Comparative Analysis of the Application of BPA and PSCAD in Voltage Sag Simulation

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Abstract. As there is no special engineering software for simulating voltage sags caused by grid faults, this paper compares the differences between the existing BPA and PSCAD simulation software in the voltage sag simulation process, and analyzes the applicability. First, analyze the similarities and differences between the transient and steady-state characteristics of the basic devices in BPA and PSCAD, as well as the parameter conversion method; Secondly, based on actual grid data, two sets of software are used to model and simulate the voltage sag caused by grid faults. Finally, through the comparison and analysis of simulation results, the different applicability of the two sets of simulation software in voltage sag simulation is summarized.

1. Introduction

The voltage sag has caused the interruption of the production process of modern industrial users, resulting in huge economic losses for users, and has become one of the most important power quality problems in the current power system\textsuperscript{[1-3]}. The voltage sag caused by the short circuit fault of the power grid is the main cause of the voltage sag in the power system. Therefore, the current power quality research is to simulate the voltage sag caused by the line fault, and then predict the sag in advance based on the simulation results and manage it which is an important research content\textsuperscript{[4]}. As the power grid companies currently do not have mature engineering software specifically for this type of business needs, it is necessary to use existing simulation tools for calculations, and comparative analysis of their applicability is required.

PSCAD (Power Systems Computer Aided Design, PSCAD) is a commercial electromagnetic simulation software. It has a graphical operation interface, intuitive simulation model, and a rich library of component modules. It mainly conducts general electromagnetic transient research of AC power systems. Fault modeling and fault simulation of power system, analysis of electromagnetic transient process of power system fault, should be used in the simulation of power grid fault voltage sag...
sag in this paper. However, since the electromagnetic transient mode is based on solving differential equations, it has the disadvantages of slow solution speed, relatively small system described, and complicated data calculations. It is generally not suitable for the analysis of long-term process of large power systems with complex parameters\cite{5}. Therefore, there is no literature report on the use of PSCAD in the simulation of large-scale power grid voltage sag.

BPA (Bonneville Power Administration, BPA) is a commercial electromechanical simulation software with the characteristics of large calculation scale, fast calculation speed, and good numerical stability. It is used in the planning, dispatching, production operation and scientific research of most power grid companies in China. BPA uses text format to store grid data and distinguishes busbars by name and voltage level. BPA uses bus name and voltage level to record power grid data, which is simple and convenient. Therefore, there is no need to form the electrical wiring diagram of the network in the calculation\cite{4}. At the same time, BPA does not limit the size of the described system. Therefore, it is widely used in practical engineering, especially for large-scale power system fault research\cite{6-7}. The national standard defines voltage sag as the process in which the root mean square value of the power frequency voltage at a certain point in the power system suddenly drops and recovers. The research object of BPA electromechanical transient simulation is the fundamental wave component\cite{8}, which covers the definition of voltage sag. At the same time, BPA is also recommended as a simulation platform for low voltage ride through modeling of wind turbines. Therefore, existing literature studies apply it to the evaluation of actual grid voltage sags\cite{7,9}. In summary, the two sets of simulation software can be applied in principle to the simulation analysis of voltage sags caused by grid faults, but their modeling difficulty, calculation speed and simulation results are different, and their applicability needs to be comprehensively considered.

In response to the above problems, this paper uses BPA and PSCAD to model and simulate the actual power grid model, and compare the simulation results to analyze the applicability of the two sets of software in different scenarios.

2. Comparative Analysis of Model Parameters

2.1. Line models
The line models of BPA include: symmetric line data card (L card), asymmetric line data card (E card), high impedance parameter line data card (L+ card), DC line data card at both ends for simulating PI-type branch (LD card)\cite{10}. There are two types of PSCAD line models: centralized PI type equivalent line and distributed parameter model \cite{11}. The former fills the actual parameters of resistance, inductance and reactance into the PSCAD circuit model, the latter contains two models of frequency dependent and single frequency. The frequency dependent model is divided into modal domain frequency modal dependent model and frequency domain frequency dependent phase domain. Models, of which the frequency-domain frequency-dependent phase-domain model has the highest accuracy. The above models are all given in the form of overhead lines. In the BPA, the line parameters are all given in the known values under the reference value of 100MVA; in the PSCAD, the line parameters are given in the actual value (effective value).

2.2. Load models
The load models in the BPA software are mostly polynomial comprehensive load models, which consider the proportion of constant power load, constant current load, and constant impedance load and its primary change characteristics with frequency\cite{5,12-13}. The most commonly used load in PSCAD is the Fixed Load mode, which can achieve constant power, constant impedance, and constant current load states by changing parameters. It can be used as a three-phase or single-phase circuit. In the BPA, the three-phase load value should be entered in the card. The bus voltage where the load is located is generally line voltage. While, the input load parameter is single-phase load, and the bus voltage input is phase voltage instead of line voltage in PSCAD. If the load in the BPA is a constant power load, the active power voltage (frequency) index and the reactive power voltage (frequency)
index should be set to 0 in PSCAD; if it is a constant impedance model, the active (reactive) power should be set to 2, the active (reactive) power frequency index is set to 0; if it is a constant current model, the active (reactive) power voltage index should be set to 1, and the active (reactive) power frequency index is set to 0.

