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Stochastic scenario-based model and investigating size of battery energy storage and thermal energy storage for micro-grid

Sirus Mohammadi [a,*], Ali Mohammadi [b]

[a] Department of Engineering, College of Electrical engineering, Yasouj Science and Research Branch, Islamic Azad University, Yasouj, Iran.
[b] Department of Mathematic, Gachsaran Branch, Islamic Azad University, Gachsaran, Iran.

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ABSTRACT

Energy storage systems (ESS) are designed to accumulate energy when production exceeds demand and to make it available at the user's request. They can help match energy supply and demand, exploit the variable production of renewable energy sources (e.g. solar and wind), increase the overall efficiency of the energy system and reduce CO_2 emissions. This paper presents a unit commitment formulation for micro-grid that includes a significant number of grid parallel PEM-Fuel Cell Power Plants (PEM-FCPPs) with ramping rate and minimum up and down time constraints. The aim of this problem is to determine the optimum size of energy storage devices like hydrogen, thermal energy and battery energy storages in order to schedule the committed units' output power while satisfying practical constraints and electrical/thermal load demand over one day with 15 min time step. In order to best use of multiple PEM-FCPPs, hydrogen storage management is carried out. Also, since the electrical and heat load demand are not synchronized, it could be useful to store the extra heat of PEM-FCPPs in the peak electrical load in order to satisfy delayed heat demands. Due to uncertainty nature of electrical/thermal load, photovoltaic and wind turbine output power and market price, a two-stage scenario-based stochastic programming model, where the first stage prescribes the here-and-now variables and the second stage determines the optima value of wait-and-see variables under cost minimization. Quantitative results show the usefulness and viability of the suggested approach.

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Introduction

The microgrid (MG) concept assumes a cluster of loads and microsources operating as a single controllable system that provides both power and heat to its local area. This concept provides a new paradigm for defining the operation of distributed generation. The penetration of renewable sources into the power system network has been increasing in the recent years. As a result of this, there have been serious concerns over reliable and satisfactory operation of the power systems. One of the solutions being proposed to improve the reliability and performance of these systems is to integrate energy storage devices into the power system network. Further, in the present deregulated markets these storage devices could also be used to increase the profit margins of wind farm owners and even provide arbitrage. The rapid interest and penetration of Distributed Energy Sources (DES), like PEM-Fuel Cell Power Plants (PEM-FCPPs), Micro Turbines (MTs), Wind Turbines (WTs) and Photovoltaic Generators (PGs), and Energy Storage Devices (ESDs) i.e. hydrogen, thermal energy and battery storages in Micro-Grids (MGs) has increased the need for using an efficient Stochastic Unit Commitment (SUC) tool. The goal of SUC is to find the best here-and-now variables (on/off status of units) and the best combination dispatch of units as wait-and-see variables over a one day horizon (with 15 min time step) to supply various practical constraints with the minimum expected total operation cost [1–3]. To serve the electrical/thermal load demand, electrical power can be produced directly by MTs, PEM-FCPPs, PGs, and WTs. Besides, the upstream network and Battery Energy Storage (BES) can support the MG. PEM-FCPPs are on the cutting edge of future technical methods and have the capability to restructure the future of energy supplying. They can use hydrogen storage and a polymer exchange to turn hydrogen and oxygen into electrical and thermal energy, more efficiently [4]. In this study, to serve the thermal load demand, five different PEM-FCPPs and one auxiliary boiler are considered. In this regard, some equality, inequality and dynamic constraints such as the minimum/maximum producible power of each unit, Spinning Reserve Requirements (SRRs) at each time interval, minimum on/off time and ramping up/down rates of PEM-FCPPS

* Corresponding author. Address: Department of Electrical Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran. Tel.: +98 917 7220625; fax: +98 711 7353502.
E-mail address: s.mohammadi@srbiau.ac.ir (S. Mohammadi).

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Nomenclature

Indices
- $eq,ineq$ equality and inequality constraint indices, respectively
- i_{FC}, i_{PG}, i_{WT} PEM-FCPPs, photovoltaic generators and wind turbines indices, respectively
- K index of iteration
- m index of habitat
- s index of scenario
- t index of time interval

