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Multi objective stochastic microgrid scheduling incorporating dynamic voltage restorer

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ABSTRACT

This paper focus on optimal scheduling of microgrid including thermal and electrical loads, renewable energy sources (solar and wind), combined heat and power (CHP), conventional energy sources (boiler and micro turbine), energy storage systems (thermal and electrical storages), and series flexible alternating current transmission system (FACTS) devices. Dynamic Voltage Restorer (DVR) is included in the line between the main network and the microgrid in order to achieve a higher power transfer to the upstream grid. In the proposed method, wind speed, solar radiation, and loads are modelled as uncertain parameters based on a stochastic approach. The problem is modelled as a linear, mixed integer, constrained, and multi objective optimization one aiming at minimizing cost and pollution at the same time. Also, a sensitivity analysis is proposed for studying the sensitive parameters in microgrid management. The proposed multi objective and stochastic problem is solved by using the augmented Epsilon-constraint method. All results and calculations are obtained by using GAMS24.1.3/CPLEX12.5.1. Finally, in order to confirm the results of the proposed method, final results are compared to the genetic algorithm method. Simulation results demonstrate the viability and effectiveness of the proposed scheduling method for microgrid.

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1. Introduction

Microgrid is a concept that includes distributed generation and local loads and it can be isolated or connected to the main grid. Microgrids have been widely investigated form different perspectives and aspects in the recent years. Many studies include uncertainty in the planning and provide a stochastic programming [1–7]. Wind speed, load levels, and solar radiation are the most important uncertainties in the microgrid management. Two stage stochastic programming is one of the stochastic subcategories that include two stages for dealing with uncertainty. In this method, at first stage, the optimal power scheduling based on the wind, solar, and load forecasts is determined and at the second stage, other variables such as remaining capacity of load, grid purchase, and other conventional distributed energy resources (DERs) are determined [1]. Probabilistic energy management is another method that is used in microgrid energy management [8,9]. In real, the uncertainties related to the loads, and output power of wind and solar units should be included in the network planning and operation. For instance, an adequate procedure is proposed to perform an optimal energy management on a typical microgrid with regard to the relevant uncertainties [10]. Also, the point estimate method is used for modelling uncertainty of the wind power and solar power and Robust optimization technique is applied to model load demand uncertainty [10]. Energy management in microgrid is mainly expressed as a mixed integer, non-linear programming (MINLP) or mixed integer, linear programming (MILP) which can be solved using mathematical approaches or meta-heuristic optimization techniques. Due to the complex optimization and non-linear programming, smart algorithms are also used for solving this problem. Although, heuristic algorithms are widely applied to solve the complex problems such as MINLP and MILP. For instance, in [11] an algorithm is presented to find energy scheduling in microgrid for energy management system (EMS) based on the multi-layer ant colony optimization. The aim of the mentioned study is to find the optimum operation of small resources for decreasing the total cost of a microgrid. Other intelligent algorithms have also been applied to solve energy management in microgrid such as PSO [12], GA [13], artificial neural network, modified bacterial foraging algorithm [14], hyper-heuristic algorithms [15], multi period artificial bee colony combined with Markov chain [16], and multi-period gravitational search algorithm [17].

