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Optimal planning and scheduling of energy hub in presence of wind, storage and demand response under uncertainty

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ABSTRACT

Energy Hub (EH) approach streamlines interconnection of heterogeneous energy infrastructures. The insight facilitates integration of Renewable Energy Resources (RERs) to the infrastructures. Consisting of different technologies, EH satisfies the hub output demands through transferring, converting, or storing the hub input energy carriers. Overall performance of power system depends upon optimal implementation of individual EHs. In this paper, a mathematical formulation is presented for optimal planning of a developed EH considering operation constraints. Two Objective Functions (OFs) are represented for deterministic and stochastic circumstances of wind power, electricity price, and the hub electricity demand. The OFs include costs associated with the hub investment, operation, reliability, and emission. The EH is constructed by Transformer (T), Combined Heat and Power (CHP), Boiler (B), and Thermal Storage (TS). The EH is developed by Wind Turbine (WT), Energy Storage (ES), and Demand Response programs (DR). The hub input energy carriers are electricity, gas, and water. The hub output demands are electricity, heat, gas, and water. CPLEX solver of GAMS is employed to solve Mixed Integer Linear Programming (MILP) model of the developed hub. A Monte Carlo simulation is used to generate scenarios trees for the wind, price, and demand. SCENRED tool and Backward/Forward technique of GAMS reduce scenarios to best ten scenarios. Simulation results demonstrate what technology with what capacity should be installed in the EH. The results substantiate when min/max capacities of the hub technologies are required to be installed in the hub. In the meantime, the results manifest when, what technology, and how much energy carrier should be operated to minimize the costs pertained to the hub investment, operation, reliability, and emission. Effectiveness of WT, ES, and DR in the deterministic and stochastic circumstances and influence of uncertainties of the wind, price, and demand are assessed on the hub planning. Finally, effect of gas network capacity and CHP is evaluated on the hub planning.

Introduction

The most significant concerns of metropolitan regions are exponential growth of energy requirements and greenhouse gases emission. The challenges lead us toward utilization of Renewable Energy Resources (RERs) such as wind and solar powers. Integration of the RERs to electric distribution networks not only avoids expansion of transmission lines, but it also prevents establishment of new fossil fuels power plants. The RERs are able to provide either clean energy or adequate amount of energy; however, fluctuations of the RERs primary resources make the output power of the RERs probabilistic and uncertain. As a result, the inherent characteristic of the RERs causes some adverse effects on stability of overall performance of electric power system.

One prominent solution to tackle the oscillations of the RERs is utilizing some cutting-edge technologies such as Electrical Energy Storage (ES) and Demand Response programs (DR) as the RERs complements. Combined Heat and Power system (CHP) is considered as an outstanding example of the distributed generations. In addition to integrating different energy infrastructures such as electricity, gas, and heat, CHP is able to smooth the RERs fluctuations. CHP, ES, and DR are not only able to smooth the RERs oscillations, they have strong potential to flatten fluctuations of power markets prices and customers demands. Furthermore, interconnection of heterogeneous energy infrastructures by CHP results in improving power system's reliability, stability, power loss, voltage profile, energy efficiency, operation costs, and emission.

As a consequence, efficient utilization of the RERs and existing energy networks cannot rely on one technology. Different technologies and innovative approaches are required to optimally plan

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Nomenclature

Indices

h	hour
d	day
s	season
sc	scenario
em	produced emission by CO_2, SO_2, and NO_2

Variables

I_e^{ch}	binary variable of charging ES
I_e^{dis}	binary variable of discharging ES
I_e^{shdo}	binary variable of shifting down the electricity demand
I_e^{shup}	binary variable of shifting up the electricity demand
I_h^{ch}	binary variable of charging TS
I_h^{dis}	binary variable of discharging TS
ELF	equivalent loss factor
OF	Objective Function
P^B	the optimized capacity of B
P^{CHP}	the optimized capacity of CHP
P^{ES}	the optimized capacity of ES
P^T	the optimized capacity of T
P^{TS}	the optimized capacity of TS
P^{WT}	the optimized capacity of WT
P_e^{Net}	purchased electricity power from the network
P_g^{Net}	purchased gas power from the network
P_g^{NetB}	purchased gas power from the network for B
P_g^{NetCHP}	purchased gas power from the network for CHP
P_w^{Net}	purchased water power from the network
P_h^{NetS}	sold heat power to the network
P_e^{ES}	available energy in ES
P_e^{ch}	charged energy amount of ES
P_e^{dis}	discharge energy amount of ES
P_e^{loss}	energy loss of ES
P_h^{TS}	available energy in TS
P_h^{ch}	charged energy amount of TS
P_h^{dis}	discharged energy amount of TS
P_h^{loss}	energy loss of TS
P_e^{shdo}	shifted down electricity demand by DR
P_e^{shup}	shifted up electricity demand by DR
P_e^{ENS}	electricity energy not supplied
P_e^{WT}	wind power

