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A heuristic multi-objective multi-criteria demand response planning in a system with high penetration of wind power generators

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HIGHLIGHTS

- The combination of renewable resources and Demand Response allows an improvement of the demand potential.
- This paper proposes a new model for the integration of wind power and Demand Response.
- The problem is modelled using a stochastic Heuristic Multi-Objective Multi-Criteria Decision Making method.
- Comprehensive numerical results indicate that the proposed model is entirely efficient.

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ABSTRACT

Integration of wind energy and other renewable energy resources in electrical systems create some challenges due to their uncertain and variable characteristics. In the quest for more flexibility of the electric systems, combination of these endogenous and renewable resources in accordance with strategies of Demand Response (DR) allows an increment/improvement of the demand potential, as well as a more secure, robust, sustainable and economically advantageous operation. This paper proposes a new model for integration of wind power and DR, thus optimizing supply and demand side operations through a price rule Time of Use (TOU), or incentive with Emergency DR Program (EDRP), as well as combining TOU and EDRP together. The problem is modelled using a stochastic Heuristic Multi-Objective Multi-Criteria Decision Making (HMM) method which aims to minimize operation costs and environmental emissions simultaneously, ensuring the security constraints through two-stage stochastic programming, considering various techno-economic indices such as load factor, electricity market prices, Energy Not Supplied (ENS) and Share Weighted Average Lerner Index (SWALI). Comprehensive numerical results indicate that the proposed model is entirely efficient in DR planning and power system operation.

1. Introduction

One of the challenging aspects of wind power units is the intermittent nature of this kind of energies. Because of the fluctuations in outage power of the wind units, integrating wind farms with Demand Response Programs (DRPs) can reduce this power unpredictability [1]. The current paper proposes the effective solution in this context.

1.1. Motivation

The challenging environmental targets set by governments and rising fossil fuel prices have affected increased production using renewable energy sources (wind, solar, mini-hydro) in electrical systems. It is possible to identify the benefits of renewable sources such as reducing emissions of pollutant gases, reducing energy imports and consequently reducing energy dependence, as well as increasing wealth and employment. Introducing and increasing exploitation of different renewable energies, a new challenge is faced in planning energy dispatch.

Renewable resources are characterized by variability; in general, predicting production amount is difficult, and renewable generation profile does not match with electric demand profile. Due to the above

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Nomenclature

Indexes

b index of system buses
i index of thermal units
j index for loads
l index of transmission lines
m segment index for the cost of thermal units
s index of wind scenarios
t index of hours
w index of wind unit

Parameters

a_t rate of incentive at hour t ($/MW h)
c^e_{im} slope of segment m in linearized fuel cost curve of unit i ($/MW h)
c_i^{ERU}/c_i^{ERD} offered energy of reserve up/down ($/MW h)
c_i^{RU}/c_i^{RD} offered capacity of reserve up/down ($/MW)
c_{wt}^{wind} cost of wind power producer
d_{jt}^0 initial electricity demand of load j at hour t
dr^{max} maximum response potential
e_{tt} elasticity of demand
$e_i^{SO_2}/e_i^{NO_x}$ emission rate of SO_2 and NO_x ($/kg)
mut_i/mdt_i minimum up/down time of generation unit i
nlc_i no load cost of unit i
$P_w^{install}$ installed capacity of wind farms (MW)
p_i^{min}/p_i^{max} minimum/maximum generation limit (MW)
ru_i/rd_i ramp up/down of generation unit i
suc_i start-up cost of generation unit i
sur_i/sdr_i spinning up/down reserve of generation unit i
$voll_j$ value of lost load in bus j ($/MW h)
w_{wt}^{max} available wind power of wind unit w (MW h)
x_l reactance of line l
ρ_t^0 initial electricity price at hour t ($/MW h)
ρ_t electricity tariff at hour t ($/MW h)
π_{cur} cost of wind spillage
ω_s probability of wind power scenario s

