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Application analysis of voltage stability index in a power system with new energy vehicles integration

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Abstract

The paper analyses the influence of new energy vehicles on the voltage stability of the power system after grid-connected charging, and introduces two voltage stability indexes (L index and VCPI index) that can intuitively reflect the voltage stability level of the power system. Based on the typical voltage stability test model of the power system, two sets of new energy vehicle loads are added for simulation analysis, and the voltage stability state of the important buses (including the charging buses) in the system under different load combinations is observed. Through the collection of data, the L index and the VCPI index were calculated, and the accuracy of the two indexes was compared and verified.

Keywords: New energy vehicles; Voltage stability index; Charging bus; Local voltage stability index; Voltage collapse proximity index

1. Introduction

In recent years, there have been many large-scale power outages caused by voltage instability in the world, resulting in huge economic losses, and the problem of voltage stability of the power system has been highly valued, and people have carried out in-depth research. At the same time, in recent years, the excessive emission of greenhouse gases, leading to the intensification of global warming, and the contradiction between energy supply and environmental pollution have become more and more obvious. New energy vehicles as a new generation of transportation, compared with traditional cars, have incomparable advantages in energy conservation and emission reduction; therefore, new energy vehicles as new energy vehicles have, in recent years, experienced rapid development. Due to the technical problems and the need to control the cost, the current new energy vehicles generally need to store the alternating current rectification in the battery when charging, so the charging load of the new energy vehicle belongs to the nonlinear load, and the harmonics generated will pose a threat to the stability of the power grid, and the large-scale grid-connected charging of new energy vehicles will have an impact on the power grid. Therefore, it is necessary to study the impact of new energy vehicles on the voltage stability of the power grid[1,2].

2. New Energy Vehicles

2.1. Basic principles of new energy vehicles

New energy vehicles refer to vehicles powered by electric energy drive motors in whole or in part, mainly including pure new energy vehicles and rechargeable hybrid vehicles. The charging methods of new energy vehicles mainly include centralized charging and distributed charging (plug and charge). The basic structure of new energy vehicles includes charge-discharge converters, battery packs, motor drive changers, drive motors, transmission systems, and

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wheels. The alternating current of the power grid is converted into direct current by the charge-discharge converter, and the charging and discharging process of the battery pack is carried out, and then the electric energy is stored by the battery pack, and the direct current is converted into alternating current by the motor drive converter for the operation of the driving motor to realize the operation of new energy vehicles.

The main factors affecting the load of new energy vehicles are the characteristics of the power battery of new energy vehicles, the operation law, the charging mode, and the development scale, and these factors should be considered for research.

2.2. Characteristics and impacts of grid-connection new energy vehicles

The use of electric energy to replace traditional petroleum-driven vehicles with electric energy has immeasurable advantages in energy conservation and emission reduction, which has become a trend of future development. However, the integration of large-scale new energy vehicles into the grid will have a huge impact on the power system [3,4]. Because the charging load of new energy vehicles is a nonlinear load, the charging behavior has the characteristics of intermittent and random, which will cause the imbalance of the power grid load, affect the power quality of the power grid, increase the difficulty of power grid optimization, and challenge the planning of the future power grid. For example, a large number of new energy vehicles are connected to the power grid during peak hours, which will cause the power grid load peak and valley difference to be further widened, increasing the burden on the power grid. This can lead to voltage drops in the distribution network, harmonic contamination, and three-phase imbalance, resulting in damage to transformers, cables, or relay devices. At the same time, as a flexible load and energy storage device, new energy vehicles can play the role of distributed energy resources and provide auxiliary services such as frequency regulation and backup for the power grid. After the new energy vehicle is connected to the grid, the following four types of power or services can be provided for the power grid: base-load energy, peak charge energy, rotating standby service, and frequency modulation service. At the same time, as an important part of the smart grid, it can further promote the development of the new energy vehicle industry by providing and integrating a variety of real-time information in the system to meet the requirements of user interaction.

