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Static Voltage Stability Analysis of Beijing Power Grid under Minimum Output Mode

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Abstract. According to the national air pollution control plan, the output of generators in Beijing power grid will be decreased, which may lead to voltage stability becoming worse. In order to analyze the changes of static voltage stability under minimum output mode, the impedance modulus margin index and sensitivity index of Beijing 2017 power grid are calculated, and the results of the two modes are compared in this paper. The results show that the reduce of generator output can enhance the power flow on transmissions, leading to the decline of static voltage stability, and change the relative order of bus voltage stability, but will not change the distribution of system voltage weak areas a lot.

Introduction

As a ultra large city power grid, Beijing power grid is an important part of Beijing-Tianjin-Hebei Power Grid. In addition to assume the task of supplying power to the capital, it also transfer power to the neighboring area. In 2017, the load of Beijing area is about 25 000MW, and about 40% of the load can be met by the capacity in the area, the rest need to be sent from Hebei and Shanxi province.

According to the national air pollution control plan, thermal power units in Beijing will be gradually shut down, and part of the load will be supplied by gas units. At the same time, with the further growth of the load, the proportion of external electricity will continue to increase. So the stability of the Beijing power grid system may become worse, especially when the gas pipeline failure, causing gas turbines forced to stop working. Due to the lack of adequate dynamic reactive power supply in the local power supply, the system voltage stability problem may be exposed earlier than the power angle stability problem under minimum output mode. Therefore, the study of the voltage stability margin of Beijing power grid under minimum output mode, the determination of the weak voltage area and the development of the corresponding reactive power compensation plan are of great significance to enhance the security of the power grid voltage and improve the safety of power consumption.

Voltage stability can be divided into mainly two categories: small disturbance voltage stability (static stability) and large disturbance voltage stability (transient stability). Static voltage stability analysis methods are based on power flow equations. The critical point of static voltage stability means the maximum transmission power point in physics, and the singular point of power flow Jacobian matrix in mathematics[1].

Researchers have proposed a variety of static analysis indicators of voltage stability so far, which can be divided into two categories: state index and margin index. The state indexes include the sensitivity index, the characteristic value index, the index based on the power flow solution, the local index, the impedance modulus margin index and so on[2,3,4,5,6,7,8]. With the help of the stability index, the network operator can identify the weak areas in the power system, so as to determine the risk of voltage instability. Through the identification of the weak link of the system, some reactive power compensation can be used to improve the voltage stability of the key node or region.

In this paper, the static voltage stability of Beijing power grid under minimum output mode is analyzed. Taking the 2017 Beijing power grid as an example, the number of the impedance modulus margin index and sensitivity index at each load bus are calculated under common mode and minimum output mode, which means almost half of the generators are shut down. Then, the index numbers are listed in a chart, in order to compare the differences of the static voltage stability and weak bus or area between the two modes. In this paper, the PSD-BPA tools developed by China Electric Power Research Institute will be used to simulate.

Static voltage stability index

The static voltage stability index is a measure of the distance collapse of the system. It is used to measure the load carrying capacity of the power system to the active load of the whole network or the node's ability to resist little disturbance. Among many static voltage stability indexes, the impedance modulus margin index and sensitivity index are the most commonly used in engineering. So in this paper, these two indexes are chosen for analysis.

Impedance Modulus Margin Index. When the load of the system reaches the transmission power limit, the system will be in a critical state. In this state, if the load increases a certain amount, the system voltage level will drop rapidly, leading to voltage instability. In order to study the stability of a critical bus, the impedance of this bus can be network equivalent (i.e. system Thevenin equivalent impedance), then forms a Thevenin equivalent system shown in Fig. 1.

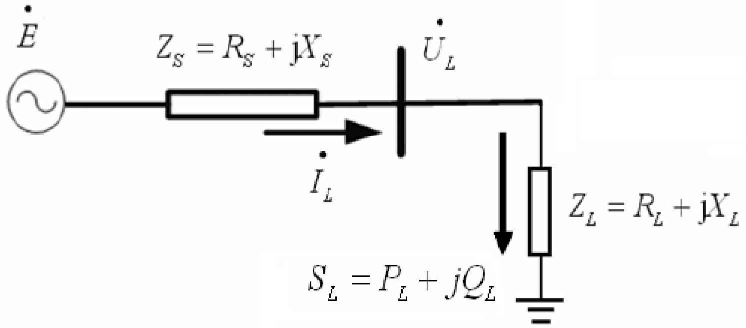

Fig. 1 Thevenin equivalent system

For the Thevenin equivalent system shown above, the voltage of the load can be written as:

$$U_L = \sqrt{E^2/2 - P_L R_S - Q_L X_S \pm \sqrt{(P_L R_S + Q_L X_S - E^2/2)^2 - Z_S{}^2 (P_L{}^2 + Q_L{}^2)}} \tag{1}$$

