Electrical Power and Energy Systems 101 (2018) 415–428

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Risk-based optimal scheduling of reconfigurable smart renewable energy based microgrids

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ARTICLE INFO

Keywords:
Reconfiguration
Reconfigurable smart microgrid
Scenario generation
Time-varying acceleration coefficients particle swarm optimization
Risk-measure
Conditional value-at risk

ABSTRACT

Due to penetration of renewable energy resources and volatility of market price, scheduling of microgrid is associated with risk. Reconfigurable smart microgrids (RSMGs) are a new generation of microgrids which require further investigations. In this paper, a daily risk-based optimal scheduling of RSMG in presence of wind turbine for microgrid operator profit maximization is presented. As a reward scheme for further use of wind, the price of selling power is considered different and more than the price of purchasing power. The wind speed, price of selling and purchasing power are considered as uncertain parameters and scenario generation based on ARMA model is used for simulation. To find the best combination of microgrid switches in each hour, TVAC-PSO algorithm is used and new constraint called maximum number of optimal topology constraint is added to limit the number of changes in the structure. Moreover, a risk measure is based on condition value-at risk (CVaR) is formulated. The proposed method is implemented on 10 and 32-bus test RSMG. Numerical results show that by assessing the risk, the expected profit of optimal scheduling problem will be improved and RSMG can achieve the greater revenue by selling power to upstream network in a longer time.

1. Introduction

Growing concerns for primary energy availability and aging infrastructure of current electrical transmission and distribution network are increasingly challenging security, reliability and economic. Microgrid is a new environment which is technically a small scale power system and consists of a variety of distributed energy resources (DERs), energy storage system and different types of load (controllable or fixed loads) that able to operate in both grid-connected and islanded modes. Microgrid can provide many opportunities such as a reliability improvement, emission and power loss reduction, power quality improvement and economic benefits by utilizing renewable energy and selling power to upstream network which eventually reduce the operation cost [1–3]. In order to achieve the above goals, control methods for microgrid are necessary. One of the most significant method for controlling structure of the microgrid is reconfiguration. Addition of the reconfiguration capability to the microgrids introduces the next generation of microgrids called RMG [4]. Reconfiguration can be handled for many goals such as a load balancing [5], service restoration [6], power loss reduction [7], voltage deviation minimization [8], reliability improvement [9] and energy cost minimization [10].

Reconfiguration is the process of changing topology of the network by modifying the open or close states of the switches. Because of the penetration of DERs, energy storage system and different types of load in microgrid, reconfiguration of microgrid will be different with common distribution network reconfiguration. Reconfiguration of microgrids is studied in [11–14]. In [11] reconfiguration has been introduced as a control action for remaining unaffected loads in microgrid. To reconfigure the microgrid graph theory and genetic algorithm are implemented. In [12], hybrid programming method presented for reconfiguration of a DC microgrid is presented for the loss reduction and restoration of the system. In [13] multi-objective reconfiguration is proposed with two goals, operation cost reduction and reliability improvement. In this paper the role of battery in fault condition for power balancing is analyzed. In [14] islanded microgrid reconfiguration is presented as an operational tool for improving loadability and decreasing power loss. The increase of loadability index of microgrid in the islanding mode is more important than the index of the grid connected. Adaptive multi-objective harmony search algorithm (AMHSA) has been used for this goal as well as power loss reduction.

Because of the penetration of renewable energy resources and deviation of demand and power market, uncertainty is increased in the microgrid. One of the main concerns of decision makers is the uncertainty handling. There are different methods for uncertainty

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https://doi.org/10.1016/j.ijepes.2018.04.005
Received 14 October 2017; Received in revised form 11 February 2018; Accepted 4 April 2018
0142-0615/

Nomenclature

Indices:

t	index for time
i	index for generator
ω	index for scenario
l	index for load
k	index for bus
j	index for branch
s	index for switch

Parameter:

$P_{gen}^{\min}/P_{gen}^{\max}$	minimum/maximum capability generation
RU	ramp up rate
RD	ramp down rate
MUT	minimum up time
MDT	minimum down time
$V_{cut-in}/\ V_{cut-out}$	cut-in/cut-out wind speed
$V_{rated}(m/s)$	rated wind speed of wind turbine
$P_{wind_{rated}}$	rated power output of wind
k_1,k_2,k_3	wind turbine coefficients
$V_k^{\max}/V_k^{\max}$	minimum/maximum value of voltage in kth bus
$I_j^{\max}$	maximum current capability of jth branch
$Z^{\max}$	maximum number of topologies during the day
ε_0, ϕ_0, θ_0	parameters of ARMA model

Variables:

