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Assessing wind uncertainty impact on short term operation scheduling of coordinated energy storage systems and thermal units

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ABSTRACT

Renewable resources, especially wind power, are widely integrated into the power systems nowadays. Managing uncertainty of the large scale wind power is often known as one of the most challenging issues in the power system operation scheduling. Additionally, energy storage systems (ESSs) have been widely investigated in the power systems owing to their valuable applications, especially renewable energy smoothing and time shift. In this paper, a stochastic unit commitment (UC) model is proposed to assess the impact of the wind uncertainty impact on ESSs and thermal units schedule in UC problem. Wind uncertainty is modeled based on the two measures. First, the wind penetration level is changed with respect to the basic level. Second, the wind forecasting error is modeled through a normal probability distribution function with different variances. The ESSs are modeled based on several technical characteristics and optimally scheduled considering different levels of the wind penetration and forecasting accuracies. The proposed formulation is a stochastic mixed integer linear programming (SMILP) and solved using GAMS software. Simulation results demonstrate that the wind uncertainty have a considerable impact on operation cost and ESSs schedule while proposed optimum storage scheduling through the stochastic programming will reduce the daily operational cost considerably.

1. Introduction

Unit Commitment (UC) is defined as to turn a generating unit on, which includes speeding up the unit, synchronizing and connecting it to the grid so it is able to deliver the power [1]. Regarding the power demand variations, the UC problem is to commit adequate units at appropriate time and with enough generated power, economically. In addition, most of the unit types in the electric power systems are the thermal units where cannot instantly turn on and produce power. Therefore, the UC problem must be solved in advance so that enough producible power is always accessible to supply the system demand [2]. A variety of methods have been proposed to model and solve the UC problem [3], but mixed integer linear programming (MILP) is a well-known method providing various advantages over other ones. The MILP convergence to the optimal solution is guaranteed in a finite number of the iterations while a flexible and accurate modeling framework is provided. Furthermore, during the search of the problem space, information on the proximity to the optimal solution is available [4–8]. Professional MILP softwares based on the branch and bound, and branch and cut algorithms have been widely developed and commercial packages with large-scale capabilities are currently available and used extensively [9,10].

Although the MILP-UC problem has been widely investigated by the researchers, but, the new challenges related to the renewable resources uncertainties, especially wind power, have attracted a considerable interest to improve the UC models and solution algorithms. Nowadays, bulk wind energy resources are penetrated into the electric power systems as large scale wind farms. The statistics indicate that wind energy projects are the fastest-growing renewable energy plants in the world, due to their sustainability, cleanness, and cost effectiveness compared to the other renewable energy resources [11,12]. The uncertainty is the main problem to utilize the wind power because the wind speed is continuously changing and afterward, the output power of wind turbines will be changed. These power fluctuations can cause considerable troubles in forecasting the overall energy harvested from a wind farm [13].

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Nomenclature

Sets

I,J	Network buses
M	Piecewise linear generation cost function segments
N	Thermal units
N_i	Thermal units located at bus i
S	Energy storage systems
S_i	Energy storage systems located at bus i
T	Time periods
W	Wind power units
W_i	Wind power units located at bus i
Ω	Scenarios