When the voltage has a unique solution, the system is in critical state. At this time, there has:

$$(P_L R_S + Q_L X_S - E^2/2)^2 - Z_S{}^2 (P_L{}^2 + Q_L{}^2) = 0 \tag{2}$$

The unique solution of the voltage is:

$$U_L = \sqrt{E^2/2 - P_L R_S - Q_L X_S} \tag{3}$$

So the load equals:

$$Z_L{}^2 = \frac{(E^2/2 - P_L R_S - Q_L X_S)^2}{P_L{}^2 + Q_L{}^2} = \frac{Z_S{}^2 (P_L{}^2 + Q_L{}^2)}{P_L{}^2 + Q_L{}^2} = Z_S{}^2 \tag{4}$$

From the derivation above, it can be obtained that when the load impedance of the bus is equal to the Thevenin equivalent impedance, the transmission power of the network reaches the limit. So the load impedance and Thevenin equivalent impedance of a bus can be compared. When the load impedance is larger than the Thevenin equivalent impedance, the system voltage is stable; when the load impedance is less than Thevenin equivalent impedance, the system voltage is instable.

So the impedance modulus margin index(IMMI) can be defined as follow:

$$IMMI = \frac{|Z_L| - |Z_S|}{|Z_L|} \tag{5}$$

The value of IMMI varies from 0 to 1. When a load bus is in no-load condition, the load impedance is infinity, so the IMMI of this bus equals to 1. When the load increases gradually to the transmission power limit, the load impedance is equal to the Thevenin equivalent impedance, so IMMI of the bus equals to 0. That means the value of IMMI can reflect the distance between the current state of the system and the limit state, and can be used to determine which bus has weaker voltage stability in the system.

Sensitivity Index. The sensitivity method is used to analyze the stability of the system by calculating the sensitivity of the system variables to the disturbance. This method can give the index of voltage stability, and can easily identify the strengths and weaknesses of each bus in the system, and give the corresponding countermeasures. The most common sensitivity criteria are dU/dQ, dU/dP, etc.

The sensitivity index can be used to judge the voltage stability of the system directly. Take the voltage sensitivity of dU/dQ as an example: the value is positive means stable, and when the index is smaller, means the bus has better stability. On the other hand, negative value indicates unstable. Therefore, the voltage sensitivity index dU/dQ can be calculated, and the magnitude of the absolute value of the sensitivity value can be sorted to find the weak bus or area of the system voltage stability.

Simulation Example of Beijing Power Grid in 2017

Beijing power grid in 2017 can be divided into 8 partitions, naming from A1 to A8. The periphery of the power grid is a double loop network structure formed by the 500kV hub substations and some south Hebei 500kV substations, and the interior consists four 500kV load stations that supply power to the city. 220kV load substations and 110kV substations are in radial connection operation.

Analysis using IMMI. Based on the data of Beijing 2017 power grid under common mode, obtained the load impedance and Thevenin equivalent impedance of each load bus, then calculated the impedance modulus margin index according to formula(5) and sorted in order from small to large. The top 20 of the buses and the corresponding IMMIs under common mode are shown in table.1.

Table.1 Beijing 2017 IMMIs under common mode

Number	Station	Partition	IMMI	Number	Station	Partition	IMMI
1	Huilong	A1	0.8200	11	Lvcun	A6	0.8723
2	Laojun	A5	0.8250	12	Xizhi	A5	0.8736
3	Xiazhuang	A8	0.8275	13	Nanyuan	A5	0.8761
4	Xisha	A8	0.8414	14	Zhichun	A2	0.8779
5	Bali	A5	0.8484	15	Changchun	A5	0.8800
6	Lianhua	A3	0.8586	16	Yanshang	A8	0.8841
7	Caoqiao	A5	0.8640	17	Mibian	A3	0.8891
8	Daxing	A6	0.8647	18	Taihu	A8	0.8900
9	Huairou	A8	0.8673	19	Kunyu	A8	0.8926
10	Gaoli	A8	0.8714	20	Yuguan	A5	0.8942

Adjusted the condition of Beijing 2017 power grid to minimum output mode, then calculated the IMMIs and sorted in order in the same manner as above. The top 20 of the buses and the corresponding IMMIs under minimum output mode are shown in table.2.