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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 ($) and operation cost ($/kW h)
$C_{OP\text{-}WT}$, $C_{CONS\text{-}WT}$ WT operation cost ($/kW h) and constant cost ($)
$C_{OP\text{-}PV}$, $C_{CONS\text{-}PV}$ PV operation cost ($/kW h) and constant cost ($)
$C_{OP\text{-}DVR}$, $C_{M\text{-}DVR}$ DVR operation cost ($/kW h) and maintenance cost ($)
$C_{M\text{-}Boiler}$, $C_{OP\text{-}Boiler}$ Maintenance cost ($) and Operation cost of boiler ($/kW h)
$C_{M\text{-}MT}$, $C_{OP\text{-}MT}$ MT maintenance cost ($) and operation cost ($/kW h)
$C_{M\text{-}ES}$, $C_{OP\text{-}ES}$ ES maintenance cost ($) and operation cost ($/kW h)
C_{Buy}, C_{Sell} constant price of buying and selling energy ($/kW h)
$C_{OP\text{-}TS}$, $C_{M\text{-}TS}$ TS maintenance cost ($) and operation cost ($/kW h)
C_{Fuel} cost of fuel ($/kW h)
$C_{CHP}(t)$ total cost of CHP ($)
$C_{PV}(t)$ total cost of PV ($)
$C_{Boiler}(t)$ total cost of boiler ($)
$C_{MT}(t)$ total cost of MT ($)
$C_{Wind}(t)$ total cost of WT ($)
$C_{ES}(t)$ total cost of ES ($)
$C_{TS}(t)$ Total cost of TS ($)
$C_{DVR}(t)$ total cost of DVR ($)
$C_{Buy}(t)$, $C_{Sell}(t)$ cost of buying and selling energy ($)
$E_{LD}(t)$ electrical load demand (kW)
$E_S(t)$ electrical storage energy (kW h)
EM_{CHP} emission of CHP (kg)
EM_{MT} emission of MT (kg)
EM_{Boiler} emission of boiler (kg)
EM_{MG} emission of main grid (kg)
EF_{CHP} emission factor of CHP (kg/Mwah)
EF_{MT} emission factor of MT (kg/Mwah)
EF_{Boiler} emission factor of boiler (kg/Mwah)
EF_{MG} emission factor of main grid (kg/Mwah)
E_S^{max}, E_S^{min} maximum and minimum electrical storage energy (kW h)
$F(Cost)$ total cost of microgrid ($)
$F(Emission)$ total produced environmental pollution by microgrid (kg)
$GT(t)$ solar radiation on tilted module plane (kW/m^2)
GT_{NOCT} solar radiation for NOCT (normal operating cell temperature) (kW/m^2)
GT_{SCT} solar radiation for STC (standard test conditions) (kW/m^2)
$NOCT$ normal operating cell temperature (°C)
N_{PVs} number of series cells in PV module
N_{PVp} number of parallel cells in PV module
$P_{MG}(t)$ main grid power (kW)
P_{WT} wind turbine power (kW)
$P_{PV}(t)$ PV power (kW)
$P_{CHP}(t)$ CHP power (kW)
$P_{MT}(t)$ MT power (kW)
$P_{Boiler}(t)$ boiler power (kW_{heat})
$P_{DVR}(t)$ DVR capacity (kW)
$P_{Buy}(t)$, $P_{Sell}(t)$ buy and sell powers (kW)
$P^D_{Line}(t)$ line power limitation with DVR
$P^{DVR}_{Line}(t)$ added power by DVR (kW)
$P_{ES}(t)$ electrical storage power (kW)
$P_{TS}(t)$ thermal storage power (kW_{heat})
${P^{max}}_{E\text{-}dech}$, ${P^{max}}_{E\text{-}ch}$ ES maximum discharge and charge rate (kW)
${P^{max}}_{T\text{-}dech}$, ${P^{max}}_{T\text{-}ch}$ TS maximum discharge and charge rate (kW)
P_{MT}^{max} maximum MT power (kW)
P_{Boiler}^{max} maximum boiler power (kW_{heat})
P_{CHP}^{max} maximum CHP power (kW)
P_{Line} line transfer power limit (kW)
$P_{PV,\ STC}$ maximum test power of PV for the STC (standard test conditions) (kW)
$R_m(t)$ reserve margin of the microgrid
${R^{max}}_m(t)$, ${R^{min}}_m(t)$ maximum and minimum reserve margin (%)
$T_j(t)$ cell temperature of PV (°C)
$TE_S(t)$ thermal storage energy ($kW\,h_{heat}$)
$T_{LD}(t)$ thermal load demand (kW_{heat})
TE_S^{max}, TE_S^{min} maximum and minimum thermal storage energy ($kW\,h_{heat}$)
TF_{CHP} CHP heat to power ratio
T_{amp}, T_{jstc} environmental and reference cell temperature of PV (°C)
T last time interval
t time
V_t wind speed (m/s)
V^{nom} nominal wind speed (m/s)
$V^{cut\text{-}in}$ minimum wind speed (m/s)
$V^{cut\text{-}out}$ maximum wind speed (m/s)
V_1 microgrid side voltage (v)
$V2$ main grid side voltage (v)
V_{dvr} injected voltage by DVR (v)
X line impedance between microgrid and main grid (ohm)
η_{CHP} CHP generator electrical efficiency
η_{Boiler} boiler generator electrical efficiency
η_{Boiler} MT generator electrical efficiency
η^E_C electrical storage charge efficiency
η^T_C electrical storage discharge efficiency
η^T_C thermal storage charge efficiency
η^T_D thermal storage discharge efficiency
η^w wind generator power coefficient
ρ air density (kg/m^3)
γ power-temperature coefficient
δ phase angle between V_1 and V_2 (rad)
Θ time interval

Abbreviations

CHP combined heat and power
DVR Dynamic Voltage Restorer
D-FACTS distribution flexible alternating current transmission system
ES electrical storage
ESS energy storage system
EMS energy management system
GA genetic algorithm
MG main grid
MPP maximum power point
MT micro turbine
MILP mixed integer linear programming
MINLP mixed integer non-linear programming
PV photovoltaic
PSO partial swarm optimization
TES thermal energy storage
TS thermal storage
WT wind turbine

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