OF	objective function
EP	expected profit
SD	shut down cost
SU	start up cost
N_{switch}	number of switching action
V	wind speed
P_{gen}	the power generation of dispatchable unit
P^s	the value of sold power
P^b	the value of purchased power
P^L	load demand
P_{grid}	power exchange between RSMG and main grid
P_{loss}	the value of power loss
λ^c	the power price of load demand
ϑ_ω^b	price of purchasing power in ωth scenario
λ_ω^s	price of selling power in ωth scenario
T_i^{on}/T_i^{off}	number of ON/ OFF hours
V_k	the value of voltage in kth bus
$Y_{t,\omega}$	the optimal configuration in time t and ωth scenario
η	risk measure of reconfiguration
π_ω	the probability of ωth scenario
S_ω	auxiliary variable to calculate CVaR
U_i	binary variable that shown the commitment state of dispatchable unit

handling like as stochastic programming, information gap decision theory (IGDT) [15], hybrid stochastic/IGDT [16], and robust optimization [17]. In [18], a new standard classification of uncertainty modeling techniques for decision making process is proposed. In this paper, the possibility of using Z-numbers for uncertainty modeling is introduced. The stochastic microgrid scheduling has been researched by wide number papers in the of literature. In [19] a new probabilistic model for load and wind power generation is presented. By using the Monte Carlo simulation (MCS), different scenarios are generated for simulating the uncertainty of these parameters (behavior of the load magnitude and wind power generation). A stochastic model for day-ahead microgrid management presented in [20]. This model uses unit commitment and reconfiguration at the same time to find the optimal topology of microgird and the optimal scheduling for microgrid units. The wind power generation and load demand are considered as uncertainty parameters and particle swarm optimization (PSO) algorithm is used for solving the problem. In [21] the reconfiguration of islanded microgrid based on uncertainty of load variability and renewable recourses output is considered as multi-objective optimization problem. Fuel consumption minimization, increasing capability of islanded microgrid to feed the maximum loads, and switching cost reduction are three objectives of this paper. To solve the problem non-dominated sorting genetic algorithm II (NSGA-II) has been used. In [22] to investigate the effect of uncertainty on the optimal operation management of microgrids, a new stochastic framework is presented. The load forecast error, wind turbine and photovoltaic (PV) power generation and market price are considered as uncertain parameters. Adaptive modified firefly algorithm (AMFA) is employed to solve the problem. A new method for optimal management of microgrids under uncertainty is presented in [23]. The $2m + 1$ point estimate method is used for modeling the uncertainty of load demand, market price, and power generation output of wind turbine and PV.

Most recent researches have turned their attention to day-ahead reconfiguration and due to technical problem, day-ahead reconfiguration can be used in networks [24,25]. Day-ahead (hourly) network reconfiguration capability can be realized by the deployment of remotely controlled switched [26]. To minimize the cost of switching operation, dynamic programming (DP) algorithm is proposed in [27] that can find the best combination of the hourly switching action. In [28] for determining intra-day distribution configuration, multi-scenario and decision theory concept has been implemented. After the structure is determined, this configuration is used to formulate a demand response scheme. Optimal daily scheduling of reconfiguration for minimizing the switching operation cost and energy losses cost is presented in [10]. Discrete genetic algorithm (DGA) is employed to solve the problem.

The literature review represents that DERs have key role in microgrid and reconfiguration process. According to the probabilistic nature of most DERs, day-ahead optimal scheduling of RSMG is associated with risk considering the intermittent power output of DERs. A limited number of papers analyzed the optimal scheduling of microgrid with uncertain parameters (such as a DERs output, market price and load demand) and risk arising from them. Moreover, due to selling the power from microgrid to the upstream network, another uncertain parameter, i.e., (hourly price of selling power to main grid) will be added to uncertain parameters. Therefore risk assessment is essential. Risk management in reconfiguration problem only has been handled for distribution network and reliability purpose [29]. In this paper, risk-based reconfiguration of distribution networks for reliability improvement in presence of reward/penalty scheme is presented. Due to uncertainty of load, generation and reliability parameters in distribution network, the distribution system operators (DSO) will consider risk in distribution network reconfiguration.

This paper presents a daily risk-based optimal scheduling of RSMG. RSMG have a different type of cost and revenue, so the objective of the paper is microgrid operator profit maximization that will be obtained from minus of them. The RSMGs that will been evaluated in this paper has a wind turbine and could buy/sell the power from/to the main grid. As a reward scheme, the price of the selling power is considered different and more than the price of purchasing power. The wind speed and price of purchasing and selling the power are considered as uncertain parameters. To simulate those parameters and find the optimal RSMG configuration of each hour, scenario generation and TVAC-PSO