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Distributed generation integrated with thermal unit commitment considering demand response for energy storage optimization of smart grid

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ABSTRACT

This paper deals with an optimal battery energy storage capacity for the smart grid operation. Distributed renewable generator and conventional thermal generator are considered as the power generation sources for the smart grid. Usually, a battery energy storage system (BESS) is used to satisfy the transmission constraints but installation cost of battery energy storage is very high. Sometimes, it is not possible to install a large capacity of the BESS. On the other hand, the competition of the electricity market has been increased due to the deregulation and liberalization of the power market. Therefore, the power companies are required to reduce the generation cost in order to maximize the profit. In this paper, a thermal units commitment program considers the demand response system to satisfy the transmission constraints. The BESS capacity can be reduced by the demand response system. The electric vehicle (EV) and heat pump (HP) in the smart house are considered as the controllable loads of the demand side. The effectiveness of the proposed method is validated by extensive simulation results which ensure the reduction of BESS capacity and power generation cost, and satisfy the transmission constraints.

1. Introduction

Distributed renewable generators (DRGs) have gained interest in the power sectors in order to reduce the greenhouse gas emissions and power generation costs [1]. Due to the high penetration of the DRGs (e.g. wind generation, photovoltaic, biomass, hydro, and so on) and the deregulation and liberalization of the power markets, conventional power systems require significant amendments in planning and operation [2]. If a high penetration of DRGs is in the power grid, the power flow in the transmission line can be overloaded. As a result, it is difficult to maintain the balance between supply and demand sides and power system stability [3–7]. Further, the competition in power trading in the power sector increased owing to a lot of independent power producers. Therefore, electricity producers should use conventional thermal units efficiently so that they can lessen the operational cost and increase the profit. The aim of the smart grid is to integrate renewable sources into the conventional power system so that emissions and power generation costs can be reduced. Optimum operations of the high penetrating DRGs and thermal units, supply and demand controls, transmission constraints, and energy storage management are challenging for the smart grid system [8–14].

The revolution of industrialization and urbanization in the modern world has caused an increase in electricity demand. If a county has a high electricity demand, the power flow in the transmission line may become overloaded.Therefore, the thermal units commitment program has to consider the transmission constraints. The energy storage system (ESS) described in Refs. [15–17] that satisfies the transmission constraints for thermal units commitment program. The ESS can maintain power flow in the transmission line within a specific range and the efficient utilization of the ESS reduces the operation cost of thermal units. However, the installation cost of the ESSs is very high and some ESSs require a maintenance cost too [18,19]. Therefore, it can increase the power generation cost. Moreover, the capacity of the ESS should be optimized in order to reduce the installation as well as the power generation costs. Refs. [20–22] propose a spinning reserve to fulfill the transmission constraints for the thermal unit

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Nomenclature

DRGs	Distributed renewable generators	a_i	Fuel constant
PV	Photovoltaic	b_i	Fuel constant
WG	Wind generation	c_i	Fuel constant
BESS	Battery energy storage system	t	Number of hours
ESS	Energy storage system	T	Total hours
HP	Heat pump	P_{Li}	Load demand
EV	Electric vehicle	P_{PVdi}	Photovoltaic power from demand side
V2G	Vehicle to grid	P_{WGi}	Power of wind generation
TS	Tabu search	P_{PVi}	Photovoltaic power from supply side
LS	Local Search	P_{Bi}	Power of batteries
SC	Solar collector	P_{EVi}	Power of electric vehicle
$maxR$	maximum benefits	P_{HPi}	Power of heat pump
TG_b	Thermal units benefits	P_{gi}^{max}	Maximum power of thermal generator unit
TG_{cw}	Cost of thermal generator without demand response	P_{gi}^{min}	Minimum power of thermal generator unit
TG_{cd}	Cost of thermal generator with demand response	T_i^{on}	Minimum up time of unit
$BESSc$	Battery energy storage system costs	T_i^{off}	Minimum down time of unit
S_{Bi}	Battery capacity	X_i^{on}	Continuously ON time of unit
P_{Ii}	Inverter capacity	X_i^{off}	Continuously OFF time of unit
CI	Inverter capacity cost	P_{Bi}^{max}	Maximum power of battery
TGc	Thermal units operating costs	P_{Bi}^{min}	Minimum power of battery
SUC	Startup cost	S_{Bi}^{max}	Maximum state of charge
P_{gi}	Thermal generators power	S_{Bi}^{min}	Minimum state of charge
NG	Total thermal unit number	$minF$	Minimum transmission constraints violation
NB	Number of batteries	P_{fij}	Power flow between nodes i and j
NI	Number of inverters	P_{fij}^{max}	Transmission constraints
CB	Battery capacity cost	P_{EVi}^{max}	EV battery maximum power
FC	Fuel cost	P_{EVi}^{min}	EV battery minimum power
NT	Total scheduling period [hour]	S_{EVi}^{max}	Maximum state of charge of EV battery
i	Number of units	S_{EVi}^{min}	Minimum state of charge of EV battery
		P_{HPi}^{max}	HP maximum power
		$T_{i(t=19)}$	Water temperature of storage tank at 19 O'clock

