Electrical Power and Energy Systems 98 (2018) 382–388

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

New metrics for assessing the performance of multi-microgrid systems in stand-alone mode

Shouxiang Wang[a,*], Xingyou Zhang[b], Lei Wu[c], Shumin Sun[b]

[a] Key Laboratory of Smart Grid of Ministry of Education, Tianjin University, Tianjin 300072, China
[b] State Grid Shandong Electric Power Research Institute, Jinan 250002, China
[c] Electrical and Computer Engineering Department, Clarkson University, Potsdam, NY 13699, USA

ARTICLE INFO

Keywords:
Multi-microgrid system
Performance assessment
Stand-alone mode

ABSTRACT

This paper proposes a set of new metrics for quantitatively assessing the performance of multi-microgrid systems which are operated in stand-alone mode. These metrics include generation penetration indices for indicating the configuration of distributed generations and loads, power exchange indices for representing energy interaction among microgrids and with the main grid, as well as reliability and economic indices for quantifying the reliable and economic operation of muti-microgrid systems. A multi-step performance assessment method for multi-microgrid systems is proposed, which considers different reliability requirements and economic characters of critical and non-critical loads as well as the energy exchange among microgrids and with the main grid for effectively calculating the proposed metrics. Case studies with practical data show the effectiveness of the proposed metrics and multi-step performance assessment method for assessing the performance of multi-microgrid systems.

1. Introduction

With the deterioration of environment and the exhaustion of traditional energy sources, renewable energy is becoming more and more attractive. However, intermittency and uncertainty of renewable energy bring significant challenges for achieving a deeper penetration into existing power systems. Fortunately, microgrid emerges as a new technology to facilitate the transition. A microgrid is composed of renewable energy generations, energy storage systems (ESSs), and loads, which can operate in grid-connected and stand-alone modes. Microgrids have been widely deployed to meet specific electricity supply requirements, such as in continuous electricity supply of isolated islands without direct grid connection or high reliability needs of hospitals.

Multiple microgrids in a local area can operate separately, or form a multi-microgrid system (MMS) to interact with each other. Connecting multiple microgrids into an MMS may improve their reliability and economics because of complementary characters of distributed generations (DGs) and loads in individual microgrids. In fact, microgrids can support each other when they are connected together [1,2].

Some studies have focused on planning [3,4], optimal energy schedule [5–7], and control of MMSs [8–11]. It can be concluded from above paper that MMS is a more complex system composed with microgrid. An MMS has distinct characteristics as compared to individual microgrid [12,13]. In fact, microgrids can support each other when they are connected together. There are many articles focusing on microgrid evaluation [14–16]. However, there is little studies focus on emerging characteristics of a MMS, and it is necessary to propose new metrics and models for assessing the performance of a MMS. Refs. [17–20] discuss a set of metrics for assessing the performance of a microgrid. However, an MMS is a more complex system composed of multiple microgrids. Thus, an MMS has distinct characteristics as compared to individual microgrid. Specifically, performances of individual microgrid are not exactly the same, and energy exchange is allowed between microgrids in an MMS system. Thus, the operation strategy of an MMS system is more complicated than a single microgrid, which can directly affect the performance of the MMS system. Indeed, the energy exchange characteristic is one of the most important operation features of an MMS system, while conventional metrics for a single microgrid cannot describe the energy exchange and operation characteristics of an MMS appropriately. Unfortunately, there is currently no suitable metrics for this aspect, and it is necessary to propose new metrics for accurately assessing the performance of MMS.

The rest of the paper is organized as follows. Section 2 introduces the general structure of MMSs. Section 3 describes the proposed metrics from four aspects of generation penetration, power exchange,

* Corresponding author.
E-mail addresses: sxwang@tju.edu.cn (S. Wang), zhxyou_sd@163.com (X. Zhang), lwu@clarkson.edu (L. Wu), epri@163.com (S. Sun).

https://doi.org/10.1016/j.ijepes.2017.12.002
Received 1 July 2017; Received in revised form 14 November 2017; Accepted 11 December 2017

Nomenclature

Variables

$C_{maintenance,j}$	maintenance cost of MG_j
$C_{operation,j}$	operation cost of MG_j
$I_{\beta}(t)$	solar irradiance at time t
$P_{gen,j}(t)$	power generation in microgrid (MG) MG_j at time t
$P_{load,j}(t)$	load demand in MG_j at time t
$P_{export}(t)$	power exported from the multi-microgrid system to the main grid at time t
$P_{import}(t)$	power imported from the main grid to the multi-microgrid system at time t
$P_{exchange,j}(t)$	net power injected into MG_j at time t (positive/negative if importing/exporting power)
$P_{critical,j}(t)$	critical load in MG_j in stand-alone mode
$P_{non\_critical,j}(t)$	non_critical load in MG_j in stand-alone mode
$P_{charge}(t)$	charging power of an energy storage system (ESS) at time t
$P_{discharge}(t)$	discharging power of an ESS at time t
$P_{MTG}(t)$	actual power output of a micro-turbine generator (MTG) at time t
$P_{WTG}(v)$	wind power output associated with wind speed v
SOC	state-of-charge (SOC) of ESS
T_c	cell temperature in °C
T_a	air temperature in °C
T_{OT}	nominal operating temperature of cell in °C
v_{ci}, v_r, v_{co}	cut-in, rated, and cut-out speeds

