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An End-to-End Network Evaluation Method for Differentiated Multi-Service Bearing in VPP

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ABSTRACT

Virtual power plant (VPP) plays an important role in improving the balance and regulation abilities of new power system. The safe and reliable operation is support by the VPP end-to-end communication network with differentiated multi-service bearing capability. For the requirement of unified and standard VPP end-to-end networking scheme, the VPP service communication metrics, as well as the communication network architecture of VPP aggregation and control are analyzed. Then, a multi-dimension hierarchical VPP end-to-end network evaluation index system is put forward. In addition, an end-to-end VPP network evaluation method considering differentiated time-sensitive and granular requirements of multiple services is proposed. Finally, the suitability analysis results of various end-to-end networking schemes and multiple services with differentiated time-sensitive and granular requirements are given, which plays a guiding role in establishing a unified standard VPP end-to-end networking scheme.

KEYWORDS

Differentiated Multi-Service Bearing, End-to-End Network, Granularity Requirements, Network Evaluation Method, Virtual Power Plant

Virtual power plant (VPP) integrates advanced information communication and intelligent metering technology to efficiently aggregate decentralized new energy power generation facilities, energy storage, and adjustable load, and it connects to the power grid to participate in peak regulation, frequency regulation and demand response to enhance the balance adjustment ability of the new power system (Bao et al., 2021; Y. Zhang et al., 2021). Since the interaction between distributed resources and grid through VPP aggregation involves distributed resource terminals (Liao et al., 2023), resource

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aggregators, and the information and multi-level coordination of the grid, the guaranteed ability of end-to-end quality of service (QoS) for VPP aggregation and regulation network is crucial for the safe and reliable operation of VPP.

In view of the differentiated time-sensitive and bandwidth granularity requirements of VPP service (Chen et al., 2021; Liao et al., 2022), VPP aggregation communication networks usually adopt high speed power line communication (HPLC), high speed radio frequency communication (HRF), 4G/5G, WiFi, optical fiber, and other communication modes to achieve heterogeneous networking. At present, most of the studies on VPP end-to-end networking schemes focus on heterogeneous network bearing schemes designed for specific engineering cases, and there is no unified standard scheme, which is not conducive to large-scale VPP development and subsequent promotion. Therefore, it is necessary to carry out the research on VPP end-to-end network evaluation technology to provide evaluation indices and performance analysis for the design of a VPP end-to-end network bearing scheme.

VPP end-to-end network evaluation includes the establishment of network evaluation indices, the appropriate comprehensive evaluation, and the sort of service carrying capacity for the end-to-end network. At present, there are few network evaluation studies considering the time sensitivity and granularity characteristics of VPP service differentiation. In one study by Jara et al. (2017), a blocking evaluation method of dynamic wavelength division multiplexing networks was studied, which considered different loads at each network connection. In a study by Yong et al. (2022), a novel analytical availability index calculation framework for adequacy evaluation was proposed based on the stochastic modeling to achieve the availability evaluation of the distribution network. In a study by Urgun et al. (2020), a new state classification approach to calculate power system reliability indices within the framework of the Monte Carlo simulation process is proposed to increase the scope and computational efficiency to evaluate reliability indices. The above documents consider indices such as real-time performance and reliability of the network; this helps to improve the rationality of the VPP end-to-end network index system but ignores the scalability of distributed resource aggregation regulation. In this, the comprehensiveness, objectivity, practicability, typicality, and standardization of the evaluation system still need to be further improved.

Research on evaluation methods of network bearing capacity mainly focuses on the analytic hierarchy process (Ge & Liu, 2019; Xiu et al., 2018; S. Zhang et al., 2016), the fuzzy analytic hierarchy process (Hao et al., 2019; Jiang et al., 2016; T. Wang et al., 2018), the Latin hypercube sampling method (Pan et al., 2018; Taghavi et al., 2022), etc. In a study by S. Wang et al. (2017), an electricity user evaluation method in smart electricity utilization was proposed. In another study by Bernardon et al. (2017), an AHP-based evaluation method for a device configuration scheme was proposed to effectively support operation planning of a low-voltage distribution station area. However, AHP can hardly reflect the ambiguity of subjective judgment. It is difficult to guarantee the consistency of the judgment matrix of AHP under a large number of evaluation indices. In a study by Dehghanian et al. (2017), a FAHP-based performance evaluation method was proposed to assess various types of components of monitoring devices in a low-voltage distribution station area. However, there still exist the following shortcomings: 1) the delay and granularity requirements of VPP multi-service differentiation are not considered; and 2) VPP end-to-end network includes remote communication and local communication, which involve a mixed networking of various communication modes. However, the existing evaluation methods evaluate only the service bearing capacity of local communication or remote communication, which cannot be applied to the bearing capacity evaluation of the VPP end-to-end network.

To solve the above problems, first, the multi-dimensional hierarchical VPP end-to-end network indices evaluation system for the differentiated multi-service bearing requirements is constructed in this paper. Secondly, the comprehensive weight is solved by the improved analytic hierarchy process (IAHP) and CRITIC, considering the demands of multi-service differentiation time sensitive. Then, the technique for order preference by similarity to an ideal solution (TOPSIS) is used to analyze the adaptability between different services and end-to-end network communication schemes, and this

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