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Evaluation of Criticality and Vulnerability of Busbar Based on Voltage Dip

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Abstract

For the purpose of evaluating the busbar voltage dip in the grid and guiding the planning, operation and reconstruction of the grid, and in consideration of various types of busbar faults and different grid operation modes, this paper establishes the evaluation indices for busbar voltage dip in the grid and defines the busbar criticality index and busbar vulnerability index from two perspectives: the influence of busbar fault, and the frequency of voltage dips caused by the fault of other busbars. The indices are employed to identify the critical and vulnerable busbars in the grid, and to evaluate the grid operation mode and grid planning/reconstruction plans, providing guidance to the planning, reconstruction and operation optimization of the grid. Finally, the feasibility of the proposed indices is proved by an example.

Key words

Busbar, fault, voltage dip, analysis, evaluation, index

1. Introduction

With the increasingly extensive utilization of electric and electronic devices in recent year, the electrical load is more and more sensitive to voltage dip, one of the most widely complained issue among power consumers. Possible causes of voltage dip include short circuit [1], switching operation, switching of transformer and capacitor banks [2], and starting of large-capacity motors [3] [4] in the power system. Short circuit-induced voltage dip often has a sharper voltage drop and a wider scope of influence than that caused by any other reasons. Against this backdrop, it is of great significance to analyze voltage dip and establish evaluation indices for the analysis [5]-[8].

Currently, there are two ways to make stochastic predictions for voltage dip: critical distance method [9] and fault point method [10]. The critical distance method only applies to the radial network and determines the amplitude of voltage dip caused by line fault [11]. In contrast, the fault point method applies to any network because it calculates the voltage dip amplitude based on the potential fault locations, fault types and fault probability. Thus, this paper selects the fault point method to analyze the voltage dip resulted from busbar fault.

Many researchers have put forward quantification indices for the influence and vulnerability of node voltage dip. For instance, Literature [12] suggests measuring the influence of different fault points on grid voltage dip by the voltage dip coefficient of fault points. However, the suggestion faces immense difficulty in determining the load-sensitive factors. Literature [13] defines the indices to identify the vulnerable parts of the grid based on the influence of fault points on voltage dip amplitude and the number of occurrences of voltage dips. In light of positive sequence, negative sequence and zero sequence impedance matrices, Literature [14] establishes a matrix for fault phase and non-fault phase voltage dips, offering a solution to determining the voltage sag of single-phase power-to-ground short-circuit. The solution does not apply to the distribution network because it ignores the line resistance. In short, none of the above has taken into account of the effect of busbar fault, fault type and grid operation mode on voltage dip. Despite the low probability, busbar fault often leads to severe voltage dips. Besides, grid operators ought to pay more attention to voltage dips on busbars. Once it is identified which busbars in the system have a big impact on voltage dip in the case of failure and which busbars are prone to faults and frequently hit by voltage dips, it would be of great help to selection of new access points for sensitive loads, and evaluation of grid operation mode and planning and reconstruction plans.

In consideration of the fault type of busbar and the operation mode of the grid, this paper analyzes the voltage dip caused by busbar fault, and establishes the voltage dip matrix and voltage sag matrix. From the perspectives of the influence of busbar fault and the frequency of voltage dips caused by the fault of other busbars, the author defines the busbar criticality index and busbar vulnerability index in the grid, aiming at identifying the critical and vulnerable busbars in the grid, and evaluating the grid operation mode and grid planning/reconstruction plans. The research results provide reference to enhancing the structure of the grid, selecting the optimal mode of operation, identifying the access points for new sensitive loads, and transferring the sensitive loads. In short, the findings can improve user satisfaction and guide the planning, reconstruction and operation optimization of the grid.

