Global Journal of Engineering and Technology Advances

eISSN: 2582-5003

Cross Ref DOI: 10.30574/gjeta

Journal homepage: https://gjeta.com/

(Review Article)

Check for updates

Physical test study on power system voltage collapse

Sheng Li *, Yuting Lu, Can Zhang and Yuting Zhu

School of Electric Power Engineering, Nanjing Institute of Technology, Nanjing, Jiangsu, China.

Global Journal of Engineering and Technology Advances, 2022, 13(03), 001–007

Publication history: Received on 17 October 2022; revised on 26 November 2022; accepted on 29 November 2022

Article DOI: https://doi.org/10.30574/gjeta.2022.13.3.0197

Abstract

In order to test and verify the phenomena of power system voltage collapse, this article chooses a single-load infinite-bus system and a single-machine single-load system as the sample systems based on the PS-5G test system to carry out the voltage stability physical tests, and an induction motor and an adjustable resistor are used to constitute the comprehensive load. The test results show that in the single-load infinite-bus system, with the decrease of the adjustable resistance gradually, the comprehensive load active power is gradually increasing and the load bus voltage is gradually decreasing; and the slight adjustment for the adjustable resistance can cause the load bus voltage collapse when the induction motor has the locked-rotor. In the single-machine single-load system, the locked-rotor of the induction motor can lead to the occurrence of the reactive power limit-induced bifurcation, it causes the terminal voltage of the synchronous generator and the load bus voltage to have an instantaneous collapse. The test results are conducive to comprehend the mechanisms of voltage instability and collapse in power systems.

Keywords: PS-5G Test System; Voltage Collapse; Induction Motor; Synchronous Generator

1. Introduction

Power system voltage stability refers to the ability of all bus voltages to maintain or return to the allowable range after the system is subjected to small or large disturbances during normal operation, without monotonous voltage drop or rise and voltage oscillation instability. The voltage stability of traditional power system was a hot topic in the electric power academia in the 2000s. With the large-scale grid connection of new energy generation such as photovoltaic (PV) and wind power, voltage stability has been given renewed attention, especially the voltage stability in the PV grid-connected system has become a current research hotspot [1, 2].

The voltage instability of power system is related to the characteristics of the power sending end, the power receiving end, as well as the transmission or distribution network. Voltage stability is influenced by both load characteristics (Thus also known as "load stability") and generator over-excitation limit, and it is also related to the operation of slow regulation characteristics devices [3, 4].

Induction motor is the largest type of dynamic load in power systems. When the motor locked-rotor happens, a large amount of reactive power will be absorbed by the motor, resulting in voltage collapse potentially. Therefore, induction motor is considered to be a key factor affecting the system voltage stability. When the synchronous generator reaches its reactive power limit, it will lose the ability to maintain a constant terminal voltage, resulting in voltage collapse of the generator terminal, that is, the reactive power limit-induced bifurcation [5, 6].

To further understand the mechanisms of voltage instability and voltage collapse in power systems, this paper conducts a series of physical tests based on the PS-5G test system.

* Corresponding author: Sheng Li

School of Electric Power Engineering, Nanjing Institute of Technology, Nanjing, Jiangsu, China.

2. PS-5G test system

PS-5G test system is composed of five power system comprehensive automation test benches (simulating the power plants), a microcomputer monitoring test bench (simulating the power grid dispatching center), multiple lines and loads, and an infinite power supply, etc. These five comprehensive automation test benches can be formed into a ring network, constituting the 5-generator test system, as shown in Figure 1 [7].