Constants
- A, B, C boiler coefficients
- $\mathrm{Bid}_{battery,t}$ bid of battery at time t
- $\mathrm{Bid}_{boiler,t}$ bid of boiler at time t
- $\mathrm{Bid}_{i_{FC},t}$ bid of PEM-FCPP i_{FC} at time t
- $\mathrm{Bid}_{pump,i_{FC},t}$ hydrogen pumping cost for PEM-FCPP i_{FC} at time t
- $\mathrm{Bid}_{MT,t}$ bid of micro-turbine at time t
- $\mathrm{Bid}_{i_{PG},t}$ bid of photovoltaic generator i_{PG} at time t
- $\mathrm{Bid}_{i_{WT},t}$ bid of wind turbine i_{WT} at time t
- Bid_{H} hydrogen selling price
- $Eggs_{\min}$, $Eggs_{\max}$ upper and lower limits of egg dedication to each cuckoo at different iterations
- $\mathrm{FC}_{battery}$, $\mathrm{MC}_{battery}$ fixed and maintenance cost for battery energy storage
- $k_{\max}$ maximum iteration
- l life time of battery energy storage
- $MTon_{i_{FC}}, MToff_{i_{FC}}$ minimum in-service and out-service time of PEM-FCPP i_{FC}, respectively
- NFC number of PEM-FCPPs in the MG
- N_{cuckoo} number of cuckoos in the population
- NPG number of photovoltaic generators in the MG
- NWT number of wind turbines in the MG
- $Nscen$ number of scenarios
- N_{var} number of variables in each habitat
- N_{eq}, N_{ineq} number of equality and inequality constraints, respectively
- $NFFEs^{k}$, MAX_NFFEs number of fitness function evaluations in iteration k and maximum number of fitness function evaluations, respectively
- $P_{D,t,s}$, $P_{D\_thermal,t,s}$ electrical and thermal load demand at time t in scenario s, respectively
- $\mathrm{OM}_{i_{FC}}, \mathrm{OM}_{i_{WT}}, \mathrm{OM}_{i_{PG}}$ operation and maintenance cost for PEM-FCPP i_{FC}, wind turbine i_{WT} and photovoltaic generator i_{PG}, respectively
- Prob_{s} probability of scenario s
- $\mathrm{Price}_{t,s}$ power price of upstream network at time t in scenario s
- $P_{i_{PG},t,s}$ electrical power produced by photovoltaic i_{PG} at time t in scenario s
- $P_{i_{WT},t,s}$ electrical power produced by wind turbine i_{WT} at time t in scenario s
- $P_{i_{FC},\max}, P_{i_{FC},\min}$ maximum/minimum producible power of PEM-FCPP i_{FC}, respectively
- $Pth_{boiler,\max}$ maximum producible thermal power of boiler
- $P_{grid,\max}$, $P_{grid,\min}$ maximum/minimum electrical power production of the utility, respectively
- $rand(.)$ random function generator in the range $[0,1]$
- r interest rate for financing the installed battery energy storage
- $R^{up}_{i_{FC}}, R^{dn}_{i_{FC}}$ ramp-up/Ramp-down rate of PEM-FCPP i_{FC}, respectively
- $SRR_{t,s}$ 10 min spinning reserve requirements at time t in scenario s
- T scheduling period
- tax tax rate of grid
- v_{cell} cell operating voltage
- $\mathbf{X}_{\max}$, $\mathbf{X}_{\min}$ vector of maximum/minimum limits of variables, respectively
- $\eta_{boiler,t}$ efficiency of boiler at time t
- $\eta_{HT,i_{FC},t}$ hydrogen tank efficiency of PEM-FCPP i_{FC} at time t
- η_{d}, η_{c} discharge and charge efficiency of battery energy storage, respectively
- δ_{m} an integer for handling the maximum value of ELR for the mth cuckoo
- θ random angle generator in the range $[\frac{-\pi}{6}, \frac{\pi}{6}]$
- $\alpha_{i_{FC}}, \beta_{i_{FC}}$ hot and cold start up cost coefficients for PEM-FCPP i_{FC}, respectively
- $\tau_{i_{FC}}$ cooling time constant for PEM-FCPP i_{FC}, respectively
- Δt time interval duration

Variables
- $C_{battery,\min}$, $C_{battery,\max}$ minimum and maximum battery size
- $C_{battery,t,s}$ energy stored in the battery at time t in scenario s
- $Egg_{m,current}$ number of current eggs related to cuckoo m
- $Egg_{m,total}$ total number of eggs related to cuckoo m
- $\mathbf{Gbest}^{k}$ best solution in iteration k
- $\mathbf{Worst}^{k}$ worst solution in iteration k
- $F(\mathbf{X})$ expected total operational costs at time span T
- $HT_{apacity}$, $TES_{capacity}$ hydrogen tank and thermal energy storage capacity, respectively
- $P_{grid,t,s}$ electrical power bought/sold from/to the utility at time t in scenario s
- $P_{battery,t,s}$ electrical power discharged/charged from/to the battery at time t in scenario s
- $P_{MT,t,s}$ electrical power generated by the micro-turbine at time t in scenario s
- $P_{cell,i_{FC},t,s}$ electrical power produced by PEM-FCPP i_{FC} at time t in scenario s
- $P_{H,i_{FC},t,s}$ equivalent electric power for hydrogen production for PEM-FCPP i_{FC} at time t in scenario s
- $P_{H\_usage,i_{FC},t,s}$ secondary hydrogen stream amount for PEM-FCPP i_{FC} at time t in scenario s
- $Pth_{boiler,t,s}$ thermal power generated by boiler at time t in scenario s
- $Pth_{i_{FC},t,s}$ recovered thermal power generated by PEM-FCPP i_{FC} at time t in scenario s
- $Pth_{TES,t,s}$ output thermal power of thermal energy storage at time t in scenario s
- $\mathbf{X}$ vector of binary and continuous variables
- $rth_{i_{FC},t,s}$ thermal to electrical energy ratio for PEM-FCPP i_{FC} at time t in scenario s
- $SU_{i_{FC},t}, SD_{i_{FC},t}$ startup/shutdown cost of PEM-FCPP i_{FC} at time t, respectively ($/15 min)
- $TCPD_{battery}$ total cost per day of battery energy storage ($/day)
- $Ton_{i_{FC},t}$ in-service time of PEM-FCPP i_{FC} after its last startup till time t
- $Toff_{i_{FC},t}$ out-service time of PEM-FCPP i_{FC} after its last shutdown till time t
- $u_{grid,t}$ operation status of utility at time t (1: ON & 0: OFF)
- $u_{battery,t}$ operation status of battery at time t (1: ON & 0: OFF)
- $u_{MT,t}$ operation status of micro-turbine at time t (1: ON & 0: OFF)
- $u_{i_{FC},t}$ operation status of PEM-FCPP i_{FC} at time t (1: ON & 0: OFF)
- $\eta_{i_{FC},t,s}$ efficiency of PEM-FCPP i_{FC} at time t in scenario s

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