2. Analysis of Voltage Dip Caused by Busbar Fault

Although busbar outlet is more likely to break down than busbar itself, the voltage dip caused by busbar outlet has far lighter consequences than that caused by busbar. For the convenience of evaluation, all the faults on busbar outlet are converted to busbar faults. There are 4 types of busbar fault: single-phase to ground fault, two-phase short circuit, two-phase to ground fault, and three-phase short circuit. Among them, three-phase short circuit has the most serious damages and impacts, while single-phase ground fault is most likely to occur. Therefore, voltage dip should be analyzed based on the specific fault type.

In operation mode *h*, the author uses fault point method [10] to calculate the voltage dip of grid busbars on the assumption that all busbars in the grid suffer from each of the four types of fault, and constructs a busbar voltage dip matrix $U_h^{(m)}$(*m*=1, 2, 3 & 4, respectively representing single-phase to ground fault, two-phase short circuit, two-phase to ground fault, and three-phase short circuit) to reflect the conditions when all grid busbars suffer from each type of fault.

$$U_h^{(m)}=\begin{bmatrix} U_{11,h}^{(m)} & U_{12,h}^{(m)} & \cdots & U_{1j,h}^{(m)} & \cdots & U_{1n,h}^{(m)} \\ U_{21,h}^{(m)} & U_{22,h}^{(m)} & \cdots & U_{2j,h}^{(m)} & \cdots & U_{2n,h}^{(m)} \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ U_{i1,h}^{(m)} & U_{i2,h}^{(m)} & \cdots & U_{ij,h}^{(m)} & \cdots & U_{in,h}^{(m)} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ U_{n1,h}^{(m)} & U_{n2,h}^{(m)} & \cdots & U_{nj,h}^{(m)} & \cdots & U_{nn,h}^{(m)} \end{bmatrix}_{n\times n} \tag{1}$$

Where $U_{ij,h}^{(m)}=\left(U_{ij,h,A}^{(m)} \quad U_{ij,h,B}^{(m)} \quad U_{ij,h,C}^{(m)}\right)$, and $U_{ij,h}^{(m)}$ denotes the voltage of the three phases *A*, *B* and *C* of busbar *j* when busbar *i* suffers from type *m* fault. The information in row i of the matrix reflects the voltage dip on each busbar when busbar *i* fails, and the information in column *j* of the matrix reflects the voltage dip on busbar *j* when all busbars fail.

Set U_{thre} as the grid voltage dip threshold. As long as there is a value of $U_{ij,h}^{(m)}$ below the threshold, it is concluded that busbar *j* undergoes voltage dip and $X_{ij,h}^{(m)}$=1, Otherwise, $X_{ij,h}^{(m)}$=0. In this way, the following voltage drip matrix is created [15]:

$$X_h^{(m)} = \begin{bmatrix} X_{11,h}^{(m)} & X_{12,h}^{(m)} & \cdots & X_{1j,h}^{(m)} & \cdots & X_{1n,h}^{(m)} \\ X_{21,h}^{(m)} & X_{22,h}^{(m)} & \cdots & X_{2j,h}^{(m)} & \cdots & X_{2n,h}^{(m)} \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ X_{i1,h}^{(m)} & X_{i2,h}^{(m)} & \cdots & X_{ij,h}^{(m)} & \cdots & X_{in,h}^{(m)} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ X_{n1,h}^{(m)} & X_{n2,h}^{(m)} & \cdots & X_{nj,h}^{(m)} & \cdots & X_{nn,h}^{(m)} \end{bmatrix}_{n\times n} \quad (2)$$

The information in row *i* of the $X_h^{(m)}$ matrix illustrates the influence range of voltage dip caused by the fault on busbar *i*, and $\sum_{j=1}^{n} X_{ij,h}^{(m)}$ describes the total number of busbars under voltage dip when busbar *i* suffers from type *m* fault in operation mode *h*. The information in column *i* of the $X_h^{(m)}$ matrix illustrates the voltage sag of busbar *i*, and $\sum_{j=1}^{n} X_{ji,h}^{(m)}$ depicts the frequency of voltage dip of busbar *i* caused by the type *m* fault on other busbars.