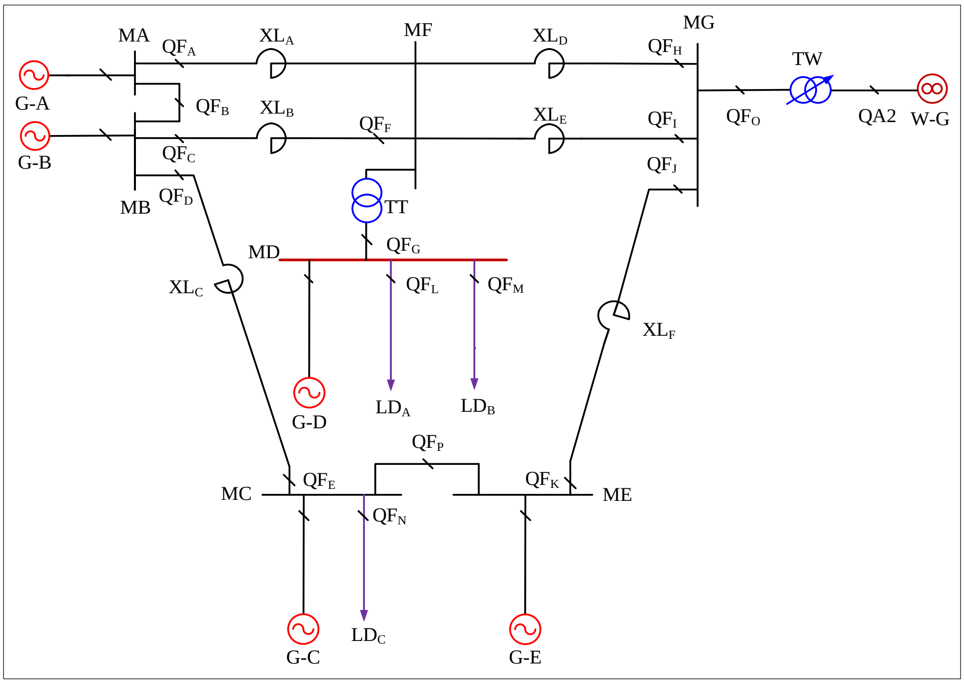


Figure 1 Connection diagram of PS-5G test system

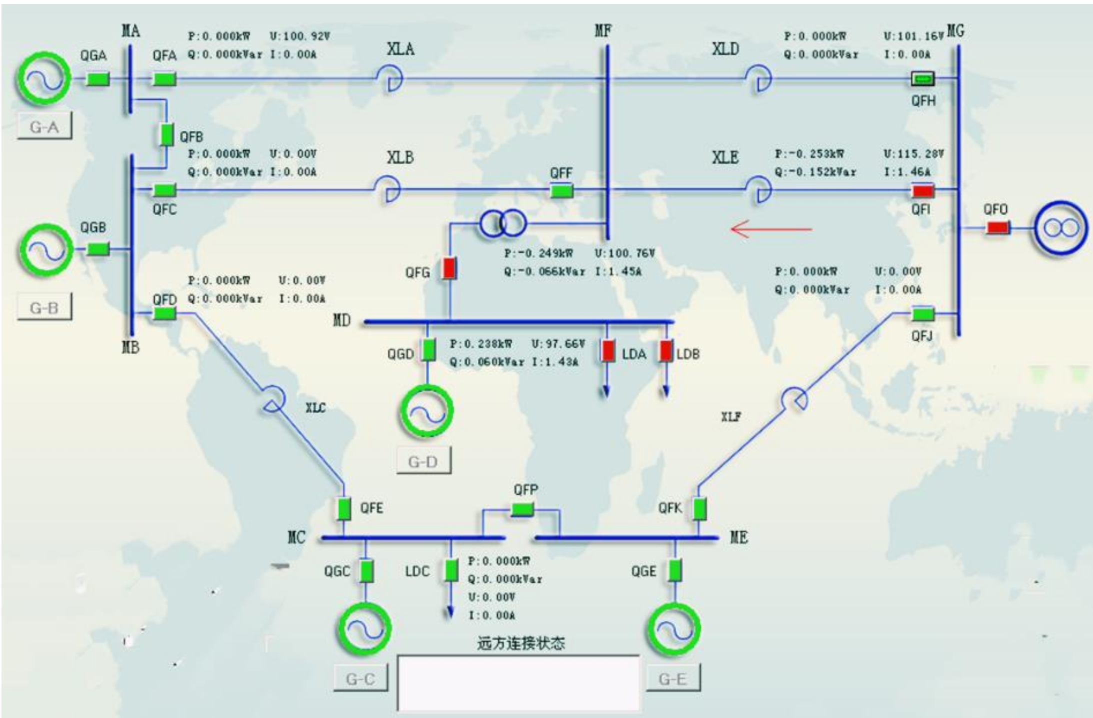


Figure 2 Monitoring interface of microcomputer monitoring test bench

The PS -5G test system is a three-phase AC system with a voltage level of 0.38 kV. Generator sets G-A, G-B, G-C, G-D and G-E provided by 5 WDT-III B comprehensive automation test benches are used to simulate 5 power plants. The infinite power supply W-G is connected to the bus MG by a 20 kVA voltage regulating transformer TW from the 380 V utility power supply, and the voltage regulating transformer can adjust the voltage of MG to the required value (line voltage). MD is the load bus, which is connected with loads LD_A and LD_B. The entire system structure is variable and optional, and different network structures can be selected by switching the breakers of line and generator on the comprehensive automation test benches.

The microcomputer monitoring test bench simulates the power grid dispatching center and uses 9 multifunctional digital electricity meters to measure the electrical quantities of all branches, including phase voltage, line voltage, phase current, active power, reactive power and frequency, etc. The monitoring interface displays the measured power data, as shown in Figure 2.

PS-5G system is helpful for the in-depth understanding of the primary and secondary equipment of power system, and can complete the re-learning process from theory to practice, verifying the theory in practice, and can also conduct test research on some innovative issues in power systems [8].

3. Physical test study on voltage stability

3.1. Selection of two typical systems

Now, based on the PS-5G test system, two typical network structures are selected by switching on and off to carry out voltage stability mechanism research. One is a single-machine infinite-bus system, as shown in Figure 3; the other is a single-machine single-load system, as shown in Figure 4. A three-phase induction motor and a three-phase adjustable resistor are added to the load side, focusing on the effect of induction motor load characteristics on voltage stability.

