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Energy management in microgrid based on the multi objective stochastic programming incorporating portable renewable energy resource as demand response option

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A B S T R A C T

Renewable energy resources are often known as cost-effective and lucrative resources and have been widely developed due to environmental-economic issues. Renewable energy utilization even in small scale (e.g., microgrid networks) has attracted significant attention. Energy management in microgrid can be carried out based on the generating side management or demand side management. In this paper, portable renewable energy resource are modeled and included in microgrid energy management as a demand response option. Utilizing such resources could supply the load when microgrid cannot serve the demand. This paper addresses energy management and scheduling in microgrid including thermal and electrical loads, renewable energy sources (solar and wind), CHP, conventional energy sources (boiler and micro turbine), energy storage systems (thermal and electrical ones), and portable renewable energy resource (PRER). Operational cost of microgrid and air pollution are considered as objective functions. Uncertainties related to the parameters are incorporated to make a stochastic programming. The proposed problem is expressed as a constrained, multi-objective, linear, and mixed-integer programing. Augmented Epsilon-constraint method is used to solve the problem. Final results and calculations are achieved using GAMS24.1.3/CPLEX12.5.1. Simulation results demonstrate the viability and effectiveness of the proposed method in microgrid energy management.

1. Introduction

Energy management of microgrid is one of most important aspects in microgrid operation. This management can be generally classified into two categories: first, generation side management and second, demand side management. Most of the previous studies have worked on generation side management and some others have studies the demand side management [1,2]. Demand side management programs are offered to modify consumer demand for energy. In such programs, rather than increasing electricity generation to meet the demand, demand side management programs motivate consumers to decrease their consumption of energy [3]. Demand response programs are the other similar programs that are designed to modify consumer demand for power. Demand response programs encourage consumers to make temporary (short-term) reductions in their energy demand in response to a signal from the network operator. Normally, demand response schedules are in the range of 1–4 h. Demand response programs designed in electrical networks can be classified into two types, reliability-based (or load-response) and market-based programs [4]. Reliability-based programs suggest customers with economic motivations such as lower electricity prices or special bill credits to modify or change their demand for energy. Reliability-based programs are mainly classified into three sub-categories: Direct load control, interruptible programs, and curtailable load programs [4]. In direct load-control programs, network operator is allowed to turn off the consumers' loads by remote control switches during periods of peak demand. In interruptible programs, large commercial and industrial customers are considered. These large scale consumers either have back-up generations that can supple their loads or their operation process can be shut down during short-term periods to satisfy the load demand reduction requirements. In curtailable load programs, the consumers reduce their consumed energy upon notice from the network operator. The targeted load size of customers is the key difference between interruptible and curtailable programs. Where, curtailable programs mainly have a