Similarly, the author constructs the voltage dip matrix and voltage sag matrix for busbar under type *m* fault in each operation mode.

3. Evaluation Indices for Grid Busbar Voltage Dip Caused by Busbar Fault

For the purpose of clearly disclosing the influence of busbar fault on grid voltage dip and the frequency of voltage dip on busbar caused by faults on other busbars in different operation modes, and giving better guidance to planning and operation control, the author proposes the following evaluation indices for grid busbar voltage dip based on the above voltage dip matrix and voltage sag matrix.

3.1 Analysis of the Influence of Busbar Fault on Voltage Dip

In operation mode *h*, the influence of type *m* fault on busbar *i* on voltage dip is expressed with $C_{Bi,h}^{(m)}$:

$$C_{Bi,h}^{(m)} = \sum_{j=1}^{n} X_{ijh}^{(m)} \quad (j \neq i) \quad (3)$$

Among the four types of faults, the three-phase short circuit fault on busbar has the biggest influence. Specifically, $\max\left\{C_{Bi,h}^{(3)}\right\}(h = 1, 2, \cdots P)$ corresponds to the most influential operation mode $HC_{Bi,max}$ when busbar *i* suffers from three-phase short circuit, *P* stands for the total number of operation modes, and the $\max\left\{C_{Bi,h}^{(3)}\right\}(i = 1, 2, \cdots n; h = 1, 2, \cdots P)$ points out the most influential busbar when the three-phase short circuit occurs.

3.1.1 Busbar Criticality Index in Operation Mode *h*

The criticality index of busbar *i* in operation mode *h* is the influence on voltage dip when busbar *i* fails. It is expressed with $C_{Bi,h}$.

$$C_{Bi,h} = \sum_{m=1}^{4} \lambda_m C_{Bi,h}^{(m)} \tag{4}$$

Where λ_m indicates the probability of type *m* fault on busbar.

$C_{Bi,h}$ is used to evaluate the criticality of the fault on busbar *i* in each operation mode. $\min\{C_{Bi,h}\}(h=1,2,\cdots P)$ points out the operation mode in which busbar *i* has the minimum criticality. Any busbar with $C_{Bi,h}$ exceeding the preset threshold C_{thre} should be categorized as a critical busbar in operation mode *h*.

3.1.2 Busbar Criticality Index in the Evaluation Period

The criticality index of busbar i i The criticality index of busbar *i* in the evaluation period is the average influence on voltage dip when busbar *i* fails. It is expressed with C_{Bi}.

$$C_{Bi} = \frac{1}{T}\sum_{h=1}^{P} t_h C_{Bi,h}$$

(5)

Where t_h describes how long the grid operates in operation mode *h* during the evaluation period.

C_{Bi} is used to evaluate the criticality of busbar *i* in the evaluation period. The most critical busbar in the evaluation period can be determined by $\max\{C_{Bi}\}(i=1,2,\cdots n)$. Any busbar with C_{Bi} exceeding the threshold C_{thre} should be categorized as a critical busbar in the evaluation period.

3.1.3 Comprehensive Index for Grid Busbar Criticality in Operation Mode *h*

The comprehensive index for grid busbar criticality in operation mode *h* refers to the total influence of the voltage dip when all busbars in the grid fail in operation mode *h*. It is expressed with $C_{B,h}$:

$$C_{B,h} = \sum_{i=1}^{n} C_{Bi,h}$$

(6)

$C_{B,h}$ is used to evaluate the influence of the voltage dip when all busbars in the grid fail in different operation modes. $\min\{C_{B,h}\}(h=1,2,\cdots P)$ points out the operation mode in which the influence on voltage dip is the minimum when all busbars in the grid fail, thereby providing the basis for selecting the optimal operation mode of the grid.