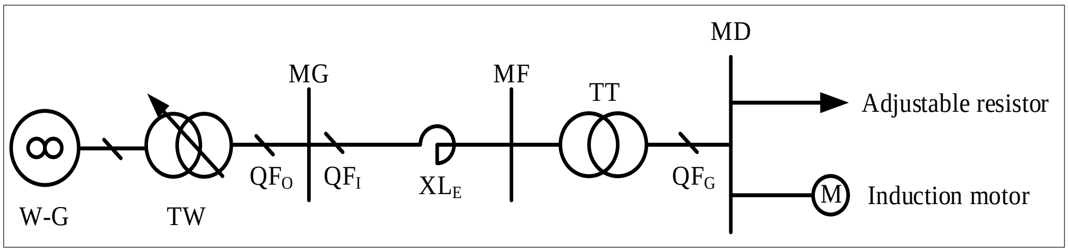


Figure 3 The single-load infinite-bus system

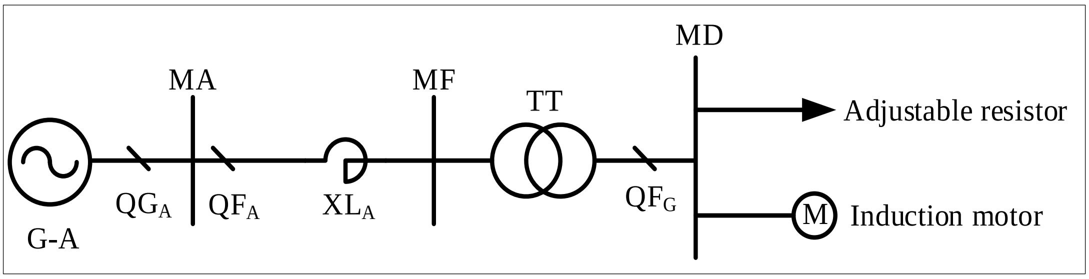


Figure 4 The single-machine single-load system

In Figure 3 and Figure 4, the impedance of transmission line XL_A is $4\angle 86°$ Ω, and the impedance of XL_E is $12\angle 86°$ Ω. The connection transformer TT capacity is 2.5 kVA, and the transformation ratio is 380 V/380 V. The load adopts a comprehensive load form composed of the adjustable resistance and the induction motor. In order to avoid excessive load current, the original load LD_A and LD_B of the system are not used. The infinite power supply W-G is connected from the utility power supply to the bus MG via the voltage regulating transformer TW. The generator G-A capacity is 2.5 kVA, the rated voltage is 0.4 kV, and the power factor is 0.8.

In order to simulate the gradual increase of comprehensive load active power to obtain the *P*-*U* (comprehensive load active power - bus voltage) curve of the system, a 3-phase adjustable resistor consisting of six 30 Ω, 5 A single-phase slide rheostat according to Y type wiring is connected to the load bus MD, and the maximum resistance value of each phase is 60 Ω. The wiring of slide rheostats is shown in Figure 5(a).

Considering that the 3-phase adjustable resistance will not cause the voltage collapse in the system, a 3-phase induction motor with different load characteristics from the resistor is connected to the bus MD. The induction motor adopts M04 type, 3-phase squirrel-cage type, rated power 100 W, rated phase voltage 220 V, rated speed 1500 rpm, and its wiring is shown in Figure 5(b).

(a) Adjustable resistor (b) Induction motor

Figure 5 Wirings of the adjustable resistor and the induction motor

3.2. Voltage stability test study for the single-machine infinite-bus system

The voltage stability physical test is carried out in the single-machine infinite-bus system shown in Figure 3, and the influence of the induction motor on the voltage stability of this system will be investigated.

The induction motor can be regarded as an approximate constant power load. To ensure the normal operation of the test, the voltage of the infinite bus MG is adjusted to 150V (line voltage). Since it is taken from the utility power supply, the voltage of bus MG can maintain constant, and the change of load has negligible effect on the voltage. The data of each electrical quantity can be viewed from the monitoring interface of the microcomputer monitoring test bench.

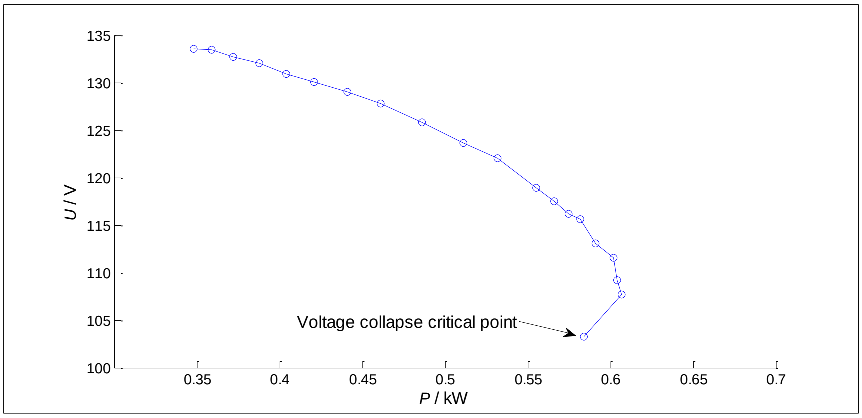
Now set the initial voltage of the bus MG as 150.86 V. Gradually reduce the resistance *R* of the adjustable resistor (the adjustment step is 0.3 Ω) to increase the active power of the comprehensive load until it is adjusted to 21 Ω, and the induction motor can run during this process. Then fine-tune the resistance value and reduce it to 20.4 Ω. At this moment, the active power *P* and reactive power *Q* of the comprehensive load are 0.607 kW and 0.099 kvar respectively, the voltage *U* of the bus MD is 107.72 V, and the motor speed *r* is 1088 rpm. The motor still can work though the voltage is low.

