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Stochastic approach to represent distributed energy resources in the form of a virtual power plant in energy and reserve markets

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Abstract: Today, traditional networks are changing to active grids due to the burgeoning growth of distributed energy resources (DER), which demands scrupulous attention to technical infrastructures, as well as economic aspects. In this study, from economic point of view, the aggregation of DERs in a distribution network to participate in joint energy and reserve markets is investigated. This approach, which is predicated upon price-based unit commitment method, has considered virtually all the technical data in the proposed model. It is worth to mention that uncertainties of loads and market prices, as an inherent characteristic of the electricity markets, are treated in this study, and their effect on the operation of virtual power plants in energy and reserve markets has been thoroughly discussed. To this end, for both uncertain parameters, a good number of scenarios are generated and using the backward reduction method the number of these scenarios is reduced. The problem is formulated as a MINLP model and is implemented in GAMS software, while its authenticity is validated using particle swarm optimisation method.

Nomenclature

Indices

i,j	index for buses
t	index for hours
N	total number of buses

Sets

S_{DG}	set of distributed generation (DG) units
S_{IL}	set of interruptible load (IL)
S_{EES}	set of electrical energy storage (EES)
S_{int}	set of tie-lines
S_{b}	set of buses

Variables

$P_{\mathrm{DG}_i^t}$; $Q_{\mathrm{DG}_i^t}$	amount of active and reactive power generated by ith DG unit at hour t for the energy market
$R_{\mathrm{DG}_i^t}$	amount of active power generated by ith DG unit at hour t for reserve market
$P_{\mathrm{IL}_i^t}$; $Q_{\mathrm{IL}_i^t}$	amount of curtailed load of ith IL at hour t
$R_{\mathrm{IL}_i^t}$	amount of curtailed load of ith IL allotted to spinning reserve market at hour t
$P_{\mathrm{DG}_i}^{\min}$; $P_{\mathrm{DG}_i}^{\max}$	minimum and maximum active power generation of ith DG unit
$P_{\mathrm{int}_i^t}$; $Q_{\mathrm{int}_i^t}$	amount of active and reactive exchanged power between virtual power plant (VPP) and the ith neighbouring grid (positive sign for purchasing from the neighbouring grid and negative sign for selling to it)
P_{E_t}; Q_{E_t}	amount of active and reactive exchanged power between VPP and upstream network (positive sign for purchasing from the neighbouring grid and negative sign for selling to it)
R_t	sum of curtailed load and DG generation allotted to spinning reserve market at hour t
P_{Load_t}; Q_{Load_t}	supplied active and reactive load by VPP to end customers
$P_{\mathrm{ch}_i^t}$; $P_{\mathrm{Dch}_i^t}$	amount of power charged/discharged into ith EES at hour t
$P_{\mathrm{Str}_i^t}$	amount of charged/discharged capacity of ith EES at hour t in kW (positive sign for charging state and negative sign for discharging state)
$P_{\mathrm{Str}}^{\min}$; $P_{\mathrm{Str}}^{\max}$	minimum and maximum capacity of ith EES in kWh
R_{ch_i}; R_{Dch_i}	maximum charge/discharge rate of ith EES in kW
Cap_i^t	state of charge of the ith EES at hour t
$C(P_{\mathrm{DG}_i^t})$	generation cost function of ith DG unit
$C(P_{\mathrm{Str}_i^t})$	operation cost function of ith EES
$C(P_{\mathrm{IL}_i^t})$	contracted cost function of IL to curtail its load in specified hours
I_t; L_t; $J_{i,t}$; $K_{i,t}$; I_i^t	binary variables
$V_{i,t}\angle\delta_{i,t}$	voltage phasor at bus i at hour t
$Y_{ij}\angle\theta_{ij}$	polar form of ijth element of admittance matrix
$T_{i,t-1}^{\mathrm{off}}$; $T_{i,t-1}^{\mathrm{on}}$	number of hours that ith DG unit has been on (+) or off (−) at the end of hour $t-1$
$V_{i,t}^{\min}$; $V_{i,t}^{\max}$;	minimum and maximum voltage magnitude at bus i at hour t
S_{ij}^t	apparent power flow in feeder i–j at hour t
$S_{ij,t}^{\max}$	maximum apparent power flow in feeder i–j at hour t
$P_{\mathrm{IL}_i^t}^{\max}$	maximum load curtailment on ith IL at hour t
P_{sub_t}	capacity of upstream substation transformer
$E_{\mathrm{Ex},t}^{\mathrm{Max}}$	maximum exchanged power with upstream grid
AR_t	adequacy reserve maintained by VPP

Constants

$\rho_{\mathrm{E},t}$	energy market price
$\rho_{\mathrm{R},t}$	spinning reserve market price
$\rho_{\mathrm{int}_i^t}$	price of power exchange with neighbouring grid
$\rho_{L,t}$	retail energy price
r_t	probability of reserve delivery
η_{Str}	efficiency of EES