Control Reliability Analysis of Distributed Storages in Energy Internet

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Keywords: Energy Internet, Control flow-information flow coupling, Distributed energy storage, Bayesian theory, Control reliability.

Abstract. As an important part of the Energy Internet, distributed storage energy needs to consider the comprehensive effectiveness of control flow and information flow. This article introduces that the information flow is from the energy distributed energy storage control point to the intercommunion point, and then to the energy distributed energy storage control point. On the basis of the flow-distributed energy storage control flow coupling model, the Bayesian conditional probability network theory is used to give the Energy Internet distributed energy storage controllability measurement under the condition of intercommunion interruption. This paper detects the impact of information transmission on distributed energy storage reliability by setting up an interrupt signal during information transmission. This modal is of great significance for the control of distributed energy storage.

Introduction

The Energy Internet is a network that includes energy and information intercommunions. The Energy Internet encompasses a variety of technologies, including the conversion of multiple energy sources, the application of energy storage, and the transmission of information. As an important part of the energy Internet, distributed energy storage is especially important for the management of information transmission in distributed energy storage [1-4].

Energy Internet Integrated Distributed Energy Storage Control Framework

The distributed energy storage control center obtains the state of each distributed energy storage through the transmitted information, and effectively manages the distributed energy storage. Such information is generally remote. The Figure 1 shows the control-distributed energy storage information flow coupling model. The connection relationship between the distributed energy storage control point and the intercommunion network point in the information uplink channel is represented by a distributed energy storage-intercommunion association matrix. Similarly, the connection relationship of the information downlink channel from the intercommunion point to the distributed energy storage control point is expressed as intercommunion-distributed energy storage correlation matrix.

The reliability of data transmission in the intercommunion network is represented by the inter-point connectivity (between 0-1), and the point connectivity is given by the rate of the effective path between the points to the initial effective path after the intercommunion network failure occurs. When some intercommunion points are disconnected, the connectivity rate between the intercommunion network points is reduced, and the effective reachable paths between the corresponding points are reduced. The connectivity ratio matrix between the intercommunion points is called the intercommunion network association matrix.
Distributed Energy Storage Control - Intercommunion Association Matrix

The distributed energy storage control topology and the intercommunion topology are respectively represented as $G_1=(V_1, E_1)$ and $G_2=(V_2, E_2)$. $V_1(V_2)$ and $E_1(E_2)$ respectively represent point and edge collection in $G_1(G_2)$. The collection of the $|V_1|=N_1$ and $|V_2|=N_2$ are used to represent the number of points in the distributed energy storage control topology and the intercommunion topology link. Distributed energy storage control points and intercommunion points are represented as $PN_i(i \in V_1)$ and $CN_j(j \in V_2)$. In the distributed energy storage control-intercommunion dual-network interaction model, the distributed energy storage control point often has a link association with some intercommunion points. When a distributed energy storage control point is connected to multiple intercommunion points, the distributed energy storage control point is said to have an alternate intercommunion connection. The distributed energy storage command-intercommunion association matrix is used to represent the relationship between the distributed energy storage command point and the intercommunion point.

Intercommunion-intercommunion Association Matrix

The intercommunion-intercommunion association matrix indicates the contact relationship among the intercommunion points in the model. The intercommunion service needs to transmit several intercommunion points from the sending point to the accepting point. Due to the construction principle of the intercommunion network, the intercommunion link between the beginning and ending points is often not unique. The concept of connectivity between intercommunion points to construct the association matrix between intercommunion points and intercommunion points is proposed in this part.

The matrix elements in the correlation matrix represent the connectivity between the points of the intercommunion network. In a distributed energy storage control network, the connectivity rate represents the number of paths between connection points. The path represents the way to pass information between points.

All feasible intercommunion links between the transmitting and receiving points of the intercommunion service are represented by the effective path. There are different ways of connecting between points. The path is defined as the sum of the lines and points of the connection between the points. The Figure 2 shows the example.
Integrated Controllability Assessment

The probability of success of an event is equal to the product of the success rate of the relevant event. The integrated command reliability of command flow-information flow in Energy Internet consists of several parts: distributed energy storage command point information monitoring (distributed energy storage command point-intercommunion point), monitoring information transmission (intercommunion point-intercommunion point), control command (intercommunion point - distributed energy storage command point). Based on the topology connection characteristics of each part, a command flow-information flow coupling model consisting of distributed energy storage command-intercommunion, intercommunion-intercommunion, intercommunion-distributed energy storage command is established. The components in the correlation matrix respectively indicate the connectivity ratio between the points. The related sections of the correlation matrix is taken for calculation. The reliability of each point could be calculated. The Figure 3 shows the model.

Example

This paper uses the Energy Internet distributed energy storage control topology shown in Figure 4 to verify the example. The control topology is a double-star radial network, including thirty-nine distributed energy storage control points. Point A is the center of energy Internet control master point (master). Point B is the Energy Internet control center spare point (spare control). Points three to
thirty-nine are the control points of the distributed energy storage devices. Therefore, the distributed energy storage control flow-information flow coupling model and the correlation matrix are first computed. After that, this paper studies the impact of information failure in distributed energy storage on distributed energy storage reliability.

The matrix is a highly sparse matrix. The row number corresponds to the distributed energy storage control point number, a total of thirty-nine points. The column number corresponds to the intercommunication point number, a total of twelve points (only the first 20 columns are shown in the table). Matrix elements 1, 0.5 indicate concatenation, and 0 indicates no connection (not shown). The intercommunication-distributed energy storage control association matrix is the transposed array of the matrix.