Continue to reduce the resistance value by 0.3 Ω, at this moment, *U* drops to 103.28 V, *P* suddenly drops to 0.584 kW and *Q* suddenly increases to 0.135 kvar, and *r* changes in a very short time from 1088 rpm down to 619 rpm and then down to 502 rpm, and finally stabilizes at 493 rpm, the motor starts to have a locked-rotor.

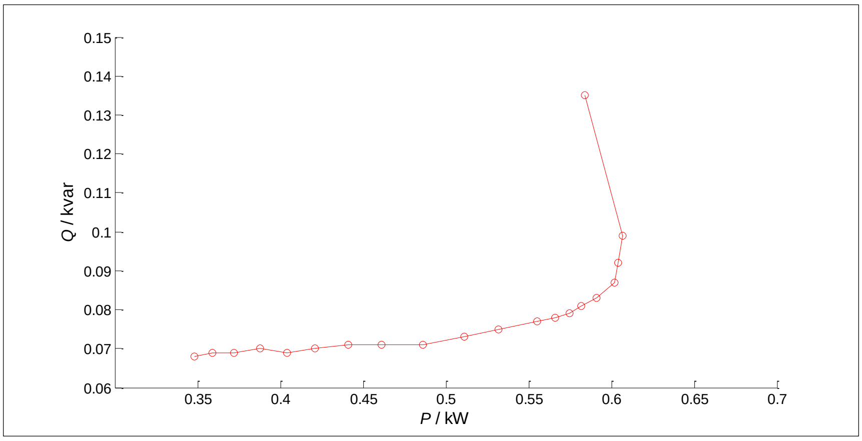
The reason for the locked-rotor of the induction motor is that with the decrease of the adjustable resistance value, the active power of the comprehensive load increases, and the voltage of the bus MD drops, so that the electromagnetic power of the motor is less than the mechanical power and a braking occurs.

Figure 6 shows the change curves of this system. From Figure 6, we can see that as soon as the induction motor has a locked-rotor, the absorbed active power by the motor decreases rapidly, while the absorbed reactive power by the motor increases significantly, and the load bus voltage drops obviously, the motor speed drops sharply.

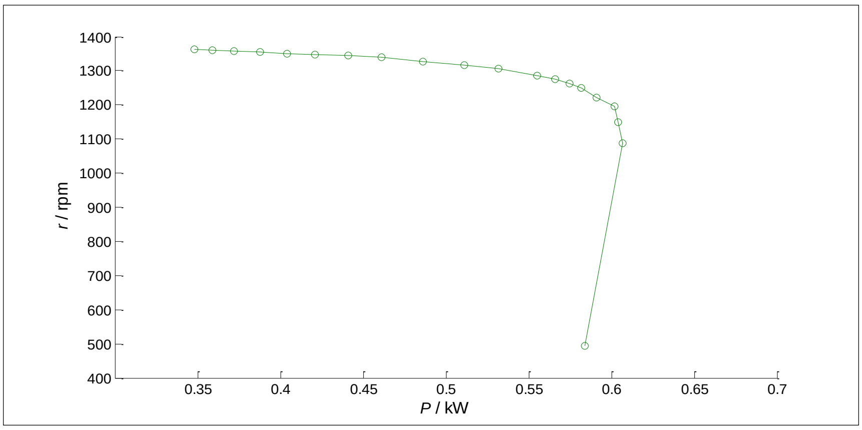
Due to the powerful support of the infinite power supply, the voltage of the bus MD will not collapse immediately at this time. If the resistance value is reduced slightly, the induction motor will stop running quickly, the speed *r* will drop to 0, and the voltage of the load bus MD will drop sharply and the voltage collapse happens. At this moment, the motor current is relatively large, in order to avoid the motor from being burned out, the power supply of the motor should be cut off quickly. The operating point with an adjustable resistance value of 20.1 Ω can be considered as the voltage collapse critical point, see Figure 6(a).