Parameters

FF	fill factor of solar cell
I_{mp}	maximum current in A of solar cell
I_{SC}	short-circuit current in A of solar cell
K_i	current temperature coefficient of solar cell in A/°C
K_v	voltage temperature coefficient of solar cell in V/°C
N_{MG}	number of MGs in a multi-microgrid system
N_{LD}	number of loads in a multi-microgrid system
$P_{charge,\min}$	minimum charging power of ESS
$P_{charge,max}$	maximum charging power of ESS
$P_{discharge,min}$	minimum discharging power of ESS.
$P_{discharge,max}$	maximum discharging power of ESS
$P_{MTG,rated}$	rated power output of an MTG
$P_{WTG,rated}$	rated power output of a wind turbine generator
SOC_{min}	minimum SOC of ESS
SOC_{max}	maximum SOC of ESS
T	stand-alone duration
V_{mp}	maximum voltage in V
V_{OC}	open-circuit voltage in V
η	electricity sell price from multi-microgrid system to the main grid
γ	electricity purchase price from the main grid

Subscript

j	index of MGs in a multi-microgrid system
k	index of loads in a multi-microgrid system
t	index of time

reliability, and economic. Section 4 presents a multi-step MMS performance assessment method to evaluate the reliability and economics of an MMS while considering the energy exchange among microgrids. Numerical case studies are discussed in Section 5 to show the effectiveness of the proposed metrics on MMS performance assessment, and conclusions are drawn in Section 6.

2. Structure of an MMS

An MMS is defined as a system which is comprised of multiple interconnected microgrids, which can operate in both grid-connected and stand-alone modes. Compared with a single microgrid, an MMS operates more flexibly in stand-alone mode by leveraging the complementary supports among multiple microgrids. Therefore, an MMS may present a better reliability and economic performance.

Fig. 1 shows the basic structure of an MMS with n microgrids of MG_1 to MG_n. The detailed components of MG_1 are depicted in Fig. 1, while other MGs have the similar components. $MG_1$is composed of PVs, wind turbines, batteries, and loads. $MGCC_1$ is the control center of MG_1. The market operator plays the role of a central dispatcher for the MMS, which determines energy flows among individual microgrids and interacts with the main grid. An MMS presents a three-layer structure, including the DG level, the microgrid level, and the MMS level. Loads in an MMS can be divided into critical and non-critical loads, according to their distinct importance. Specifically, critical loads in an MMS are loads that cannot be interrupted.

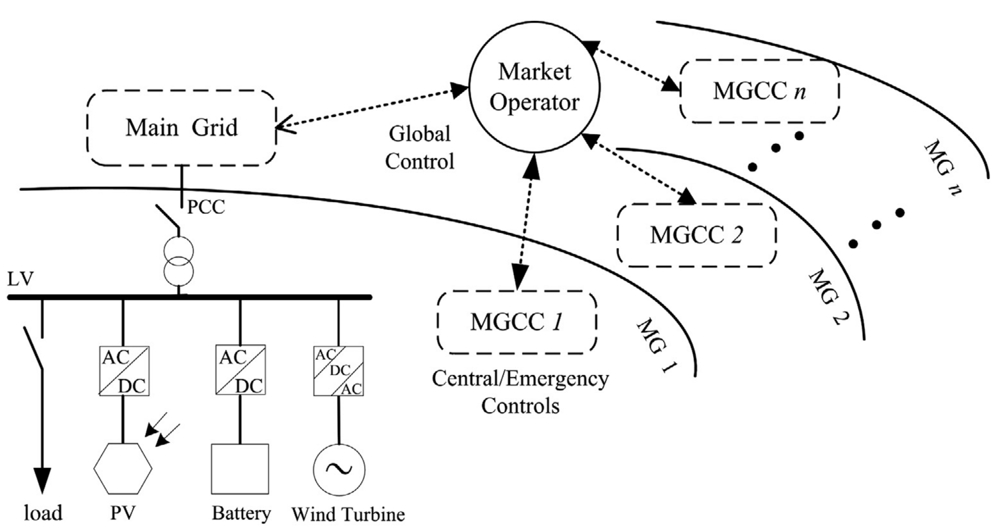

Fig. 1. The basic structure of an islanded MMS.