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Sustainable planning of hybrid microgrid towards minimizing environmental pollution, operational cost and frequency fluctuations

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A B S T R A C T

Microgrids mainly use conventional and renewable energy resources at the same time. Conventional energy resources produce environmental pollution and need high cost for operation. In recent years, penetration of renewable resources such as photovoltaic and wind turbine has been rapidly grown in microgrids. Reduction of power losses and pollution are the main advantages of integrating renewable resources into networks. But, the renewable energy resources comprise low inertia and stability of the network integrated with such units is low. As a result, the environmental pollution and stability of microgrid are considered as the main problems and a new modeling of microgrid energy management is proposed by this paper to tackle such drawbacks. In this regard, environmental pollution is reduced by including hydrogen gas station and carbon capture-storage system. As well, the virtual synchronous generator is used to provide sufficient inertia and improving transient stability. The uncertain parameters are incorporated in the planning and stochastic programming is applied to tackle such uncertainties. Problem is mathematically expressed as a stochastic mixed integer linear programming and solved by the augmented Epsilon-constraint method. Finally, a comprehensive sensitivity analysis is carried out to evaluate the results. Based on the simulation results, by installing carbon capture-storage system, operational cost of microgrid is reduced from 64.998 $ to 56.043 $ and 1791.75 kg of carbon dioxide is stored. The revenue equal to 24 $ in one day is achieved by H_2 station without any pollution. The stability of microgrid is also significantly improved by installing virtual synchronous generator. The results demonstrate the viability and effectiveness of the proposed method to minimize environmental pollution, operation cost and frequency fluctuations in microgrid energy management.

1. Introduction

Microgrids usually include distributed generations (DGs) and local loads that can be isolated or connected to the main grid. The environmental pollution, global warming, and limits of fossil fuel resources are the main reasons for utilizing renewable resources. These resources can be suitably integrated into small networks such as microgrids. In real microgrids, because of limitations on the renewable energy resources such as stochastic generation, it is not possible to supply the demand only by renewable energy resources and the operator has to apply conventional energy resources in addition to the renewable ones. Application of renewable and conventional energy resources causes several problems in microgrids. Conventional energy resources produce environmental pollution and the network operator is often willing to reduce the conventional energy resources and increase the renewable energy units. On the other hand, high penetration level of renewable resources reduces the inertia of the microgrid and leads to stability problems such as fast frequency deviations and stability collapse. Since the inertia of renewable energy resources is less than the inertia of conventional generators. Thus, if all energy resources are chosen as renewable, the microgrid inertia will be significantly reduced and it is not possible to control the frequency of the microgrid. Therefore, low inertia problem and environmental pollution are occurred by renewable and conventional generators, respectively. As a result, it is required to tackle these two problems (i.e., environmental pollution related to the conventional units and stability problem associated with renewable units) in microgrid scheduling and planning.

Different aspects of microgrids have been investigated by researchers so far. Control and energy management are two important aspects of microgrid studies. Frequency and voltage control