(a) *P*-*U* curve



(b) *P*-*Q* curve



(c) *P*-*r* curve

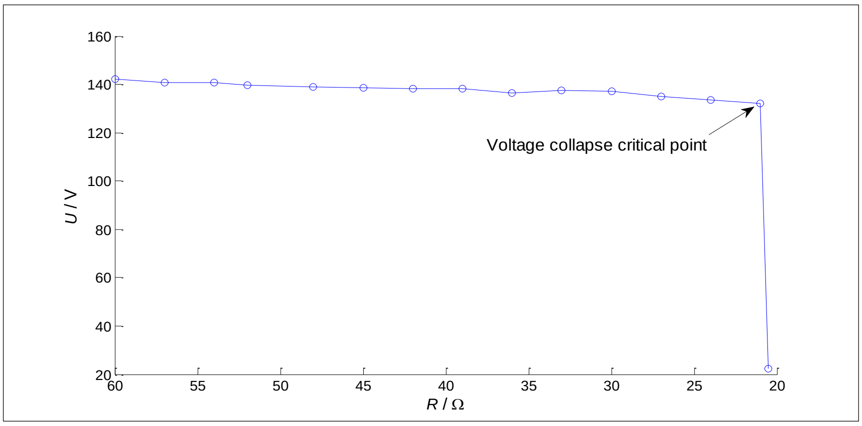
Figure 6 Change curves of the single-load infinite-bus system

3.3. Voltage stability test study for the single-machine single-load system

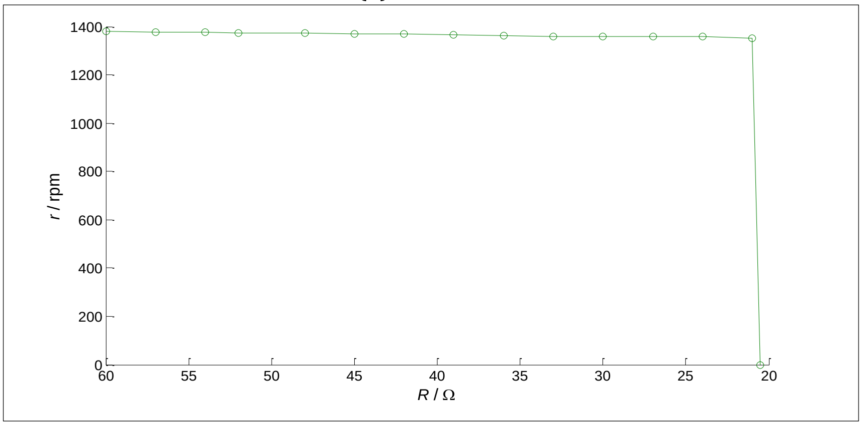
The voltage stability physical test is now carried out in the single-machine single-load system shown in Figure 4, and the influence of the limit-induced bifurcation on the voltage stability of this system will be investigated.

The excitation mode of the synchronous generator G-A chooses the self-shunt excitation mode, and the control mode of the microcomputer excitation regulator is "Constant U_F" (the mode of keeping the generator terminal voltage constant). Due to the finite capacity of the generator, in this system, any change in the load will cause a change in the generator terminal voltage. In order to ensure that the test is carried out normally, after the generator is connected, the generator terminal voltage is adjusted to 150 V (line voltage) by using the demagnetization operation.

