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Multi-objective dynamic economic and emission dispatch with demand side management

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ABSTRACT

This paper proposes a combined model of Multi-Objective Dynamic Economic and Emission Dispatch (MODEED) with Demand Side Management (DSM) to investigate the benefits of DSM on generation side. This model considers a day ahead based load shifting DSM approach. In order to analyse the effect of DSM on the generation side, the objectives of dynamic economic and emission dispatch problem were minimized individually and simultaneously with and without DSM. A test system with six thermal generating units was considered for the validation of the proposed method. In this paper, authors used Multi-Objective Particle Swarm Optimization (MOPSO) algorithm to minimize the objectives of MODEED problem simultaneously. The simulation results of the MOPSO algorithm have also been compared with the non-dominated sorting genetic algorithm (NSGA-II). It is clear from the results that the proposed combined model is able to give benefits to both utilities and generating companies.

1. Introduction

Nowadays the electric power markets are showing more attention to the demand side management programs because of the exciting benefits such as system peak reduction, financial savings to the utilities and consumers, efficient utilization of network infrastructure, proper load profile improvement. DSM helps not only utilities and consumers but also provides impressive benefits to generating companies too [1,2]. DSM implementation in the existing electric power grids requires the latest information and communication technologies. By using these technologies, a two way communication is established between the power supplier and consumers. Central energy consumption controller and smart meters are the main devices for their dynamic communication [3,4].

Dynamic pricing policies like Time of Use (ToU) pricing, critical peak pricing, real time pricing, off peak low pricing and day ahead pricing are the smart pricing tools for the process of DSM implementation [5–7]. Incentive based DSM which involves more participants reduces the system peak demand and improves the load profile shape [8]. According to literature, the three DSM categories such as environmentally driven type, network driven type and market driven type are generally used. The environmental driven DSM mainly focuses on the social and environmental standards like reduction of greenhouse gas emission. The network driven type aims in maintaining the reliability of the system and the market driven type targets the financial savings of the utilities and consumers [9–11]. In [12], a day-ahead based load shifting DSM technique was implemented in a smart grid environment with the help of a heuristic algorithm. The real time pricing based energy control strategy was developed in [13] to manage the peak load demand. An energy management algorithm was proposed in [14] to achieve the pricing strategies and operating states of consumers.

The dynamic economic and emission dispatch (DEED) is a crucial optimization problem in the power system operation and control. DEED problem gives the on line generating schedules over a certain predicted load demand period by minimizing cost and emission simultaneously. The generation cost function with valve point loading effect is modelled as a non convex function which has multiple local minima. This dynamic optimization problem has to satisfy many constraints like equality, inequality and ramp-rate limits throughout the dispatch period [15–17]. DSM problem which handles the demand side is also considered as an optimization problem. DSM program should be implemented with a large number of controllable devices and each device has different consumption patterns. So, the evolutionary algorithms are preferably used to handle the such type of complexities [12].

In literature, many meta heuristic based optimization techniques have been proposed to solve the Dynamic Economic Dispatch (DED) problem. For example, the Enhanced Genetic Algorithm (E-GA) and Enhanced Differential Evolutionary (E-DE) algorithms were proposed for DED problems in [18]. In [19], the combination of GA and DE was used to solve the DED problem with different generating unit combinations like hydro-thermal, solar-thermal and wind-thermal. Enhanced PSO based DEED problem with wind uncertainties was proposed in [20]. Nowadays, the focus is mainly moving towards the combination of DED and DSM

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Nomenclature

$C_{g,t}(P_{g,t})$	fuel cost function during the time interval t
$E_{g,t}(P_{g,t})$	emission function during the time interval t
$P_{g,t}$	power output of g^{th} generating unit at the t^{th} time interval
G	total number of generating units
τ	total number of dispatch intervals
a_g, b_g, c_g	fuel cost coefficients of g^{th} generating unit
d_g, e_g	coefficients for the valve point loading effect of g^{th} generating unit fuel cost function
γ_g, β_g, α_g	emission coefficients of g^{th} generating unit
ξ_g, λ_g	coefficients for the valve point loading effect of g^{th} generating unit emission function
$P_{D,t}$	total load demand power at t^{th} time interval
$P_{L,t}$	total transmission power losses at t^{th} time interval
$P_g^{\min}$	minimum real power output of g^{th} generating unit
$P_g^{\max}$	maximum real power output of g^{th} generating unit
UR_g	ramp up limit of g^{th} generating unit
DR_g	ramp down limit of g^{th} generating unit
$\psi(t)$	load demand value after DSM scheduling at the time instant t
$\zeta(t)$	targeted load demand value at the time instant t
$FL(t)$	forecasted load demand value at time instant t
$CL(t)$	connected load demand at time interval t
$DL(t)$	disconnected load demand at time interval t
N	total types of controllable appliances
X_{lit}	number of l type controllable appliances which are shifted from i to t time slot