Constants

α_e^{loss}	loss efficiency of ES
α_h^{loss}	loss efficiency of TS
$\alpha_e^{\min}$	minimum factor of ES
$\alpha_e^{\max}$	maximum factor of ES
$\alpha_h^{\min}$	minimum factor of TS
$\alpha_h^{\max}$	maximum factor of TS
η_e^{ch}	charge efficiency of ES
η_e^{dis}	discharge efficiency of ES
η_h^{ch}	charge efficiency of TS
η_h^{dis}	discharge efficiency of TS
η_{ee}^{CON}	electricity efficiency of AC/AC converter
η_{ee}^{T}	electricity efficiency of T
η_{ge}^{CHP}	gas to electricity efficiency of CHP
η_{gh}^{B}	gas to heat efficiency of B
η_{gh}^{CHP}	gas to heat efficiency of CHP
π_e^{DR}	cost of shifting electricity demand
π_e^{ENS}	cost of electricity energy not supplied
π_e^{Net}	hourly electricity price
π_e^{ES}	cost of charging and discharging ES
π_{em}	cost of CO_2, SO_2, and NO_2 emissions
π_g^{Net}	price of network gas power
π_h^{Net}	price of selling heat power to the network
π_h^{TS}	cost of charging and discharging TS
π_w^{Net}	price of network water power
A^{CHP}	availability of CHP
A^{Net}	availability of electricity network
A^{WT}	availability of WT
CC	investment cost of the hub components
MC	maintenance cost of the hub components
RC	replacement cost of the hub components
EF_{em}^{Net}	emission factor for electricity network
EF_{em}^{CHP}	emission factor for CHP
EF_{em}^{B}	emission factor for B
$ELF^{\max}$	maximum ELF
EL	economic life of the project
EL_n	economic life of the hub components
if	inflation rate
ir	real interest rate
ir_{no}	nominal interest rate
k_n	single payment present worth for the hub components
LPF^{shdo}	load participation factor for shifting down the electricity demand
LPF^{shup}	load participation factor for shifting up the electricity demand
P^{BMax}	maximum capacity permitted for installation of B
P^{CHPMax}	maximum capacity permitted for installation of CHP
P^{TMax}	maximum capacity permitted for installation of T
P^{ESMax}	maximum capacity permitted for installation of ES
P^{TSMax}	maximum capacity permitted for installation of TS
P^{WTMax}	maximum capacity permitted for installation of WT
P_e	hourly electricity demand
P_h	hourly heat demand
P_g	hourly gas demand
P_w	hourly water demand
$P_e^{Net\max}$	maximum capacity of electricity network
$P_g^{Net\max}$	maximum capacity of gas network
$P_w^{Net\max}$	maximum capacity of water network
$P_h^{Net\max}$	maximum capacity of heat network
$\Pr o_{EP}$	reduced electricity price scenarios
$\Pr o_{WP}$	reduced wind power scenarios
$\Pr o_{ED}$	reduced electricity demand scenarios
PWA	present worth annual payment
r_n	replacement number of the hub components
w	hourly wind speed
w_{ci}, w_{co}	required min/max wind speed for WT
w_r	rated wind speed
x, y, z	WT characteristics

the technologies and to subtly balance demand and supply at the moment [1]. In fact, dealing with financial, technical, and environmental issues regarding energy results in coordinate utilization of different energy sectors and technologies.

Existing approaches for modeling different energy infrastructures such as electricity, heat, cooling, and transportation are considered in [2]. Micro Grid (MG) and Virtual Power Plant (VPP) are propounded as some examples of the approaches in which can