Set the initial generator terminal voltage (the bus MA voltage) as 150.26 V. Gradually reduce the resistance value of the adjustable resistor (the adjustment step is 3 Ω), and the active power of the comprehensive load increases gradually. During the adjustment process, the voltage of the bus MD fluctuates greatly but generally shows a downward trend. When the adjustable resistance value is reduced to 21 Ω, the active power P of the comprehensive load at the bus MD increases to 0.830 kW, the voltage U decreases to 132.26 V, the motor speed r of the induction motor decreases to 1350 rpm, and the motor can still run.



(a) R-U curve



(b) R-r curve

Figure 7 Change curves of the single-machine single-load system

Now further, slightly reduce the adjustable resistance value (about 0 ~ 0.5 Ω), the motor speed r drops suddenly, from 1350 rpm to 1321 rpm in a very short time and then to 635 rpm, the motor starts to have a locked-rotor and absorbs a lot of reactive power. Immediately afterward, the generator terminal voltage drops to 32.04 V instantaneously. This is because the reactive power generated by the synchronous generator has reached the limit and could no longer maintain a constant terminal voltage, so a limit-induced bifurcation occurs. At the same moment, the voltage U of the bus MD drops to 22.50 V instantly, and the motor speed r drops to 0 rapidly, as shown in Figure 7. The operating point with an adjustable resistance value of 21 Ω can be considered as the voltage collapse critical point, see Figure 7(a).

4. Conclusion

Based on the PS-5G test system, a single-machine infinite-bus system and a single-machine single-load system are selected to conduct physical tests for the voltage stability study. The induction motor is a type of constant power dynamic load, in the single-machine infinite-bus system, when its terminal voltage drops to the locked-rotor voltage, the motor speed will drop suddenly, and the motor will absorb a large amount of reactive power, which may cause a voltage collapse at the load bus. In the single-machine single-load system, the locked-rotor of the induction motor will also cause the reactive power limit-induced bifurcation of the synchronous generator, resulting in an instantaneous voltage collapse of the generator terminal and the load bus. Physical tests verify the real existence of the limit-induced bifurcation in power systems.

Compliance with ethical standards

Acknowledgments

This work is supported by the Scientific Research Project of Nanjing Institute of Technology (ZKJ202102), and the Jiangsu Province College Student Innovation Training Plan Key Project (202211276009Z).

Disclosure of conflict of interest

The Authors confirm that the content of this manuscript has no conflict of interest.

References

[1] Sheng Li, Zhinong Wei, Yanan Ma. Fuzzy load-shedding strategy considering photovoltaic output fluctuation characteristics and static voltage stability. Energies. 2018; 11 (4): 779.

[2] LIU Yunxin, YAO Liangzhong, LIAO Siyang, XU Jian, SUN Yuanzhang, CHENG Fan, CUI Wei, LI Feng. Study on the impact of photovoltaic penetration on power system static voltage stability. Proceedings of the CSEE. 2022; 42(15): 5484-5496.

[3] CARSON W TAYLOR. Power system voltage stability. New York: McGraw-Hill; 1994.

[4] FU Xu, WANG Xifan, DU Zhengchun. Survey of power system voltage stability study. Electric Power Automation Equipment. 2016; 36 (1): 17-23.

[5] LI Ziheng, WANG Kang, LI Qi, LI Li, XIN Huanhai. Transient voltage stability analysis based on speed-voltage coordinate plane. Electric Power Automation Equipment. https://doi.org/10.16081/j.epae.202204054.

[6] ZHONG Hao, YAO Dan. Quick tracking of limit-induced bifurcation point of voltage stability. Electric Power Automation Equipment. 2014; 34(12): 65-69.

[7] Wuhan Electric Auto-technique Research Institute of HUST. Operating instruction of PS-5G power system microcomputer monitor test system. 2007.

[8] KUMA SHI Jamalihan, WANG Yangzheng, DAI Xunjiang. Experimental research of physical simulation for power system stability. High Voltage Engineering; 2007, 33(9): 129-133.