The number of valid paths between intercommunication points in the initial normal intercommunication state is shown in Table 1.

|    | 1   | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   |
|----|-----|------|------|------|------|------|------|------|------|------|
| 1  | 1   | 17.960 | 9.156 | 9.156 | 8.516 | 8.340 | 8.516 | 8.516 | 8.516 | 8.516 |
| 2  | 17.960 | 1    | 8.516 | 8.516 | 6.655 | 8.340 | 9.156 | 9.156 | 9.156 | 9.156 |
| 3  | 9.1567 | 8.5167 | 1    | 6.867 | 6.867 | 6.655 | 6.867 | 6.867 | 6.867 | 6.867 |
| 4  | 9.1567 | 8.5167 | 6.867 | 1    | 6.867 | 6.655 | 6.867 | 6.867 | 6.867 | 6.867 |
| 5  | 8.5167 | 9.1567 | 6.867 | 2    | 6.867 | 6.655 | 6.867 | 6.867 | 6.867 | 6.867 |
| 6  | 8.3404 | 8.3404 | 6.655 | 4    | 6.655 | 6.655 | 1    | 6.655 | 6.655 | 6.655 |
| 7  | 8.5167 | 9.1567 | 6.867 | 2    | 6.867 | 6.655 | 6.867 | 6.867 | 6.867 | 6.867 |
| 8  | 8.5167 | 9.1567 | 6.867 | 2    | 6.867 | 6.655 | 6.867 | 6.867 | 6.867 | 6.867 |
| 9  | 8.5167 | 9.1567 | 6.867 | 2    | 6.867 | 6.655 | 6.867 | 6.867 | 6.867 | 6.867 |
| 10 | 8.5167 | 9.1567 | 6.867 | 2    | 6.867 | 6.655 | 6.867 | 6.867 | 6.867 | 1    |

Scenario 1: The spare point (point B) fails.
When the standby adjustment point (Point B) in the intercommunication network fails, its intercommunication-intercommunication association matrix is calculated.

Scenario 2: Assume that point six is in intercommunication failure, and point twenty five point nine directly connected to point six. The Energy Interconnection distributed energy storage controllable probability matrix is shown in Table 2. Since the point six is located at the end of the intercommunication network, it has little effect on the topology of the entire intercommunication network after the intercommunication failure occurs, which only affects the surrounding energy distributed energy storage points. At this time, the degree of controllability between the point nine directly connected to the point six and other energy points is greatly reduced.

Scenario 3: The point six-point nine intercommunication line fails. The total network distributed energy storage controllable probability is shown in Table 2. After an intercommunication failure occurs, this fault only affects the surrounding points and has little effect on the points in other places. In this failure, the control between point six and point nine has decreased due to this failure.
Table 2. Differences of controllability probability under different failure conditions.

| Point controllable probability | Scenario 1 | Scenario 2 | Scenario 3 |
|-------------------------------|------------|------------|------------|
| B-point 9                     | 0.060 4    | 0.520 4    | 0.542 2    |
| point6-point9                 | 0.176 2    | 0          | 0.823 8    |
| B-point6                      | 0.176 2    | 0.941 2    | 0.979 1    |

Table 2 shows the controllable probability comparison of energy-related points in different intercommunion failure scenarios. After the intercommunion failure of the standby point, the information exchange network has changed from the original network topology to a single connection structure. The connection rate of the entire network is thus reduced. The other two forms of failure do not have much impact on the entire network, only slightly affecting the points around the fault, and have little effect on the points elsewhere.

Summary

Based on the Energy Internet, this paper establishes the Energy Internet distributed energy storage control flow-information flow coupling model, which fully considers the intercommunion network topology, Internet information flow accessibility and flow accessibility. Based on conditional probability Bayesian theory, this paper gives the definition and calculation method of controllable probability under intercommunion congestion. Through the analysis of three practical cases, the controllable probability matrix under different fault conditions is obtained, and the validity of the calculation method of controllable probability between Energy Internet distributed energy storage points under different connection interruption schemes is verified. The Bayesian-based Energy Internet distributed energy storage control flow-information flow coupling model proposed in this paper is of great importance to make power decisions and improve stability in signal transmission.

Acknowledgment

This work was supported by State Grid (Suzhou) City & Energy Research Institute (Economic Modeling Analysis of User-side Cold and Thermal Power Storage System).

References

[1] Li Dezhi, Tian Shiming, Wang Weifu, Gong Feixiang, et al. Business Model Research and Economic Analysis of Distributed Energy Storage [J]. Distribution and Utilization. 2019, 36 (04): 86-91.

[2] Jia Yangyang, Han Aoyang, Yu Litao, Zhang Zhisheng. Research on Economic Dispatching of Distributed Energy System with Energy Storage Device [J]. Journal of Qingdao University (Engineering and Technology Edition), 2019, 34(01): 53-57.

[3] Gan Wei, Guo Jianbo, Li Xiangjun, Ai Xiaomeng, et al. Distributed Energy Storage Optimization Scheduling for Multiple Application Requirements [J]. Power System Technology, 2019, 43 (05): 1504-1511.

[4] Tian Shiming, Luan Wenpeng, Zhang Dongxia, Sun Yaojie, et al. Energy Internet technology form and key technologies [J]. Proceedings of the CSEE, 2015, 35(14): 3482-34.