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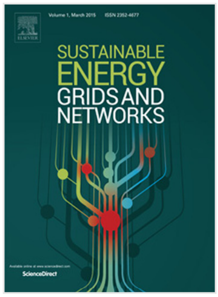

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Robust Operating Zones Identification for Energy Storage Day-ahead operation

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***Abstract*—This paper presents a tool to robustly allocate the allowable operating zones of active and reactive power margins for multi-energy storage systems (ESSs) without violating typical distribution system constraints. This tool helps ESSs to manage its day-ahead energy independently without violating the power system constraints. The main contribution is considering the power uncertainties (loads and renewable energy) without taking very conservative decisions. For defining a robust operating zone (ROZ) for ESSs; first, a particle swarm optimization (PSO) algorithm detects the day-ahead worst-case power flow due to loads, renewable energy sources (RESs), and contingency uncertainties. Second, a second-order cone programming problem (SOCP) optimizer determines the maximum charge and discharge active powers for each ESS that maintains safe system operation limits (voltage limits, cables capacity, and reverse power flow limits). While an uncertainty budget designed by the fuzzy expert, the PSO uses this budget to reshape its searching space with less conservatism. Case studies with one hundred different uncertainty scenarios are conducted on a real 41-bus Canadian system. Simulation results have shown that the proposed algorithm provides robust operating zones for ESSs that consider uncertainties with reducing conservatism.**

***Index Terms*— Energy storage system (ESS), particle swarm optimization (PSO), uncertainty budget, wind power uncertainty, worst-case power flow.**

A. Acronyms

CDF	Cumulative density function
CL	Confidence level
CPU	Critical power uncertainty
DNO	Distribution network operator
ESS	Energy storage system
OPF	Optimal power flow
PDF	Probabilistic density function
PF	Power flow model
PSO	Particle swarm optimization
RES	Renewable energy sources
RO	Robust optimization
ROZ	Robust operating zone
ULL	Power uncertainty lower limit
UUL	Power uncertainty upper limit
WCU	Worst-case uncertainty

B. Sets

$\mathcal{N}_b$	Set of power system buses
$\mathcal{N}_k$	Set of the sampled time horizon
$\mathcal{N}_l$	Set of loads' buses
$\mathcal{N}_r$	Set of RES' buses
$\mathcal{N}_s$	Set of energy storage systems
$\mathcal{N}_t$	Set of power system branches
$\mathcal{D}$	Original Set of active, reactive power uncertainty

C. Parameters

$\bar{\ell}_t$	Nominal Ampacity of branch *t*
$\hat{p}_{lk}$	Load *l* mean active power at time *k*
$\hat{p}_{rk}$	RES *r* mean active power at time *k*
Λ_{bp}	Voltage sensitivity to active power at bus *b*
Λ_{bq}	Voltage sensitivity to reactive power at bus *b*
S_s	Nominal capacity of the storage *s*
r_t, x_t	Resistance, and reactance of branch *t*
n_T	Number of system branches
n_b	Number of system buses
n_k	Size of time horizon
n_l	Number of buses with loads
n_r	Number of buses with RES
n_s	Number of ESS units
$\overline{v}$	Maximum per-unit allowable bus voltage
$\underline{v}$	Minimum per-unit allowable bus voltage
η_s	the efficiency of storage *s*
$\omega_{max}, \omega_{min}$	Max and min. particles speeds
M	Number of contingencies' scenarios
$Max.Iter, c_1, c_2$	Maximum number of PSO iterations, PSO individual and social acceleration constants
OT	Number of expected outages
α, β	Voltage deviation fitness function parameters

D. Uncertain Variables

$\tilde{p}_{bk}$	Active power uncertainty of bus *b*at time *k*
$\tilde{p}_{lk}$	Active power uncertainty of load *l* at time *k*
$\tilde{p}_{rk}$	Active power uncertainty of RES *r* at time *k*
$\tilde{q}_{bk}$	Reactive power uncertainty of bus *b* at time *k*

E. Decision Variables

$X_k^j(\tau)$	Particle number-*j* position for a certain power uncertainty combination at time *k* calculated at PSO iteration τ
$R_{ULL_{bk}}$	Risk of ULL power at bus *b* and time *k*
$R_{UUL_{bk}}$	Risk of UUL power at bus *b*and time *k*
$\overline{\Gamma_{ik}}$	Uncertainty budget upper limit weight for bus *i* at time *k*
$\underline{\Gamma_{ik}}$	Uncertainty budget lower limit weight for bus *i* at time *k*
$\overline{p_{sk}}$	ROZ upper limit of storage *s* at time *k*
$\underline{p_{sk}}$	ROZ lower limit of storage *s* at time *k*
$V_k^j(\tau)$	Particle number-*j* speed for a certain power uncertainty combination at time *k* calculated at PSO iteration τ
fV_k	Voltage deviation fitness function at time *k*
$loss_k$	Total power loss at time *k*
p_{sk}	Active power of storage s at time *k*
q_{sk}	Reactive power of storage s at time *k*
v_{0ik}^*	Voltage of bus *i* at time *k* in case of WCU-*PF* model before ESS participation
v_{bk}	Voltage norm of bus *b* at time *k*
V_{bk}	Voltage magnitude of bus *b*at time *k*

I. Introduction

Day after day, the world witnesses an increasing penetration level of renewable energy resources (RESs) in power systems. As RESs are indispatchable, combining energy storage systems (ESSs) with RESs is a necessity for enhancing profitability and ensuring system stability. In addition to renewable integration, ESSs have many other power applications [1], [2], and it participates in ancillary services markets [3], e.g. voltage support in weak grids [4].

Unfortunately, the lack of regulatory rules and grid codes for ESSs in different applications is one of the main challenges facing effective integration of ESSs in grid systems [1], [5]. While ESS acts as an electrical load or generator, it is desired to define the safe dispatchability zones of each ESS in the case