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Nomenclature

Symbols, indexes and parameters

A Wind generator blade area (m^2)
$C_{M\text{-}CHP}$, $C_{OP\text{-}CHP}$ CHP maintenance cost ($) and operation cost ($/kWh)
$C_{OP\text{-}WT}$, $C_{CONS\text{-}WT}$ WT operation cost ($/kWh) and constant cost ($)
$C_{OP\text{-}PV}$, $C_{CONS\text{-}PV}$ PV operation cost ($/kWh) and constant cost ($)
$C_{M\text{-}MT}$, $C_{OP\text{-}MT}$ MT maintenance cost ($) and operation cost ($/kWh)
$C_{M\text{-}ES}$, $C_{OP\text{-}ES}$ ES maintenance cost ($) and operation cost ($/kWh)
C_{Buy}, C_{Sell} Constant price of buying and selling energy ($/kWh)
$C_{M\text{-}H2}$, $C_{M\text{-}G}$ H_2 and gasoline stations maintenance costs ($)
$C_{M\text{-}VSG}$ VSG maintenance cost ($/kWh)
CP_{H2}, CS_{H2} Cost of producing ($/kWh) and selling H_2 ($/Lit)
CS_G, CP_G Cost of selling and producing gasoline ($/Lit)
C_{Fuel} Cost of fuel ($/kWh)
$C_{Buy}(t)$, $C_{Sell}(t)$ Cost of buying and selling energy ($)
$C_G(t)$ Cost of gasoline station ($)
$C_{CCS}(t)$ Cost of CCS system ($)
$C_{H2}(t)$ Cost of H_2 station ($)
$C_{CHP}(t)$ Total cost of CHP ($)
$C_{PV}(t)$ Total cost of PV ($)
$C_{MT}(t)$ Total cost of MT ($)
$C_{Wind}(t)$ Total cost of WT ($)
$C_{ES}(t)$ Total cost of ES ($)
$C_{VSG}(t)$ Cost of VSG ($)
df and dt Frequency (Hz) and time (s) variations
EF_i Emission factor for ith generator (kg/kWh)
EF_{CHP} Emission factor of CHP (kg/kWh)
EF_{MT} Emission factor of MT (kg/kWh)
EF_{VSG} Emission factor of VSG (kg/kWh)
EF_{MG} Emission factor of main grid (kg/kWh)
EF_G Emission factor of gasoline (kg/Lit)
E_S^{max}, E_S^{min} Maximum and minimum energy of ES (kWh)
$E_{LD}(t)$ Electrical load demand (kW)
$E_S(t)$, $E_S(0)$ ES energy and Initial state of charge (kWh)
$EM_G(t)$ Emission of gasoline station (kg)
$EM_{CHP}(t)$ Emission of CHP (kg)
$EM_{MT}(t)$ Emission of MT (kg)
$EM_{VSG}(t)$ Emission of VSG (kg)
$EM_{MG}(t)$ Emission of microgrid (kg)
$E_{H2}(t)$ Energy for producing H_2 (kWh/Lit)
e_i Constrained objective functions
f, f^* Microgrid frequency and references frequency
$fp(x)$ Objective functions
GT_{SCT}, GT_{NOCT} Solar radiation for STC and NOCT (kW/m^2)
$GT(t)$ Solar radiation on tilted module plane (kW/m^2)
H Inertia ($kg.m^2$)
k_{vi}, k_r Virtual inertia ($kg.m^2$) and constant coefficient
k_{vd}, k_k Damping and constant coefficient
$NOCT$ Normal operating cell temperature (°C)
N_{PVs}, N_{PVp} Number of series and parallel cells in PV module
$P^{max}{}_{E\text{-}dech}$, $P^{max}{}_{E\text{-}ch}$ ES maximum discharge and charge rate (kW)
P_{MT}^{max}, P_{CHP}^{max} Maximum powers of MT and CHP (kW)
P_{Line} Line transfer power limit (kW)
$P_{PV,\,STC}$ Maximum test power for the STC (kW)
P_G and P_L Total produced and demanded powers (kW)
$P_{WT}(t)$ WT power (kW)
$P_{VSG}(t)$ VSG output (kW)
$P_{VSG}^i(t)$, $P_{VSG}^d(t)$ Inertia response and damping power (kW)
$P_{PV}(t)$ PV power (kW)
$P_{CHP}(t)$ CHP power (kW)
$P_{MT}(t)$ MT power (kW)
$P_{Buy}(t)$, $P_{Sell}(t)$ Buy and sell powers (kW)
$P_{ES}(t)$ ES power (kW)
$P_{Gi}(t)$ Produced power by ith generator (kW)
$R_m(t)$ Reserve margin of the microgrid
$R^{max}{}_m(t)$, $R^{min}{}_m(t)$ Maximum and minimum reserve margin (%)
$R_{H2}(t)$ Revenue by selling H_2 ($)
$R_G(t)$ Revenue by selling gasoline ($)
$R_{CCS}(t)$ Revenue of CCS system ($)
R_p, ST_P Revenue and store prices by CCS system ($/kg)
r_i Range of ith objective function
s_i Feasible region of ith objective function
T_{amp}, T_{jstc} Environmental and reference temperature of PV (°C)
T Last time interval
t Time (h)
$T_j(t)$ Cell temperature of PV (°C)
$V(t)$ Wind speed (m/s)
$VOL_{H2}(t)$, $VOL_G(t)$ Volume of H_2 and gasoline (Lit)
V^{nom} Nominal wind speed (m/s)
$V^{cut\text{-}in}$, $V^{cut\text{-}out}$ Minimum and Maximum wind speed (m/s)
x Vector of decision variables
ρ and Θ Air density (kg/m^3) and Time interval
η_{CHP} CHP generator electrical efficiency
η_{MT} MT generator electrical efficiency
$\eta^E{}_C$, $\eta^E{}_D$ ES charge and discharge efficiency coefficients
η^w Wind generator power coefficient

Abbreviations

ANN	Artificial neural network
BFA	Bellman ford algorithm
CCS	Carbon capture and storage
CHP	Combined heat and power
CA	Clustering algorithm
CO_2	Carbon dioxide
DG	Distributed generation
DVR	Dynamic voltage restorer
ESS	Energy storage system
HHA	Hyper heuristic algorithm
MBFO	Modified bacterial foraging algorithm
MPABC	Multi period artificial bee colony
MPGSA	Multi period gravitational search algorithm
MILP	Mixed integer linear programming
MINLP	Mixed integer non-linear programming
MIQP	Mixed integer quadratic programming
MT	Micro turbine
MPP	Maximum power point
PSO	Particle swarm optimization
PV	Photovoltaic
PDF	Probability distribution function
SQP	Sequential quadratic programming
VSG	Virtual synchronous generator
WT	Wind turbine

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