Parameters

BG_n^0	Initial on/off state of thermal unit n
$C_{n,t}^{CSU}$	Constant start-up cost of thermal unit n at time period t
$C_{n,t}^{CSD}$	Constant shut-down cost of thermal unit n at time period t
$C_{i,t}^{CLS}$	Constant cost of load shedding at bus i and time period t
ES_s^{Rated}	Rated energy of energy storage system s
ES_s^0	Initial stored energy in energy storage system s
k_n	Constant coefficient of piecewise linear generation cost function of thermal unit n
N_n^{GC}	Number of segments of generation cost function of thermal unit n
P_n^{RD}	Ramp-down limit of thermal unit n
P_n^{RU}	Ramp-up limit of thermal unit n
P_n^{SDR}	Shut-down ramp limit of thermal unit n
P_n^{SUR}	Start-up ramp limit of thermal unit n
P_n^{Min}	Minimum generation capacity of thermal unit n
P_n^{Max}	Maximum generation capacity of thermal unit n
P_ω	Probability of occurring scenario ω
$PD_{i,t}$	Demand at bus i and time period t
$PL_{i,j}^{Max}$	Capacity of the line between buses i and j
PS_s^{Rated}	Rated power of energy storage system s
PS_s^{CRU}	Charge ramp-up limit of energy storage system s
PS_s^{CRD}	Charge ramp-down limit of energy storage system s
PS_s^{DRU}	Discharge ramp-up limit of energy storage system s
PS_s^{DRD}	Discharge ramp-down limit of energy storage system s
$PW_{w,t}$	Forecasted mean wind power of wind unit w at time period t
$PW_{w,\omega}^{FE}$	Per-unit forecasting error of wind power unit w at scenario ω
$PW_{i,t,\omega}^{B}$	Sum of the generated power of wind units located at bus i, time period t, and scenario ω
T_n^D	Number of time periods thermal unit n must be initially offline due to minimum down-time constraint
$T_n^{D_0}$	Number of time periods thermal unit n has been offline prior to the first period of the time span
T_n^{MD}	Minimum down-time of thermal unit n
T_n^{MU}	Minimum up-time of thermal unit n
T_n^U	Number of time periods thermal unit n must be initially online due to minimum up-time constraint
$T_n^{U_0}$	Number of time periods thermal unit n has been online prior to the first period of the time span
$XL_{i,j}$	Reactance of the line between buses i and j
α_n	Constant coefficient of quadratic generation cost function of thermal unit n
β_n	First order coefficient of quadratic generation cost function of thermal unit n
γ_n	Second order coefficient of quadratic generation cost function of thermal unit n
η_s^{Ch}	Charge efficiency of energy storage system s
η_s^{Di}	Discharge efficiency of energy storage system s
$\lambda_{n,m}$	Slope of segment m of piecewise linear generation cost function of thermal unit n

Variables

$BG_{n,t}^{State}$	Binary variable indicating on/off state of thermal unit n at time period t
$BS_{s,t}^{Ch}$	Binary variable indicating charge state of energy storage system s at time period t
$BS_{s,t}^{Di}$	Binary variable indicating discharge state of energy storage system s at time period t
$C_{i,t,\omega}^{LS}$	Load shedding cost in bus i, at time period t, and scenario ω
$C_{n,t}^{SD}$	Shut-down cost of thermal unit n at time period t
$C_{n,t,\omega}^{PG}$	Generation cost of thermal unit n at time period t and scenario ω
$C_{n,t}^{SU}$	Start-up cost of thermal unit n at time period t
$ES_{s,t}$	Stored energy in energy storage system s at time period t
$P_{m,n,t,\omega}^{PL}$	Generated power in segment m of piecewise linear generation cost function of thermal unit n at time period t and scenario ω
$P_{i,t,\omega}^{BLS}$	Shed load at bus i, time period t, and scenario ω
$PW_{w,t,\omega}^{WS}$	Spilled power of wind unit w, at time period t, and scenario ω
$PG_{n,t,\omega}$	Generated power of thermal unit n at time period t and scenario ω
$PG_{i,t,\omega}^{B}$	Sum of the generated power of thermal units located at bus i, time period t, and scenario ω
$PG_{n,t,\omega}^{Max}$	Maximum producible power of thermal unit n at time period t and scenario ω
$PI_{i,t,\omega}^{B}$	Injected power at bus i, time period t, and scenario ω
$PL_{i,j,t,\omega}$	Flow of the line between buses i and j, at time period t, and scenario ω
$PS_{s,t}^{Ch}$	Charged power into energy storage system s, at time period t, and scenario ω
$PS_{i,t}^{BCh}$	Sum of the charged power into energy storage systems located at bus i, at time period t, and scenario ω
$PS_{s,t}^{EC}$	Net charged power into energy storage system s at time period t and scenario ω
$PS_{s,t}^{Di}$	Discharged power from energy storage system s at time period t and scenario ω
$PS_{s,t}^{ED}$	Net discharged power from energy storage system s at time period t and scenario ω
$PS_{i,t}^{BDi}$	Sum of the net discharged power from energy storage systems located at bus i, time period t, and scenario ω
$PW_{i,t,\omega}^{BWS}$	Sum of the spilled power of wind units located at bus i, time period t, and scenario ω
$T_{n,t}^{D}$	Number of time periods thermal unit n has been offline prior to the start-up in time period t
$\delta_{i,t,\omega}$	Voltage angle of bus i at time period t and scenario ω