3.1.4 Comprehensive Index for Grid Busbar Criticality in the Evaluation Period

The comprehensive index for grid busbar criticality in the evaluation period refers to the total average influence of the voltage dip when all busbars in the grid fail during the evaluation period. It is expressed with C_B:

$$C_B = \frac{1}{T}\sum_{h=1}^{P} t_h C_{B,h} \tag{7}$$

C_B is used to evaluate the influence of the voltage dip when all busbars in the current grid architecture fail during the evaluation period. The index C_B provides the basis for evaluating the grid planning or reconstruction plans. The process goes as follows: calculate the C_B of each grid planning/reconstruction plan, and the plan with the minimum C_B is the optimal plan.

3.2 Analysis of Voltage Dip on a Busbar When Other Busbars Fail

In operation mode *h*, the frequency of voltage dip on busbar *i* when other busbars suffer from type *m* fault is expressed with $V_{Bi,h}^{(m)}$:

$$V_{Bi,h}^{(m)} = \sum_{j=1}^{n} X_{ji,h}^{(m)} \quad (j \neq i) \tag{8}$$

Among the four types of faults, the voltage dip on a bus bar occurs most frequently when other busbars suffer from three-phase short circuit. $\max\{V_{Bi,h}^{(3)}\}(h=1,2,\cdots P)$ points out $H_{VBi,max}$, the operation mode in which the voltage dip on a bus bar occurs most frequently to busbar *i* when other busbars suffer from three-phase short circuit. $\max\{V_{Bi,h}^{(3)}\}(i=1,2,\cdots n;h=1,2,\cdots P)$ is used to determine the busbar under voltage dip when other busbars suffer from three-phase short circuit.

3.2.1 Busbar Vulnerability Index in Operation Mode *h*

The vulnerability index of busbar *i* in operation mode *h* describes the frequency of voltage dip on busbar *i* when other busbars fail in operation mode *h*.

$$V_{Bi,h} = \sum_{m=1}^{4} \lambda_m V_{Bi,h}^{(m)} \tag{9}$$

$V_{Bi,h}$ is used to evaluate the vulnerability of busbar *i* in each operation mode. $\min\{V_{Bi,h}\}(h=1,2,\cdots P)$ points out the operation mode in which busbar *i* has the least vulnerability. Any busbar with $V_{Bi,h}$ exceeding the preset threshold V_{thre} should be categorized as a vulnerable busbar in operation mode *h*.

3.2.2 Busbar Vulnerability Index in Evaluation Period

The vulnerability index of busbar *i* in evaluation period refers to the average frequency of voltage dip on busbar *i* when other busbars fail in the evaluation period.

$$V_{Bi} = \frac{1}{T} \sum_{h=1}^{P} t_h V_{Bi,h} \tag{10}$$

V_{Bi} is used to evaluate the vulnerability of busbar *i* in the evaluation period. $\max\{V_{Bi}\}(i=1,2,\cdots n)$ points out the most vulnerable busbar in the evaluation period. Any busbar with V_{Bi} exceeding V_{thre} should be categorized as a vulnerable busbar.

3.2.3 Comprehensive Index for Grid Busbar Vulnerability in Operation Mode *h*

The comprehensive index for grid busbar vulnerability in operation mode *h* refers to the total frequency of the voltage dip on each busbar when other busbars in the grid fail in operation mode *h*. It is expressed with $V_{B,h}$:

$$V_{B,h} = \sum_{i=1}^{n} V_{Bi,h} \tag{11}$$

$V_{B,h}$ is used to evaluate the frequency of the voltage dip on a bus when other busbars in the grid fail in different operation modes. $\min\{V_{B,h}\}(h=1,2,\cdots P)$ points out the operation mode in which the frequency of voltage dip on a busbar is the minimum when all busbars in the grid fail, thereby providing the basis for selecting the optimal operation mode of the grid.

