in the mathematical formulation. As any potential contingency and wind power generation condition is represented explicitly by means of the scenario set, the corresponding amount of SR could be implicitly determined by solving stochastic UC problem. Generation of the required scenario set could be carried out by using Monte Carlo Simulation (MCS) approach in combination with a scenario reduction technique [13]. Several