3. Voltage Stability Index

New energy vehicles can be used as a distributed power generation device; a large number of new energy vehicles connected to the grid will have a huge impact on the power grid when the load change makes it difficult to maintain the balance of the system power, eventually leading to voltage instability. Studying the voltage stability indexes can provide effective information for the dispatch of the power grid and ensure the safety and stability of the power grid operation [5].

3.1. Concept of voltage stability

When the power system is disturbed, the bus voltage can be restored to the original state or reach a new steady-state level, and the system is considered to be voltage-stable. Factors such as the operation mode of the system, the distribution of power supply and load, and the grid structure can all affect the voltage stability of the system. Load changes are a major cause of voltage instability, which can occur when a load change disrupts the balance of system power. Reference [6] proposed that load-induced crashes should measure the maximum load increase that the system can withstand before the crash occurs; Crashes caused by accidents should be able to evaluate whether the system can guarantee that no crash will occur after the accident and measure the severity of the accident. It should be possible to find the weakest area in the voltage stability in the system so that when it is necessary to prevent the occurrence of voltage instability, effective measures can be taken to deal with it.

3.2. Voltage stability index

Voltage stability index can be divided into state indexes and margin indexes, such as voltage sensitivity index (VSF), load margin index, Jacobian matrix minimum singularity index, voltage instability proximity index (VIPI) based on the saddle-node bifurcation (SNB), voltage collapse proximity index (VCPI) based on the sensitivity analysis, and local voltage stability index (L index), et al [6].

The requirements for the voltage stability index are [6]: (1) The proximity of voltage collapse: it can reflect the gap between the operating state of the system and the voltage collapse point, that is, the size of the voltage stability margin, and give a measure of voltage safety. (2) Mechanism research: the information of weak voltage areas and nodes, key generators, and branches should be reflected to provide information for determining voltage collapse, making system improvements, and implementing operation strategies.

3.2.1. Local voltage stability L index

The L index is a quantitative index that represents the distance between the actual voltage value and the stability limit value. The advantages of the L index are that the physical concept is clear, the structure is simple, the calculation is fast, and there are clear upper and lower limits, which can be used for the local regional load growth in the multi-node system, and the voltage stability problem of calculating the continuous increase of the load has sufficient accuracy, which is suitable for online analysis. The L-index is the simplest and most effective way to measure the critical range of voltage stability.

An intuitive method for calculating the L-index is described in Reference [7], as shown in Eq. (1):

$$L = \frac{4[V_0 V_L \cos(\theta_0 - \theta_L) - V_L^2 \cos^2(\theta_0 - \theta_L)]}{V_0^2} \quad \text{.....................(1)}$$

The derivation of this formula mainly uses the Thevenin equivalent method, where V_0 refers to the no-load voltage of the load bus and V_L refers to the load voltage. When the L index of the bus in the system is less than 1, the system is regarded as stable voltage; when the value is equal to 1, it is regarded as the critical value of voltage stability; when 1 is exceeded, the bus will be voltage destabilized. This index can intuitively reflect which busbars are prone to voltage collapse.

3.2.2. Voltage collapse proximity index (VCPI) based on sensitivity analysis

The VCPI index is based on the load flow equation and can be used to determine the quiescent voltage stability of each load bus in the system. According to Reference [8], the principle of VCPI is to add a small disturbance increment to a particular bus, assuming that the corresponding variable of the total reactive power output of all generators induced by this is Δ∑QG, which can be defined as follows:

$$VCPI = \frac{\Delta\Sigma Q_G}{\Delta Q_L} \quad \text{..................(2)}$$

By definition, a system with high voltage stability has a low VCPI value of the voltage collapse proximity index, with a minimum of 1. The voltage collapse proximity index VCPI of the system with adjacent voltage collapse becomes larger, and at the voltage rush point, the voltage collapse proximity index VCPI will reach infinity. The VCPI index can vividly represent the change in the total reactive power of the system after a small increment for the PQ node in the system. Its limitation is that for PQ nodes without reactive power, the calculation of VCPI index is meaningless, and there is an upper limit on the reactive power output of the generator. When the reactive power of a node changes, the reactive power input of the surrounding generator is required, and when the upper limit of the reactive power output of the surrounding generator set cannot meet the reactive power deficiency requirements, the system will have a voltage collapse, which is not reflected in the VCPI index.

