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Optimal energy management of the smart parking lot under demand response program in the presence of the electrolyser and fuel cell as hydrogen storage system

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A B S T R A C T

Nowadays, utilization of distributed generation sources and electric vehicles (EVs) are increased to reduce air pollution and greenhouse gas emissions. Also, intelligent parking lots (IPL) are increased in response to the increase in the number of EVs. Therefore, optimal operation of distributed generation sources and IPL in the power market without technical scheduling will follow some economic problems for the owner of IPL and some technical problems for the operator of distribution network. Therefore, in this paper, an optimal energy management has been proposed for an IPL which includes renewable energy sources (wind turbine and photovoltaic system) and local dispatchable generators (micro-turbines). Also, determination of optimal charge and discharge powers of hydrogen storage system (HSS) containing electrolyser, hydrogen storage tanks and fuel cell has been considered in the proposed model. Furthermore, the time-of-use rates of demand response program are proposed to flatten the load curve to reduce the operation cost of IPL. The objective function includes minimizing the operation costs of upstream grid and local dispatchable generators as well as charging and discharging cost of IPL subject to the technical and physical constraints under demand response program in the presence of HSS. The proposed model is formulated as a mixed-integer linear programming and solved using GAMS optimization software under CPLEX solver. Four case studies are investigated to validate the proposed model to show the positive effects of demand response program and HSS on reduction of IPL's operation cost.

1. Introduction

In monopoly electricity market, consumers had to buy electricity from the utility that held the monopoly for the supply of electricity in the area where these consumers were located. Some of these utilities were vertically integrated, which means that they would generate the electrical energy, transmitted it from power plants to the load centers and distributed it to the individual consumers. In other cases, the utility from which consumers would purchase electricity was only responsible for its sale and distribution in a local area. This distribution utility in turn had to purchase electrical energy from a generation and transmission utility that had a monopoly over a wider geographical area.

In today's world, due to reduction of fossil fuel resources and increase of environmental pollution and greenhouse gases [1,2], policymakers of electrical industry are forced to make decisions about restructuring in the electricity industry [3].

In addition, today, investment in the field of renewable energy sources (RESs) increases [4,5] owing to the increase of electrical energy consumption, reduction of fossil fuel resources and increase of greenhouse gas emissions. Furthermore, restructured electricity market moves to create smart electricity networks in the future which are defined as microgrids on the demand side. Therefore, microgrids will play an important role in supplying electricity consumption [6]. Local dispatchable generators (LDGs) in the microgrids will have main advantages such as higher efficiency, fewer losses and lower environmental impacts. Distributed power generation will be possible using RESs such as wind turbine (WT) [7], PV system [8,9], micro-turbines (MT) [10,11] and fuel cell (FC) [12,13].

In the microgrids, new concepts of electric vehicle intelligent parking lot [14,15] and demand response program [16,17] can be noted to improve the efficiency and performance of system which has been targeted in this study.

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Nomenclature

Acronyms

DRP	demand response program
EL	electrolyser
EVs	electric vehicles
FC	fuel cell
GAMS	General Algebraic Modeling System
HSS	hydrogen storage system
HST	hydrogen storage tanks
IPL	intelligent parking lot
LDG	local dispatchable generators
MIP	mixed-integer linear programming
MTs	micro-turbines
PV	photovoltaic
RES	renewable energy sources
SOC	state-of-charge
TOU	time-of-use
UG	upstream grid
WT	wind turbine

Indices

f	auxiliary index for linear modeling of minimum ON-time and OFF-time of LDG which starts from 1 to the maximum amount of $\{mut_j, mdt_j\}$
i	index of EV
j	index of LDG
k	index of WT
p	index of PV system
t	index of time periods