3.2.4 Comprehensive Index for Grid Busbar Vulnerability in the Evaluation Period

The comprehensive index for grid busbar vulnerability in the evaluation period refers to the total average frequency of the voltage dip on a bus bar when other busbars in the grid fail during the evaluation period. It is expressed with V_B:

$$V_B = \frac{1}{T}\sum_{h=1}^{P} t_h V_{B,h} \tag{12}$$

V_B is used to evaluate the frequency of the voltage dip on a busbar when all busbars in the current grid architecture fail during the evaluation period. The index V_B provides the basis for evaluating the grid planning or reconstruction plans. The process goes as follows: calculate the V_B of each grid planning/reconstruction plan, and the plan with the minimum V_B is the optimal plan.

4. Application Principles

In practice, the following principles should apply:

(1) Try to avoid operating in locations of critical or vulnerable busbars.

(2) If the failure rate of a critical busbar (including the line it serves) is significantly increased due to bad weather or equipment problems, the operation mode should be adjusted in a timely manner so that it is no longer a critical busbar.

(3) Do not use vulnerable busbars that are frequently affected to supply power to voltage-sensitive loads.

(4) Reduce the number of critical busbars and vulnerable busbars on the grid, if necessary, by adjusting the grid architecture and strengthening the expansion planning and construction of the power supply.

5. Case Study

In practice, the following principles should apply: The IEEE-30 busbars system shown in Figure 1 is used as an example in this study, the system parameters can be found in literature [16]. The system contains two voltage levels: 132 kV and 33 kV, and consists of 6 generating units, 30 buses, 37 lines and 4 transformers. The connection mode of every transformer is Y0/Y0. Four operation modes are tested for a year. The first mode to operate for 7,320h is shown in figure 1, the second mode operates for 360h with switches on line 16-17, line 20-10 & line 23-24 break, the third mode operates for 480h with switches on line 5-7, line 2-6 & line 4-6 break, and the fourth mode operates for 600h with switches on line 5-7, line 2-6, line 4-6, line 16-17, line 20-10 & line 23-24 break. In the example, the probability [17] of occurrence of single-phase short circuit is 0.83 that of the two-phase short circuit is 0.08, that of the three-phase short circuit is 0.04, and that of the two-phase to ground fault is 0.05.

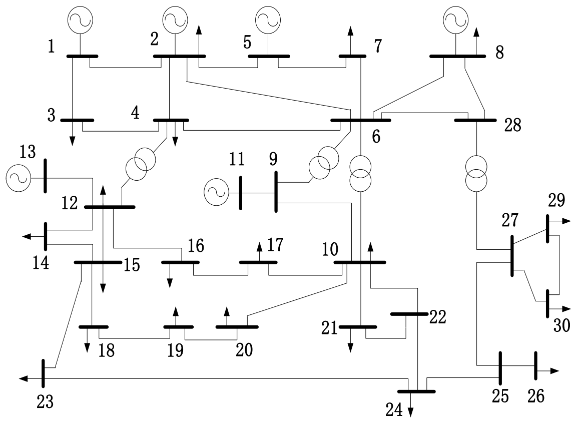

Fig. 1. Example analysis of voltage dip caused by busbar faults

According to the above mentioned analysis method, evaluation indices and application principle for voltage dip in the grid, the author calculates and analyzes the grid illustrated in Figure 1. The busbar criticality and vulnerability indices are displayed in Tables 1&2. The threshold of voltage dip amplitude U_{thre} is 0.7.