4. Case Analysis

4.1. Grid-connected model of new energy vehicles

The model is based on the model of a large system with 11 busbars, consisting of two generators G1 and G2 (supplying power to the load area via five parallel transmission lines of up to 200 km) and a local generator G3 supplying power to the load area. The bus 11 is a bus that controls the voltage through an on-load transformer tap. This model has been used to analyze the voltage stability of the system under large disturbances, as well as other aspects of voltage stability, and it has been verified to be reliable. When studying the voltage stability of new energy vehicles connected to the grid, it is only necessary to add two sets of new energy vehicle models (EV1 and EV2) to the original test system, and the research on the grid connection of new energy vehicles can be carried out. As a result, the final system model added two charging station buses, DD1 and DD2. As shown in Fig. 1, the voltage stability test model of the new energy vehicle connected to the grid is the model.

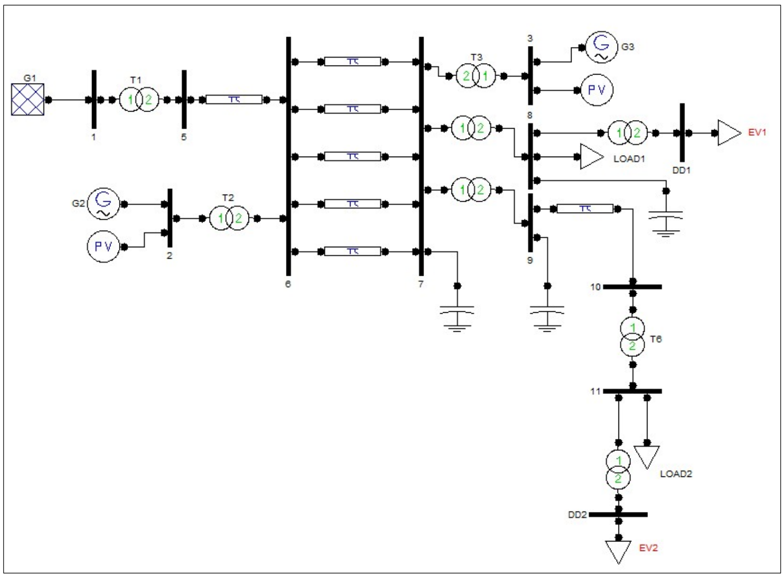


Figure 1 Voltage stability test model of new energy vehicles grid-connected system

4.2. Application analyses of L index and VCPI index

4.2.1. Calculation of L index

Change the permeability of the load of new energy vehicles, obtain the original data on the bus Bus8, Bus11, DD1 and DD2 under different load combinations, and calculate the L index of each bus. As shown in Table 1, it can be seen that with the increase of the charging load of new energy vehicles (PEV1 and PEV2), the L index value will increase accordingly, indicating that the voltage stability of the bus bar becomes poor. In Table 1, "p.u." indicates the unit value.

Table 1 L index values of important buses

P_{EV1}/p.u.	P_{EV2}/p.u.	L_8	L_{11}	L_{DD1}	L_{DD2}
0.8	0.8	0.4448	0.3193	0.4668	0.3376
0.8	0.9	0.4459	0.3205	0.4681	0.3439
0.8	1	0.4469	0.3224	0.4692	0.3510
0.8	1.1	0.4479	0.3242	0.4702	0.3591
0.8	1.2	0.4489	0.3262	0.4716	0.3685
0.9	0.8	0.4459	0.3200	0.4737	0.3386
0.9	0.9	0.4468	0.3219	0.4747	0.3449
0.9	1	0.4477	0.3234	0.4759	0.3521
0.9	1.1	0.4488	0.3251	0.4772	0.3602
0.9	1.2	0.4500	0.3270	0.4784	0.3697
1	0.8	0.4469	0.3211	0.4811	0.3396
1	0.9	0.4480	0.3226	0.4825	0.3460
1	1	0.4490	0.3244	0.4834	0.3532
1	1.1	0.4501	0.3261	0.4848	0.3615
1	1.2	0.4511	0.3280	0.4863	0.3710
1.1	0.8	0.4478	0.3222	0.4900	0.3408