Variables

C_{it}^{ST} start-up cost of generation unit i in hour t ($)
D_{jt} modified demand after implementing DRPs
F_{cost} total expected cost ($)
$F_{emissions}$ total emissions (kg)
F_{lts} power flow through line l (MVA)
I_{it} binary status indicator of generating unit i
L_{jt} load after implementing DRPs
L_t^{final} hourly load after implementing DRPs
LS_{jts} involuntary load shedding in load j (MW)
P_{itm}^e generation of segment m in linearized fuel cost curve of unit i (MW h)
P_{it}^{tot} total scheduled power of unit i (MW)
P_{its}^{tot} total deployed power of unit i (MW)
P_{wt}^{wind} scheduled wind power of wind unit w (MW)
SR_{its}^U/SR_{its}^D deployed up/down reserve of unit i (MW)
SR_{it}^U/SR_{it}^D scheduled up/down reserve of unit i (MW)
W_{wst}^{spil} wind power spillage of wind farm w (MW)
Y_{it}/Z_{it} binary start-up/shutdown indicator of unit i
δ_{bts} voltage angle at bus b in scenario s (rad)

challenges and difficulties, variability, predictability and profile difference can cause energy deprivation in certain periods, and excess energy in other periods [2].

1.2. Literature review

Increasing operational flexibility is considered as a key solution to mitigate the problems caused by intermittent nature of renewable sources, allowing safe operation of the electrical system [3]. To make electrical systems more flexible, networks should be evolved into smart grids by implementing innovative concepts such as DR programs [4], network reinforcement and existence of faster production groups in order to ensure continuity of energy supply [5], concept of vehicle-to-grid [6] and storing electricity [7].

Integrated demand response of multi-energy systems has been discussed in [8]. Some studies have focused on finding solutions for optimal operation of micro-grids with renewable resources utilizing DR. Optimal renewable resource planning in the presence of DR has been studied in [9]. Techno-economic optimization of a stand-alone micro-grid comprising hybrid PV/Wind generations and battery storage with DR implementation has been presented in [10].

A number of researchers have modelled some of the DRPs considering different market designs and have investigated impacts of these programs on various aspects of electricity market operations through decision-making models [3,11,12].

In [13], authors have analysed strategy of wind units considering intraday DR exchange. A DR market design has been proposed in [14] to expand renewable energy resources and reduce emissions using economic models. The latest data has been updated using decision-making process employed for wind units to offer in the energy market. In [11], the ability of DR to improve smart system performance is demonstrated. A stochastic multi-objective market equilibrium has been determined in [15] to evaluate uncertainties in DR programs. Assigning a strategic priority to the most effective DRP from ISO point of view is one of the most important issues. Multi-Criteria decision-making (MCDM) or Multi-Attribute Decision Making (MADM) is an appropriate approach to select the optimum DR program [16].

Some reports have employed multi-attribute decision-making methods for distribution system planning [17]. Reference [18] has solved a generation planning problem using MADM. An MCDM model has been developed to evaluate profits of residential energy programs [19]. All these studies have been conducted for distribution systems without considering renewable energy.

In this perspective, international experiments and results of DR have been analysed and it is observed that DRPs can be effectively recognized as possible solutions to obtain a more flexible electrical network [20]. Demand management is a concrete measure for energy economy, where consumers change electricity demand through energy price variations throughout the day or in response to incentives designed to reduce demand during peak periods [21].

On this basis, allowing customers' potential to be catalysed through DR programs, a new window of opportunities might be created to increase flexibility of the electric system in handling variability of wind potential or contingency events. The uncertainty of the wind potential has been incorporated into the Security Constrained Unit Commitment (SCUC) models in a number of recent publications [22]; DR strategies have also been proposed in the SCUC problem [23–25]. Although many reports have studied impact of DRPs, combination of Multi-Objective (MO) problem with MCDM has not been addressed in the literature. The outstanding results show that the proposed approach can be effectively employed as a valuable tool by system operators to recognize which strategy is more efficient.