Table 1. Busbar criticality index

Busbar	$C_{Bi,h}$				C_{Bi}	$\max\{C^{(3)}_{Bi,h}\}$	$Hc_{Bi,max}$
	h=1	h=2	h=3	h=4			
1	14.36	14.36	4.87	12.92	13.74	15	1 2
2	26.96	27.36	5.86	13	24.86	28	1 2
3	12.44	13.27	4.14	10.34	11.88	27	1 2
4	26.38	26.38	7.74	10.38	24.26	29	1 2
5	6.6	6.6	1.9	1.92	6.022	7	1 2
6	28.08	28.04	20.6	15.09	26.78	30	1
7	4.78	4.71	6.78	15	5.587	22	1
8	27.76	27.2	20.31	15.92	26.52	28	1 2
9	19.9	13.01	21.96	16	19.46	24	3
10	19.12	11.04	21.99	14.13	18.6	24	3
11	3.76	6.6	8.35	15.28	4.917	16	4
12	17.28	9	18.02	10.84	16.54	22	3
13	10.52	9	10.41	9	10.35	11	1 3
14	6.23	8	6.25	8.04	6.428	9	4
15	15.24	8.09	15.3	8.09	14.46	20	3
16	12.09	8	13.14	8	11.7	16	3

17	13.78	8	15.8	11.31	13.48	22	3
18	6.63	6.1	6.57	6.18	6.574	13	1 3
19	6.54	5.09	10.08	5.92	6.632	12	1 3
20	10.1	4.89	10.35	5.09	9.556	15	3
21	18.17	11	18.22	14.09	17.6	23	3
22	18.17	10.96	18.22	14.09	17.6	23	3
23	10.21	6.18	11.52	6.34	9.851	18	3
24	15.18	10	15.21	10.44	14.64	19	3
25	6.09	6.14	6.08	8.27	6.241	11	4
26	2	2.15	2.13	2.27	2.032	5	4
27	5.92	6	6.77	9.12	6.18914	13	4
28	20.92	16.21	17.63	15	20.14	26	1
29	3.18	4.84	4.79	5	3.461	5	1234
30	3.18	3.18	3.15	5	3.303	5	1234
$C_{B,h}$	391.57	321.4	334.14	302.1	—	—	—
C_B	—	—	—	—	379.4	—	—

Table 2. Busbar vulnerability index

Busbar	$V_{Bi,h}$				V_{Bi}	$\max\left\{V_{Bi,h}^{(3)}\right\}$	$Hv_{Bi,max}$
	h=1	h=2	h=3	h=4			
1	4.26	4.26	2.34	2.32	4.02	6	1 2
2	6.17	6.21	3.26	3.23	5.81	10	2
3	8.09	7.26	4.92	4.87	7.66	9	1 2
4	9.05	8.09	4.92	4.87	8.5	11	1
5	5.18	5.18	2.92	2.89	4.9	7	1 2
6	9.88	9.88	6.27	9.1	9.62	12	4
7	8.17	8.17	6.27	9.1	8.13	12	4
8	6.26	6.26	3.59	6.25	6.113	10	4
9	11.03	11.18	9.54	10.07	10.9	15	3
10	17.08	12.1	15.19	11.07	16.36	20	1
11	1.25	2.17	2.08	3.02	1.45	5	1 3
12	12.46	9.85	9.38	9.17	11.96	18	1
13	2.17	2.22	2.09	2.15	2.17	5	1 2 4
14	17.2	11.9	15.03	11.89	16.5	21	1
15	19.93	13.64	17.76	12.87	19.07	21	1
16	14.47	9.85	12.42	9.17	13.8	21	1
17	16.12	12.11	15.98	11.07	15.6	20	1
18	20.68	13.76	17.77	12.87	19.7	21	1
19	20.72	13.76	18.68	12.87	19.78	22	1
20	18.9	13.71	17.77	12.87	18.2	22	1
21	16.29	12.15	16.1	12.79	15.87	21	1
22	16.2	12.24	16.15	12.79	15.8	20	1
23	20.89	13.63	18.65	12.87	19.92	23	1
24	19.18	15.02	18.08	12.87	18.5	24	1
25	17.45	16.07	16.28	15.76	17.2	22	1
26	17.45	16.11	16.28	15.76	17.2	22	1