1.1	0.9	0.4491	0.3237	0.4912	0.3472
1.1	1	0.4502	0.3254	0.4922	0.3545
1.1	1.1	0.4513	0.3272	0.4936	0.3628
1.1	1.2	0.4523	0.3292	0.4950	0.3722
1.2	0.8	0.4493	0.3232	0.4998	0.3419
1.2	0.9	0.4502	0.3247	0.5010	0.3483
1.2	1	0.4515	0.3264	0.5024	0.3557
1.2	1.1	0.4524	0.3284	0.5037	0.3641
1.2	1.2	0.4536	0.3304	0.5051	0.3738

4.2.2. Calculation of VCPI index

Change the permeability of the load of new energy vehicles to obtain the raw data on Bus8, Bus11, DD1 and DD2 under different load combinations, and calculate the VCPI index of each bus, as shown in Table 2. It can be seen that with the increase in the charging load of new energy vehicles, the VCPI index value also increases, indicating that the voltage stability of the bus becomes poor.

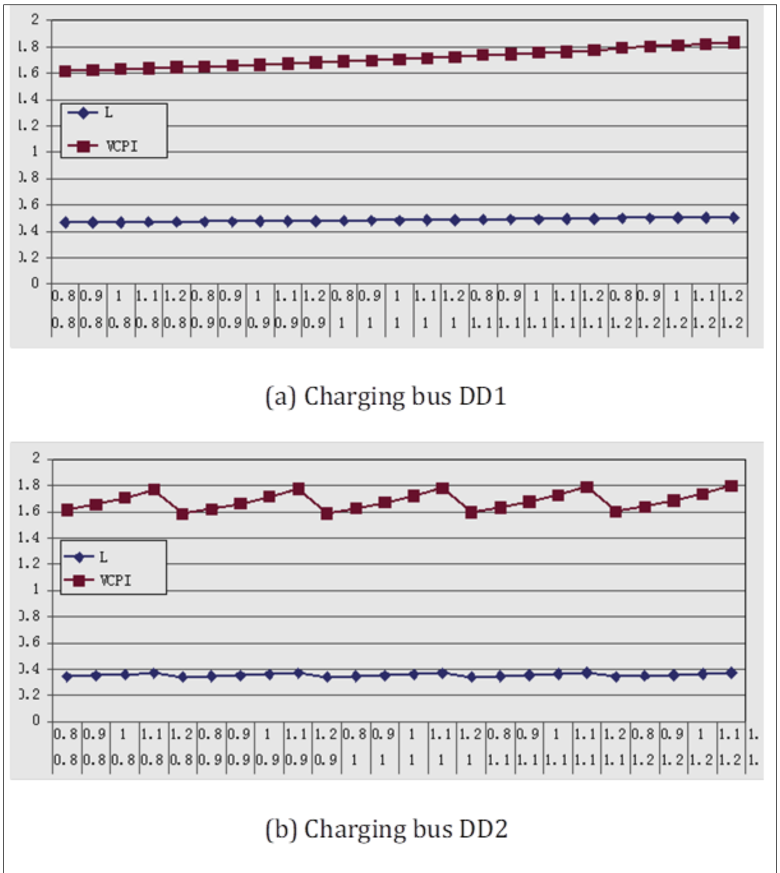
Table 2 VCPI values of important buses

P_{EV1}/p.u.	P_{EV2}/p.u.	$VCPI_8$	$VCPI_{11}$	$VCPI_{DD1}$	$VCPI_{DD2}$
0.8	0.8	1.492	1.461	1.616	1.578
0.8	0.9	1.499	1.470	1.623	1.614
0.8	1	1.505	1.481	1.631	1.657
0.8	1.1	1.512	1.492	1.639	1.707
0.8	1.2	1.520	1.505	1.648	1.768
0.9	0.8	1.498	1.466	1.650	1.583
0.9	0.9	1.505	1.476	1.658	1.620
0.9	1	1.511	1.486	1.665	1.663
0.9	1.1	1.518	1.497	1.675	1.715
0.9	1.2	1.527	1.511	1.684	1.775
1	0.8	1.505	1.471	1.691	1.588
1	0.9	1.511	1.481	1.698	1.626
1	1	1.517	1.491	1.706	1.669
1	1.1	1.525	1.503	1.716	1.722
1	1.2	1.533	1.515	1.725	1.782
1.1	0.8	1.512	1.478	1.739	1.595
1.1	0.9	1.517	1.486	1.746	1.633
1.1	1	1.526	1.498	1.756	1.677
1.1	1.1	1.532	1.508	1.764	1.728
1.1	1.2	1.539	1.521	1.774	1.789
1.2	0.8	1.518	1.483	1.794	1.602
1.2	0.9	1.525	1.493	1.803	1.639

-1.2	1	1.532	1.503	1.812	1.685
1.2	1.1	1.540	1.515	1.822	1.737
1.2	1.2	1.548	1.528	1.834	1.798

4.2.3. Comparative analysis of the index curves

Fig. 2 shows the change curves of the two indexes on the new energy vehicle charging buses DD1 and DD2, which can intuitively reflect the performance of the indexes.



(a) Charging bus DD1

(b) Charging bus DD2

Figure 2 The change curves of L index and VCPI index on the charging buses of new energy vehicles

By drawing the curve, the abscissa is set as the charging load combination of EV1 and EV2 of the new energy vehicle, and the ordinate is expressed as the corresponding voltage stability index value of each bus, so that the voltage stability of each node can be intuitively seen. By comparing the curve changes of the two indexes on the charging buses DD1 and DD2, it can be preliminary concluded that both the L index and the VCPI index can correctly reflect the stable state and change trend of the bus voltage.

