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Optimal operation management of fuel cell/wind/photovoltaic power sources connected to distribution networks

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A B S T R A C T

In this paper a new multiobjective modified honey bee mating optimization (MHBMO) algorithm is presented to investigate the distribution feeder reconfiguration (DFR) problem considering renewable energy sources (RESs) (photovoltaics, fuel cell and wind energy) connected to the distribution network. The objective functions of the problem to be minimized are the electrical active power losses, the voltage deviations, the total electrical energy costs and the total emissions of RESs and substations. During the optimization process, the proposed algorithm finds a set of non-dominated (Pareto) optimal solutions which are stored in an external memory called repository. Since the objective functions investigated are not the same, a fuzzy clustering algorithm is utilized to handle the size of the repository in the specified limits. Moreover, a fuzzy-based decision maker is adopted to select the 'best' compromised solution among the non-dominated optimal solutions of multiobjective optimization problem. In order to see the feasibility and effectiveness of the proposed algorithm, two standard distribution test systems are used as case studies.

1. Introduction

The application of the RESs such as wind, fuel cell and photovoltaic in the new competitive electric power markets has gained significant attention due to the economic and environmental concerns of fossils and nuclear fuel-based electricity energy as well as reduction of fossil resources [1]. Also, the existence of some important aspects as the quality of the RESs such as compatibility with other modular subsystem packages, fully automation possibility, low emission release, high efficiency and proper power quality and reliability have made them even more popular than before [2].

In recent years, so many researchers have attended to investigate the use of some kinds of renewable energies like wind energy, biogas energy, fuel cells, photovoltaic cells, combined heat and power systems (CHP), etc., in the distribution voltage level [3–6]. Nevertheless, there are some significant considerations to get use of the RESs appropriately and efficiently. Regions like offshore and high altitude areas that have more constant and stronger winds are suitable to be used for the construction of wind farms. The power stored in the airflows can be employed to rotate wind turbines and so generate a clean and consistent electric power. Fuel cell with a modular structure allows for simple construction and operation with possible applications for distributed and portable power generation [7]. Also as a result of their fast response, fuel cells have a good quality to follow and supply the load changes while maintaining the high efficiency at the same time [3–6]. Another new technology in the field of renewable energy technologies is photovoltaics (PV). PV is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect [8]. Like the other kinds of renewable energies, PV has found many applications including satellites, electric vehicles, remote dwelling, boats, on roofs, and by the use of DC–AC converters in the grids which are connected to the power system. All these applications and many other benefits that are not mentioned here make it critical to investigate the effect of the RESs on the distribution network especially in the area of the DFR problem.

Electric distribution networks are generally designed and constructed as the radial networks so as to have suitable and proper protection coordination. Nevertheless, the necessity of having a secure network, supplying all consumers, minimizing power losses and improving power quality, it is required to change the structure and the topology of the network using automatic or manual

Abbreviations: MHBMO, modified honey bee mating optimization; DFR, distribution feeder reconfiguration; PV, photovoltaic; FC, fuel cell; MOP, multiobjective optimization problem; MDFR, multiobjective DFR; RESs, renewable energy sources.