27	15.33	15.19	13.49	14.86	15.19	19	1
28	9.05	9.05	7.28	10.01	9.02	13	1
29	15.33	15.19	13.49	14.78	15.18	19	1
30	15.33	15.19	13.49	14.86	15.19	19	1
$V_{B,h}$	391.5	321.4	334.4	302.1	—	—	—
V_B	—	—	—	—	379.4	—	—

5.1 Identification of Critical Busbars

When the threshold C_{thre}=20, it can be seen from Table 1 that busbars 2, 4, 6, 8 & 28 are the critical busbar of the first operation mode, busbars 2, 4, 6 & 8 are the critical busbar of the second operation mode, busbars 6, 8, 9 & 10 are the critical busbar of the third operation mode, there are no critical busbar in the forth operation mode, busbars 2, 4, 6, 8 & 28 are the critical busbar in the evaluation period.

According to $\max\left\{C_{Bi,h}^{(3)}\right\}(i=1,2,\cdots 30; h=1,2,3,4)=C_{B6,1}^{(3)}=30$, it is determined that busbars 6 cause the most influential voltage dips when it suffers from three-phase short circuit in operation mode 1.

5.2 Identification of Vulnerable Busbars

When the threshold V_{thre}=15, it can be seen from Table 1 that busbars 10, 14, 15, 17, 18, 19, 20 21, 22, 23, 24, 25, 26, 27, 29 & 30 are the vulnerable busbar of the first operation mode, busbars 24, 25, 26, 27, 29 & 30 are the vulnerable busbar of the second operation mode, busbars 10, 14, 15, 17, 18, 19, 20, 21, 22, 23, 24, 25 & 26 are the vulnerable busbar of the third operation mode, busbars 25 & 26 are the vulnerable busbar in the forth operation mode, busbars 10, 14, 15, 17, 18, 19, 20 21, 22, 23, 24, 25, 26, 27, 29 & 30 are the vulnerable busbar in the evaluation period.

According to $\max\left\{V_{Bi,h}^{(3)}\right\}(i=1,2,\cdots 30; h=1,2,3,4)=V_{B24,1}^{(3)}=24$ shows that the busbar causing the most frequent voltage dips during three-phase short circuit is busbar 24 operating in mode 1. Therefore, busbars 24 should not serve as the access points of sensitive loads.

5.3 Determination of the Optimal Operation Mode

The indices $C_{B,h}$ and $V_{B,h}$ help evaluate the criticality and vulnerability of grid busbars in different operation modes. As shown in Table 1, $\min\left\{C_{B,h}\right\}(h=1,2,3,4)=C_{B,4}=302.1$, i.e. the operation mode 4 is the mode in which the voltage dip is least influential when all busbars in the grid fail. According to Table 2, $\min\left\{V_{B,h}\right\}(h=1,2,3,4)=V_{B,4}=302.1$, indicating that the operation mode 4 features the fewest total frequency of voltage dip on a busbar when other busbars fail in the grid.

As the optimal operation mode of the grid, mode 4 should be adopted for longer time during the year.

5.4 Analysis of Comprehensive Indices of the Grid in the Evaluation Period

Referring to Tables 1&2, it is known that C_B=V_B=379.4. The two comprehensive indices reflect the average influence and the total average frequency of fault of each busbar in the grid during the evaluation period. If the grid needs reconstruction in future, the plans should be compared based on their corresponding comprehensive indices.

6. Conclusion

Based on the fault point method and in view of busbar fault types and grid operation modes, this paper defines the busbar criticality index and vulnerability index from such two perspectives as the influence of busbar fault, and the frequency of voltage dips caused by the fault of other busbars, uses the proposed indices to evaluate the voltage dip of busbars in the grid, and identifies the critical and vulnerable busbars in the grid. The conclusions can provide valuable references for selecting the optimal operation mode of the grid, choosing the best grid planning or reconstruction plans, identifying the access points of new sensitive loads and transferring sensitive loads. Moreover, the findings help make targeted guidance planning, operation and transformation, thus ensuring the safe operation of the grid.

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