As can be seen from Table 1, for the L index, the bus index values of the system are less than 1, indicating that the system can maintain voltage stability. The L index value with the largest value can be regarded as the weak link (namely the weak area) in the system, and compared with the L index value of the four buses, it can be analyzed that the L index value of DD1 under different load combinations is the largest, and the monitoring of the bus should be strengthened because the voltage stability of the node is the weakest.

As can be seen from Table 2, when the charging load of EV1 remains the same, the larger the charging load of EV2, the larger the VCPI index value of each bus, indicating that its voltage stability deteriorates. When EV1 is greater than the charging load of EV2, the voltage stability of bus DD1 will be worse than that of bus DD2.

In addition, from the comparison of the indexes of each busbar, the curve change of the VCPI index is more obvious than that of the L index, and the fluctuation range is greater, that is, the greater the sensitivity to the change of the charging load of new energy vehicles

5. Conclusion

In this paper, the voltage stability test system model of new energy vehicles is established, and the PSAT toolbox in MATLAB is used to analyze the grid-connected voltage stability of new energy vehicles, and different voltage amplitude and phase angle data are obtained by changing different combinations of access loads. The simulation results are used to calculate the voltage stability index of each bus.

Through the comparison of the two index values of the important bus in the system, it can be seen that the VCPI index values fluctuate greatly under different combinations, which is easier to observe. Comparing the calculation results of the two indexes, it is more meaningful for the VCPI index to simulate a small increment to analyze the voltage stability in the current operating state because the L index only analyzes the current parameters, which is equivalent to studying the overall situation from the system part, and in actual operation, due to the different structures, it is difficult to obtain the no-load voltage and phase value of the bus. According to the comparison of the performance of the two indexes in Chapter 3, VCPI is better and more reliable than L without considering the upper limit of reactive power output.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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