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Smart real-time scheduling of generating units in an electricity market considering environmental aspects and physical constraints of generators

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HIGHLIGHTS

- Considering several physical and environmental constraints of generating units.
- Proposing a hybrid method based on LSSVM-CA3 for solving the CEED problem.
- Real-time scheduling of generating units in electricity spot markets.
- A holistic optimization method for real-time prediction in a dynamic environment.

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ABSTRACT

Optimal scheduling of generating resources plays a significant role as a decision-making tool for power system operators in the liberalized and real-time electricity spot markets. The real-time scheduling of generating units will become a very complex task with respect to the instantaneous fluctuation of the load demand due to several demand response scenarios in the smart grid context. In this study, a hybrid mathematical method for the online scheduling of units based on the least square support vector machine (LSSVM) and the third version of cultural algorithm (CA3) has been presented, where the CA3 has been specifically employed to tune the adjusting parameters of LSSVM. For the training purpose of the proposed method, the optimal scheduling of the daily load curve for four different test systems and various physical and environmental constraints of generating units have been prepared by using a modified mixed integer quadratic programming (MIQP) to deal with non-convex behaviors of the test systems. A mean squared error (MSE) objective function has been used to reduce the prediction errors during the training process to enhance the precision and reliability of the results. A radial basis function (RBF) and the proposed LSSVM-CA3 were used to check the convergence process. A high accuracy of generator schedule predictions are demonstrated by comparing the results of the proposed method with those of artificial neural networks. From the results, it can be inferred that the method is highly compatible for real-time dispatching of generation resources in deregulated electricity markets.

1. Introduction

Due to deregulation of power systems, it is vital to operate the power grid with the highest possible degree of reliability and economy to enhance the competition of power plants in liberalized electricity markets. This problem can be solved by the economic load dispatch (ELD) problem through a set of sophisticated computational skills which tackle different power grid constraints [1]. The aim of the ELD problem is to define the optimal scheduling of generating units which minimizes the total generation cost while all the operational constraints and the load demand are satisfied. This task can be very challenging when considering the environmental aspects of conventional generators, such as coal, oil and natural gas units. The reduction of fossil-fuel based generation resources and the improvement of their energy efficiency is a foremost priority of the energy roadmaps in many countries worldwide [2]. In

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Nomenclature

Indexes

ANN	artificial neural network
CA3	third version of the cultural algorithm
CEED	combined environmental economic dispatch
CF	cost function
KKT	Karush-Kuhn-Tucker
LSSVM	least square support vector machine
MSE	mean squared error
MAE	mean absolute error
NRMSE	normalized root mean squared error
RBF	radial basis function
RMSE	root mean squared error
PF	penalization factor
PPF	price penalty factor
POZ	prohibited operating zone
SVM	support vector machine

Variables

a_i, b_i, c_i	fuel cost coefficients of unit i
$\alpha_i, \beta_i, \gamma_i, \eta_i, \delta_i$	emission cost coefficients of unit i
d_i, e_i	fuel cost coefficients of unit i regarding valve-point effects
$B(t)$	belief space of cultural algorithm
$F_{ct}(P_i^t)$	total CEED generation cost at time t
$f_{emc}(P_i^t)$	emission cost function at time t
$f_{gc}(P_i^t)$	generation cost function at time t
$h_i^{max-max}$	max-max price penalty factor
$I_j(t)$	closed interval of $N(t)$
l, u	the lower and upper bound which are initialized by the domain values
$L_j(t)$	score of the lower bound at $N(t)$
N_G	number of generating units
$N(t)$	normative knowledge component of the cultural algorithm
N_{ij}	a normalized number for individual i and component j
n_s	number of variables of the situational component
n_x	number of variables of the normative component
nz_i	number of prohibited zones for unit i
ψ	sets of units with POZ
Ψ	sets of units with S_R
P_i^t	power output of unit i at time t
P_D^t	load demand of the system at time t
P_i^0	previous output power $(t-1)$
$P_{i,1}^L$	lower bound of unit i at the first prohibited zone i
P_i^{min}, P_i^{max}	minimum and maximum generation limits of the ith generating unit
$P_{i,m}^L, P_{i,m-1}^U$	lower and upper bound of the mth prohibited zones of unit i
$P_{i,N_i^{pz}}^U$	the last upper bound of the nzth prohibited zones of unit i
$S(t)$	situational knowledge component of the cultural algorithm
S_i^t	spinning reserve from unit i at time t
S_R	total system spinning reserve requirement
S_i^{max}	maximum spinning reserve contribution of unit i
δ_j	step size of the belief interval
$\delta_j^2(t)$	the variance of normalized number N_{ij}
$U_j(t)$	score of the upper bound of $N(t)$
UR_i, DR_i	up and down ramp rate limits of unit i
$X_j(t)$	dimension of belief space at component j
$X_l(t)$	an accepted response
$x_{ij}(t)$	the mean of normalized number N_{ij}
$x_{lj}(t)$	an accepted response of the component j
$\acute{x}_{ij}(t)$	influence function
$x_j^{min}(t), x_j^{max}(t)$	minimum and maximum boundary of the closed interval at generation t
$\hat{y}(t)$	best individual of the solution vector

addition, conventional generators may have physical constraints, such as prohibited operating zones (POZs) which is associated with their steam valve operation or any vibration in their shaft bearings. The operating area of generating units that have POZs can be divided into a number of feasible sub-regions. This issue converts the classical ELD problem into a non-convex and nonlinear problem with discontinuous operating zones, where the problem simultaneously requires the minimization of the total generation cost and the emission level while maintaining the equality and inequality constraints of the system [3]. The new resulting problem is called combined environmental economic dispatch (CEED). Classical approaches, such as the gradient method, linear programming, the lambda iteration method, quadratic programming, the base point and participation factors method, and the Lagrange relaxation algorithm, have substantial difficulty in dealing with the CEED problem [4]. New types of deterministic optimization algorithms with the inclusion of modification techniques such as mixed integer programming, nonlinear programming algorithm and dynamic programming for solving the CEED problem have been presented [5]. As the CEED problem is the main subroutine of a bigger problem, the so-called unit commitment (UC), and lots of valuable contributions with respect to deterministic optimization algorithms have been made in this area. Therefore, it would be appreciated to tackle some of the recent innovative solutions for the UC and its applications. Koltsaklis et al. [6] presented a generic mixed-integer linear programming (MILP) which incorporates a unit commitment solution for daily energy planning with a long-term generation expansion framework with several system considerations including ramping limits, system reserve requirements, renewable penetration limits as well as the CO_2 emission effects of conventional generation resources. The same authors developed a mid-term energy planning (MEP) model through a unit commitment model for generation and transmission system planning with an ability to perform a day-ahead electricity market calculation for yearly basis. Their proposed method is capable of quantifying the effects of different costs on the day-ahead electricity market and the energy mixture of the system [7].

Niknam et al. [8] proposed a new mathematical solution for the UC problem based on benders decomposition where the solution divides the UC into a master problem and a sub-problem. They have tried to solve the master problem with help of the mixed integer optimization where a non-linear optimization has been assigned to take care of the sub-problem. Simoglou et al. [9] presented a new 0/1 MILP formulation for the self-scheduling of thermal generation resources in the co-optimized energy and reserve day-ahead markets where the generating units start-up cost has been divided into three subcategories as hot, warm and cold through to each predefined power output trajectories. Delarue et al. [10] investigated the effect of uncertainty of the load and wind generation on the multi-day ahead UC where they have