Table.2 Beijing 2017 IMMIs under minimum output mode

Number	Station	Partition	IMMI	Number	Station	Partition	IMMI
1	Huilong	A1	0.7882	11	Lianhua	A3	0.8533
2	Xiazhuang	A8	0.7945	12	Xizhi	A5	0.8546
3	Laojun	A5	0.7953	13	Zhichun	A5	0.8581
4	Xisha	A8	0.8107	14	Changchun	A2	0.8600
5	Bali	A5	0.8179	15	Nanyuan	A5	0.8620
6	Gaoli	A8	0.8280	16	Taihu	A8	0.8645
7	Caoqiao	A5	0.8375	17	Yuguan	A5	0.8648
8	Daxing	A6	0.8442	18	Tuanhe	A4	0.8723
9	Lvcun	A6	0.8475	19	Kunyu	A8	0.8801
10	Huairou	A8	0.8520	20	Ronghua	A2	0.8840

From the results shown in Table.1 and Table.2, we can find that compared to the common mode, the values of IMMI become smaller, meaning the static voltage stability worse. This may because when half of generating units in the area are shut down, power flow on transmissions become heavier. In addition, the relative ordering of the IMMI values is changed, this may because the shutting down of power plants changes the distribution of power flow. However, the weak areas of the power grid have not change much, are still mainly in A5 and A8, indicating the shutdown of generation units will not change the distribution of weak areas to a great extent.

Analysis using Sensitivity Index. Based on the data of Beijing 2017 power grid under common mode, improved each load bus a small amount of reactive power, then measured corresponding voltage variation and calculated the sensitivity of dU/dQ in each bus. The top 20 of the buses and the corresponding sensitivity indexes(SI) under common mode are shown in table.3.

Table.3 Beijing 2017 SIs under common mode

Number	Station	Partition	$SI*10^{-5}$	Number	Station	Partition	$SI*10^{-5}$
1	Guanting	A5	44.575	11	Dongbei	A5	10.971
2	Bada	A7	14.427	12	Cuilin	A4	10.681
3	Lianhua	A3	12.943	13	Taoyuan	A5	10.565
4	Zuoan	A8	12.872	14	Di'an	A8	10.543
5	Caoqiao	A5	12.185	15	Caochang	A5	10.179
6	Xizhi	A5	11.852	16	Xiazhuang	A8	10.090
7	Mibian	A3	11.797	17	Huilong	A1	10.077
8	Daxing	A6	11.533	18	Maling	A8	9.815
9	Taiyang	A8	11.394	19	Lucheng	A5	9.774
10	Zhangyi	A8	11.232	20	Changchun	A2	8.844

Adjusted the condition of Beijing 2017 power grid to minimum output mode, then calculated the sensitivity indexes and sorted in order in the same manner as above. The top 20 of the buses and the corresponding sensitivity indexes under minimum output mode are shown in table.4.

Table.4 Beijing 2017 SIs under minimum output mode

Number	Station	Partition	$SI*10^{-5}$	Number	Station	Partition	$SI*10^{-5}$
1	Guanting	A5	53.325	11	Mibian	A3	13.325
2	Caoqiao	A5	18.223	12	Di'an	A8	13.117
3	Bada	A7	16.964	13	Huilong	A1	12.460
4	Xizhi	A5	15.575	14	Lucheng	A5	12.258
5	Cuilin	A4	15.382	15	Dongbei	A5	12.109
6	Taiyang	A8	14.376	16	Maling	A8	11.993
7	Zhangyi	A8	14.309	17	Yongding	A6	11.547
8	Daxing	A6	13.977	18	Cuilin	A4	11.249
9	Zuoan	A8	13.730	19	Changchun	A2	10.902
10	Lianhua	A3	13.541	20	Nanyuan	A5	10.136

The results shown in Table.3 and Table.4 are similar to the results of IMMIs shown in Table.1 and Table.2. The values of sensitivity indexes increase, the order changes and the weak areas of the power grid are still in A5 and A8.

Conclusions

According to the national air pollution control plan, thermal power units in Beijing power grid will be gradually shut down in recent years, which may lead to voltage stability becoming worse. Therefore, the study of the voltage stability margin of Beijing power grid under minimum output mode is important and useful. In this paper, the impedance modulus margin index and sensitivity index of Beijing power grid in 2017 under the normal mode and the minimum output mode are calculated, and the results of the two modes are compared. The results show that the reduce of generator output can enhance the power flow on transmissions, leading to the decline of static voltage stability, and change the relative order of bus voltage stability, but will not change the distribution of system voltage weak areas a lot.

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