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Nomenclature

X	state variables vector
n	number of state variables
N_{FC}	number of FC power sources
N_{PV}	number of PV power sources
N_{Wind}	number of wind power sources
N_b	number of branches
R_i	resistance of ith branch (Ω)
I_i	current of ith branch (A)
$P_{FC,i}$	active power production of the ith fuel cell power source (kW)
$P_{PV,i}$	active power production of the ith PV power source (kW)
$P_{Wind,i}$	active power production of the ith wind power source (KW)
P_{sub}	active power production of the substation (kW)
η_i	electrical efficiency of the ith FC
PLR_i	part load ratio of the ith FC
$C_{FC,i}$	cost of electrical energy generated by of the ith FC power source ($)
$C_{PV,i}$	cost of electrical energy generated by of the ith PV power source ($)
$C_{Wind,i}$	cost of electrical energy generated by of the ith Wind power source ($)
C_{sub}	cost of power generated at substation bus ($)
Price	cost of power per unit generated at substation bus ($)
Gr	annual rates of benefit
LF	loading factor
$E_{FC,i}$	emission of the ith FC power source (lb)
$E_{PV,i}$	emission of the ith PV power source (lb)
$E_{Wind,i}$	emission of the ith wind power source (lb)
E_{Grid}	emission of large scale sources (substation bus that connects to grid) (lb)
$NO_{xFC,i}$	nitrogen oxide pollutants of the ith FC power source (lb kWh^{-1})
$SO_{2FC,i}$	sulphur oxide pollutants of the ith FC power source (lb kWh^{-1})
$NO_{xPV,i}$	nitrogen oxide pollutants of the ith PV power source (lb kWh^{-1})
$SO_{2PV,i}$	sulphur oxide pollutants of the ith PV power source (lb kWh^{-1})
$NO_{xWind,i}$	nitrogen oxide pollutants of the ith wind power source (lb kWh^{-1})
$SO_{2Wind,i}$	sulphur oxide pollutants of the ith wind power source (lb kWh^{-1})
NO_{xGrid}	nitrogen oxide pollutants of the grid (kg)
SO_{2Grid}	sulphur oxide pollutants of the grid (kg)
$P_{min,FC,i}$	minimum active power of the ith FC power source (kW)
$P_{max,FC,i}$	maximum active power of the ith FC power source (kW)
$P_{min,PV,i}$	minimum active power of the ith PV power source (kW)
$P_{max,PV,i}$	maximum active power of the ith PV power source (kW)
$P_{min,Wind,i}$	minimum active power of the ith wind power source (kW)
$P_{max,Wind,i}$	maximum active power of the ith wind power source (kW)
$\lvert P_{ij}^{Line}\rvert$	absolute power flowing over distribution lines (kW)
$P_{ij,max}^{Line}$	maximum transmission power between the nodes i and j (kW)
$P_{ij,min}^{Line}$	minimum transmission power between the nodes i and j (kW)
V_{max}	maximum value of voltage magnitudes of ith bus (V)
V_{min}	minimum value of voltage magnitudes of ith bus (V)
$f_i(X)$	ith objective function
$J_i(X)$	equality constraints of ith objective function
$g_i(X)$	inequality constraints of ith objective function
f_i^{min}	lowest limit of ith objective function
f_i^{max}	highest limit of ith objective function
N_f	is the number of the objective functions in the MOP
$\mu_{fi}(X)$	membership function for ith objective function
D	drone
X_{queen}	best particle among the entire population or the queen
$X_{brood,j}$	the jth brood
Sp	queen spermatheca matrix
N_{Sp}	size of the queen spermatheca
$\Delta(f)$	absolute difference between the fitness of the drone and the fitness of the queen
α	speed reduction factor
γ	random value in the range of [0,1]
Prob(D)	probability of adding the sperm of drone D to the queen spermatheca
$S(t)$	queen speed
$F_i(X)$	values of the augmented $f_i(X)$
N_{eq}	number of equality constraints of the DFR problem
N_{ueq}	number of inequality constraints of the DFR problem
L_1	penalty factor
L_2	penalty factor
N_{ipop}	number of the bees
S_{queen}	queen speed
S_{max}	maximum speed of the queen
S_{min}	minimum speed of the queen
K_1	value of the production of NOx (lbk Wh^{-1})
K_2	values of the production of SOx (lbK Wh^{-1})
f_i^{queen}	the value of the ith objective function for the queen
f_i^{drone}	the value of the ith objective function for the drone
w_i	the weighting of the ith objective function
M_i	the mean value of the drones' population column-wise
m_i	the mean value of the ith element of the control vector in the drones' population column-wise
r_k	random value in the range of [0,1]
T_F	a constant factor which decides the value of mean to be changed. Can be 1or 2
$X_{q,k}$	the kth new queen generated for implementing modifying the breeding process
$X_{D,m}$	the mth new drone generated for implementing modifying the breeding process
round	the mathematic function which rounds each value to the nearest integer
rand( )	the function for the generation of random value
$Y_{k,m}$	the new individual generated through modification process
Z	the new individual generated through modification process

switches. However, the radial structure of the networks and discrete nature of the switches is a main obstacle to get use of the classical optimization methods in the multiobjective distribution feeder reconfiguration (MDFR) problem. Classical optimization methods have suggested transforming the multiobjective opti-