Parameters

a^j, b^j	coefficients of LDG's operation cost
$DRP^{\max}$	maximum percentage of load that can be participated in demand response program
G^t	solar radiation on PV
LHV_{H2}	lower heating value of hydrogen
$load_0^t$	base load at time t
$M^{i,t}$	binary variable, which is 1 if the EV is in the IPL; otherwise 0
MUT_j	minimum up time of LDG
MDT_j	minimum down time of LDG
N_{Ev}	number of parked EV in the intelligent parking lot
$N_{H2,\max}^{EL}$	maximum produced hydrogen molar limit in electrolyser
$N_{H2,\max}^{FC}$	maximum consumed hydrogen molar limit in fuel cell
$N_{\max}$	maximum switching between the charge/discharge modes
$P_{\min}^{EL}$	minimum consumed power limit in electrolyser
$P_{\max}^{EL}$	maximum consumed power limit in electrolyser
$P_{\max}^{FC}$	minimum produced power limit in fuel cell
$P_{\min}^{FC}$	maximum produced power limit in fuel cell
P_{t0}^{H2}	pressure of hydrogen tank in the base-time period
$P_{initial}^{H2}$	initial pressure of hydrogen tank
$P_{\max}^{H2}$	maximum limit of hydrogen tank pressure
$P_{\min}^{H2}$	minimum limit of hydrogen tank pressure
P_R^k	rated power of WT
$P_W^{k,t}$	output power of WT
$P_{PV}^{p,t}$	output power of PV
$P_{LDG,\max}^j$	maximum power of LDG
$P_{LDG,\min}^j$	minimum power of LDG
$P_{UG}^{\max}$	maximum exchanged power between IPL and upstream grid
$P_{Ch,\max}^i$	maximum charging power limit of EV
$P_{Dch,\max}^i$	maximum discharging power limit of EV
$\Re$	gas constant
RD^j, RU^j	ramp up and down rates of LDG
s^p	area of PV
$SOC_{\max}^i$	maximum SOC of EV
$SOC_{\min}^i$	minimum SOC of EV
$SOC_{Arrival}^{i,t}$	initial SOC of EV at the arrival time to IPL
T_a	ambient temperature around the PV
T_p^i	approximate time of EV presence in the intelligent parking lot
T_{H2}	mean temperature inside the vessel
t_a^i	approximate arrival time of EV to the intelligent parking lot
t_d^i	approximate time of EV departure from intelligent parking lot
UDC^j	startup cost of LDG
V_c^k	cut-in speed of WT
V_R^k	rated speed of WT
V_F^k	cut-out speed of WT
V^t	predicted wind speed
V_{H2}	overall tank volume
η^{FC}	fuel cell efficiency
η^{EL}	electrolyser efficiency
$\pi_{Ch,Ev}^i$	charging price of EV in the intelligent parking lot
$\pi_{Dch,Ev}^i$	discharging price of EV in the intelligent parking lot
η_{dis}	discharging efficiency of EV
η_{ch}	charging efficiency of EV
η^p	conversion efficiency of PV array
π_{UG}^t	upstream grid price
Δt	sampling time to count available EVs in the intelligent parking lot
$\Delta SOC_{\max}^i$	maximum charge/discharge rate of EV

Variables

$C_{LDG}^{j,t}$	operation cost of LDG
$Dn_{j,f}$	auxiliary variable for linear modeling minimum down time constraint of LDG
DRP^t	free variable for possibility of demand response program implementation (positive for load increase and negative for load decrease)
$load^t$	the new load with demand response program implementation of
$N_{H2,t}^{FC}$	consumed hydrogen molar by fuel cell
$N_{H2,t}^{EL}$	produced hydrogen molar by electrolyser
P_{UG}^t	purchased power from UG by IPL
$P_{Ch,Ev}^{i,t}$	charging power of EV
$P_{Dch,Ev}^{i,t}$	discharging power of EV
$P_{LDG}^{j,t}$	scheduling power of LDG
P_t^{H2}	hydrogen tank pressure
P_t^{EL}	consumed power by electrolyser
P_t^{FC}	produced power by fuel cell
$SOC^{i,t}$	SOC of EV
$SC_{LDG}^{j,t}$	startup cost of LDG
$SOC_{Departure}^{i,t}$	SOC of EV in departure time