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Nomenclature

Symbols, indexes and parameters

A	Wind generator blade area (m^2)
A'	Wind generator blade area for portable WT (m^2)
$C_{CHP}(t)$	Total cost of CHP at time t ($)
$C_{PV}(t)$	Total cost of PV at time t ($)
$C_{Boiler}(t)$	Total cost of boiler at time t ($)
$C_{MT}(t)$	Total cost of MT at time t ($)
$C_{Wind}(t)$	Total cost of WT at time t ($)
$C_{ES}(t)$	Total cost of ES at time t ($)
$C_{TS}(t)$	Total cost of TS at time t ($)
$C_{Buy}(t)$	Cost of buying at time t ($)
$C_{Sell}(t)$	Cost of selling at time t ($)
$C_{M\text{-}CHP}$	Maintenance cost of CHP ($)
$C_{OP\text{-}CHP}$	Operation cost of CHP ($/kWh)
$C_{OP\text{-}WT}$	WT operation cost ($/kWh)
$C_{OP\text{-}PV}$	PV operation cost ($/kWh)
$C_{CONS\text{-}WT}$	WT constant cost ($)
$C_{CONS\text{-}PV}$	PV constant cost ($)
$C_{M\text{-}Boiler}$	Maintenance cost of boiler ($)
$C_{OP\text{-}Boiler}$	Operation cost of boiler ($/kWh)
$C_{M\text{-}MT}$	Maintenance cost of MT ($)
$C_{OP\text{-}MT}$	Operation cost of MT ($/kWh)
$C_{M\text{-}ES}$	ES maintenance cost ($)
C_{Sell}	Cost of selling ($)
C_{Buy}	Cost of buying ($)
C_{Fuel}	Cost of fuel ($)
$C_{OP\text{-}ES}$	ES operation cost ($/kWh)
$C_{OP\text{-}TS}$	TS operation cost ($/kWh)
$C_{M\text{-}TS}$	TS maintenance cost ($)
$DR_{REV}(t)$	Demand response revenue ($)
$E_{LD}(t)$	Electrical load demand at time t (kW)
$E_S(t)$	Electrical storage energy at time t (kWh)
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}	Maximum electrical storage energy (kWh)
E_S^{min}	Minimum electrical storage energy (kWh)
$F\,(Cost)$	Total cost of microgrid ($)
$F\,(Emission)$	Total pollution of microgrid (kg)
$GT(t)$	Solar radiation on tilted module plane (kW/m2) of PV at time t
GT_{NOCT}	Solar radiation in NOCT (normal operating cell temperature) (kW/m^2)
GT'_{NOCT}	Solar radiation in NOCT (normal operating cell temperature) (kW/m^2) for portable PV
GT_{SCT}	Solar radiation in STC (standard test conditions) (kW/m^2)
GT'_{SCT}	Solar radiation in STC (standard test conditions) (kW/m^2) for portable PV
$NOCT$	Normal operating cell temperature (°C)
$NOCT'$	Normal operating cell temperature (°C) for portable PV
N_{PVs}	Number of series cells in PV module
N'_{PVs}	Number of series cells in portable PV module
N_{PVp}	Number of parallel cells in PV module
N'_{PVp}	Number of parallel cells in portable PV module
$P_{MG}(t)$	Main grid power at time t (kW)
$P_{WT}(t)$	Wind turbine power at time t (kW)
$P_{WT}{}^{PORT}(t)$	Portable wind turbine power at time t (kW)
$P_{PV}(t)$	PV power at time t (kW)
$P_{PV}{}^{PORT}(t)$	Portable PV power at time t (kW)
$P_{CHP}(t)$	CHP power at time t (kW)
$P_{MT}(t)$	MT power at time t (kW)
$P_{Boiler}(t)$	Boiler power at time t (kW$_{heat}$)
$P_{Buy}(t)$	Buying power at time t (kW)
$P_{Sell}(t)$	Selling power at time t (kW)
$P_{Battery}{}^{PORT}(t)$	Battery power for PRER at time t (kW)
$P_{ES}(t)$	Electrical storage power at time t (kW)
$P_{TS}(t)$	Thermal storage power at time t (kW$_{heat}$)
$P^{max}{}_{E\text{-}dech}$	Electrical storage maximum discharge rate
$P^{max}{}_{E\text{-}ch}$	Electrical storage maximum charge rate
$P^{max}{}_{T\text{-}dech}$	Thermal storage maximum discharge rate
$P^{max}{}_{T\text{-}ch}$	Thermal storage maximum charge rate
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 in STC (standard test conditions) (kW)
$P'_{PV,\,STC}$	Maximum test power in STC (standard test conditions) (kW) for portable PV
R_{PRER}	Revenue by PRER ($/kWh)
t	Time (h)
$T_j(t)$	Cell temperature of PV at time t (°C)
$T_j{}'(t)$	Cell temperature of portable PV at time t (°C)
$TE_S(t)$	Thermal storage energy at time t (kWh$_{heat}$)
$T_{LD}(t)$	Thermal load demand at time t (kW$_{heat}$)
TE_S^{max}	Maximum thermal storage energy (kWh$_{heat}$)
TE_S^{min}	Minimum thermal storage energy (kWh$_{heat}$)
TF_{CHP}	CHP heat to power ratio
T_{amp}	Environmental temperature (°C)
T'_{amp}	Environmental temperature (°C) for portable PV
T_{jstc}	Reference cell temperature (°C) of PV
T'_{jstc}	Reference cell temperature (°C) of portable PV
V_t	Wind speed at time t (m/s)
V^{nom}	Nominal wind speed (m/s)
$V^{nom'}$	Nominal wind speed (m/s) for portable WT
$V^{cut\text{-}in}$	Minimum wind speed (m/s)
$V^{cut\text{-}in'}$	Minimum wind speed (m/s) for portable WT
$V^{cut\text{-}out}$	Maximum wind speed (m/s)
$V^{cut\text{-}out'}$	Maximum wind speed (m/s) for portable WT
η_{CHP}	CHP generator electrical efficiency
η_{Boiler}	Boiler generator electrical efficiency
η_{Boiler}	MT generator electrical efficiency
$\eta^E{}_C$	Electrical storage charge efficiency
$\eta^T{}_C$	Electrical storage discharge efficiency
$\eta^T{}_C$	Thermal storage charge efficiency
$\eta^T{}_D$	Thermal storage discharge efficiency
η^w	Wind generator power coefficient
$\eta^{w'}$	Wind generator power coefficient for portable WT
ρ	Air density (kg/m^3)
ρ'	Air density (kg/m^3) for portable WT
γ	Power-temperature coefficient
γ'	Power-temperature coefficient for portable PV
θ	Time interval

Abbreviations

CHP	Cool-Heat-Power
DG	Distributed generation

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