optimization. The impacts of Demand Response (DR) program on the Unit Commitment (UC) problem were investigated in [21]. In [22], the UC problem with the economic and environment DR program was proposed. In [23], a GA based DED and DSM combination was proposed for an efficient energy management in a micro grid environment. A novel model of DED problem integrated with demand response in regional grids was proposed in [24]. In [25], a MODEED problem with game theory based DR model was presented. The DEED problem and DSM combination model incorporating high wind penetration was proposed in [26,27]. The main goal of DEED and DSM combination models proposed in the literature was to show the impacts of DSM on the supply side. From the overall literature, the DED problem is incorporated with either incentive based DR program or ToU based DSM method. In the incentive based DR program, the power supplier can control the customers' loads directly by providing impressive incentives. The ToU based DSM method introduces different prices for all individual time slots which make consumers move their loads to low pricing slots. In this paper, authors proposed a model which uses MODEED problem and a day-ahead based load shifting DSM program for residential loads. Compared to other DED and DR combinations in the literature, all necessary DSM constraints for the residential loads were considered in this paper without any load curtailment. In this proposed model, authors also considered the consumers' comfort by providing different delay times for all controllable loads based on their daily life style. The proposed combined model is mainly focusing on the benefits of DSM program towards the generation side with different residential participation levels. To the best of authors' knowledge, the proposed model has not been reported in the literature. The proposed combined model can be solved effectively by the evolutionary algorithms. In this paper, the proposed model uses non dominated sorting based MOPSO [28,29] algorithm with a fuzzy optimization tool for minimizing MODEED problem simultaneously and single objective PSO algorithm for minimizing the DSM technique. For a comparison purpose, the objectives of MODEED problem were minimized using NSGA-II and the results of both MOPSO and NSGA-II were also compared.

The organization of the paper is as follows. Section 2 explains the problem formulation and the DSM approach. The proposed combined model is explained in the Section 3. Section 4 explains the test system considered in this paper with different assumptions. The simulation results and their comparison are given in the Section 5. Section 6 gives the conclusion of the paper.

2. Problem formulation

2.1. Multi-objective dynamic economic and emission dispatch (MODEED) problem

The dynamic economic and emission dispatch is the most important optimization problem in the power system operation and control for satisfying the economic and social aspects. In this DEED problem, the total fuel cost and emission are the two different conflicting objectives which are to be minimized simultaneously. The mathematical formulation of the objective functions are shown as follows [2,29,30]

Minimize

$$F_1 = \sum_{t=1}^{\tau} \sum_{g=1}^{G} C_{g,t}(P_{g,t}), \tag{1}$$

$$F_2 = \sum_{t=1}^{\tau} \sum_{g=1}^{G} E_{g,t}(P_{g,t}), \tag{2}$$

where F_1 and F_2 are the total fuel cost and emission of G number of generating units over a τ total number of dispatch intervals. $C_{g,t}(P_{g,t})$ and $E_{g,t}(P_{g,t})$ are the fuel cost and emission functions respectively during the time interval t and $P_{g,t}$ is the g^{th} generating unit power output at the t^{th} time interval. The total amount of emissions such as NO_x and SO_x are modelled as a sum of quadratic and exponential terms in the emission function. The fuel cost function with valve point effect is modelled as a sum of quadratic and sinusoidal terms. The mathematical formulation of these functions are given in Eqs. (3) and (4).

$$C_{g,t}(P_{g,t}) = a_g P_{g,t}^2 + b_g P_{g,t} + c_g + |d_g \sin(e_g(P_g^{\min} - P_{g,t}))|, \tag{3}$$

$$E_{g,t}(P_{g,t}) = (\gamma_g P_{g,t}^2 + \beta_g P_{g,t} + \alpha_g) + \xi_g \exp(\lambda_g P_{g,t}), \tag{4}$$

where a_g, b_g, c_g are the g^{th} generating unit fuel cost coefficients and d_g, e_g are the fuel cost coefficients due to the valve point loading effect. γ_g, β_g and α_g are the g^{th} generating unit emission coefficients and ξ_g, λ_g are the emission coefficients due to the valve point loading effect.

2.1.1. Constraints

In DEED optimization problem, the objective functions are subjected to the following equality and inequality constraints:

1. Power balance constraint:

$$\sum_{g=1}^{G} P_{g,t} - P_{D,t} - P_{L,t} = 0 \ ,\forall \quad t \in \{1,2,\ldots,\tau\}, \tag{5}$$

where $P_{L,t}$ and $P_{D,t}$ are the t^{th} time interval total transmission power losses and total load demand power respectively. $P_{L,t}$ can be calculated by using B-loss coefficient method. The general mathematical form for the loss calculation is as follows

$$P_{L,t} = \sum_{g=1}^{G} \sum_{j=1}^{G} P_{g,t} B(g,j) P_{j,t}. \tag{6}$$

where $B(g,j)$ is the power transmission network loss coefficient value. $P_{g,t}$ and $P_{j,t}$ are the t^{th} time interval g^{th} and j^{th} generating unit