commitment program. The spinning reserve requires additional installation and maintenance costs for the power producer. Refs. [23–27] propose a power system using thermal units commitment and electric vehicle (EV) technology. The EV can deliver power to the power system through the vehicle to grid (V2G) technology. By introducing the EV into the thermal unit commitment program, the total operational cost of the power system has been reduced. A thermal units commitment program integrated with the demand response is proposed in Refs. [28–33]. The demand response can reduce thermal units cost and the transmission constraints are satisfied. Nowadays, uncertain power sources like DRGs are integrated with the conventional thermal generator, therefore, the power system has to maintain the transmission constraint as well as the balance between supply-demand sides. An ESS can fulfill these requirements. On the other hand, the advent of smart houses in the demand side, the capacity of the ESS and utilization of inconvenient thermal units can be reduced by the controllable loads such as EV and heat pump (HP) in smart houses. Furthermore, over the past few years, Tabu search (TS) has been applied to many difficult combinatorial optimization problems because TS is one of the most efficient heuristic techniques in the sense that it finds quality solutions in relatively short running time [34]. Usually, TS is an extension of classical local search (LS) methods, it can quite easily handle complicated constraints that are typically found in real-life applications. In fact, basic TS can be seen as simply the combination of LS with short-term memories. There are three basic elements of the TS that are search space, neighborhood solutions, and short-term Tabu lists. The search space of an LS or TS heuristic is simply the space of all possible solutions that can be considered (visited) during the search. A neighborhood solution is constructed to identify adjacent solutions that can be reached from current solution. Previously mentioned that TS is to pursue LS whenever it encounters a local optimum by allowing non-improving moves; cycling back to previously visited solutions is stopped by the use of memories, called Tabu lists, that record the recent history of the search, that is a key idea that can be linked to artificial intelligence concepts [35].

This paper proposes a smart grid system which consists of DRGs (e.g. wind generation (WG) and photovoltaic (PV)), thermal units and battery energy storage systems (BESSs) in the supply-side and a large number of residential and smart houses in the demand-side. A smart house is designed with a PV system, EV, HP, and solar collector (SC). Smart houses on the demand-side are incorporated with the thermal units and BESSs in the supply-side. The TS algorithm is applied as an optimization method to determine the optimal operation of thermal units and BESSs in the supply-side, and EVs and HPs of smart houses in the demand side. The BESSs satisfy the transmission constraints, and as well, the BESSs capacities are optimized by integrating with the controllable loads (EVs and HPs) of the smart houses. The proposed system is verified for different weather conditions (e.g. fair, cloudy and rainy days), along with different rates of demand-response such as 0%, 30%, and 50%. Furthermore, benefits for fifteen years operation of the proposed system in different weather and demand response conditions are evaluated. In addition, optimized capacities of batteries and inverters are determined. The effectiveness of the proposed system is verified by the numerical simulation using MATLAB® environment.

The outline of this paper is as follows: Section 2 depicts a brief