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

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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 multi-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 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,
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 MG1 to MGn. The detailed components of MG1 are depicted in Fig. 1, while other MGs have the similar components. MG1 is composed of PVs, wind turbines, batteries, and loads. MGCC1 is the control center of MG1. 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.](image-url)
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