2.3. Transformer models
In BPA, T card is used to represent double-wound transformer, and 3 double-wound transformers are often used to simulate three double-wound transformers. PSCAD provides two transformer models: classic model and electromagnetic model. In the BPA, the fundamental frequency of the transformer is 50Hz and the reference capacity is 100MVA. PSCAD should calculate the parameter values under the corresponding reference capacity. The input parameters in BPA include the equivalent resistance caused by copper loss and the unit value of leakage reactance, while in PSCAD, the unit value of copper loss and leakage reactance is directly input. The connection method of the transformer is not given in BPA, but in PSCAD, it is set according to the default value.

3. Simulation Modeling of Actual Power Grid

3.1. Simulation area selection
In this paper, 220kV Linzhai substation and 110kV network related to Linzhai substation in actual power grid which a certain area of a certain city in a certain province in the southeast are used to simulate the 110kV voltage sag fault simulation. Select Minlinzhai 21 (220kV substation), Minlinzhai 12, 11 (110kV substation), Minfengting 11, 12 (110kV substation), and perform the simulation model equivalent. The actual area circuit diagram is shown in Figure 1, etc. The effective circuit model is shown in Figure 2, where node 1 corresponds to Minlinzhai 21, and nodes A, B, C, D, and N correspond to Minlinzhai 11, Minlinzhai 12, Minfengting 11, Minfengting 12, and Minlinzhai Z1.

3.2. Model parameter setting
In this paper, the methods described above are used in the BPA and PSCAD to model the area in Figure 2, and the parameter settings are shown in Table 1.
### Table 1: Parameters of Simulation

| Element       | Parameter            | BPA          | PSCAD        |
|---------------|----------------------|--------------|--------------|
| Source        | Voltage/kV           | 230          |              |
|               | Active power/MW      | 50           |              |
| Equivalent load| Reactive power/MVAR | 15           |              |
| Line          | Resistance (unit value) | 0.00807     | 1.067        |
|               | Reactance (unit value) | 0.02724     | 3.602        |
| Transformer   | Leakage reactance    | 0.0091       | 0.14         |
|               | Transformation ratio/kV | 230/115     |              |

3.3. **Initial Power Flow Verification**

The accuracy of the network topology is the prerequisite for the mutual conversion of BPA and PSCAD. Only when the overall model and parameter conversion are correct can the applicability of the two sets of simulation software be correctly compared and analyzed. Therefore, the consistency of the initial power flow is used to ensure the reliability of the simulation verification. This paper verifies the simulation results of the model shown in Figure 2 in two kinds of software. The parameter settings are shown in Table 1. Table 2 shows the initial power flow in each software when the model has no failure.

### Table 2: Comparative of Initial Power Flow Simulation Results of BPA and PSCAD

| Test Point                        | BPA     | PSCAD    | Error  |
|-----------------------------------|---------|----------|--------|
| High voltage side of transformer  | Voltage | 230      | 230    | 0      |
| (test point 1)                    | (kV)    |          |        |        |
|                                   | Active  | 50.3     | 50.4   | 0.20%  |
|                                   | power   |          |        |        |
|                                   | (MW)    |          |        |        |
|                                   | Reactive| 18       | 17.80  | 1.11%  |
|                                   | power   |          |        |        |
|                                   | (MVAR)  |          |        |        |
| Low voltage side of transformer   | Voltage | 113.43   | 113.4  | 0.03%  |
| (test point 2)                    | (kV)    |          |        |        |
|                                   | Active  | 50.20    | 50.24  | 0.08%  |
|                                   | power   |          |        |        |
|                                   | (MW)    |          |        |        |
|                                   | Reactive| 15.80    | 15.56  | 1.51%  |
|                                   | power   |          |        |        |
|                                   | (MVAR)  |          |        |        |
| Load side                         | Voltage | 112.46   | 112.5  | 0.04%  |
| (test point 3)                    | (kV)    |          |        |        |
|                                   | Active  | 50       | 49.7   | 0.6%   |
|                                   | power   |          |        |        |
|                                   | (MW)    |          |        |        |
|                                   | Reactive| 15       | 15     | 0      |
|                                   | power   |          |        |        |
|                                   | (MVAR)  |          |        |        |

It can be seen from Table 2 that when there is no fault, the voltage, active power and reactive power RMS of BPA and PSCAD under steady-state conditions are relatively close, and the errors are within the acceptable range, which verifies the feasibility of model transformation.

4. Simulation analysis of voltage sag

4.1. Simulation results of different fault types

In order to compare and analyze the simulation results of voltage sag between BPA and PSCAD, fault is set for the line, and the fault setting point is shown in Fig. 2. Taking into account the inherent operating time and arc extinguishing time of the switch, grid faults are generally difficult to remove within 50ms. However, except for the 10kV distribution network line with multi-level protection for considering power supply reliability, general dedicated line power supply line faults can be removed within 120ms. Therefore, the failure start time of the example in this paper is 300ms, the failure duration is 120ms, and the total simulation time is 600ms.

Set the fault type as three-phase short-circuit fault, two-phase (AB phase) ground fault, two-phase (AB phase) short-circuit fault, and single-phase (A phase) short-circuit fault. The fault setting point is shown in Figure 2. When the fault occurs, the voltage rms at the bus node of Minlinzhai 11 in Figure 2
is shown in Figure 3, Figure 4, Figure 5, and Figure 6. The residual voltage rms when the sag occurs is selected, compared.

![Fig.3 Simulation results of three-phase short circuit fault](image1)

![Fig.4 Simulation results of two-phase ground fault](image2)

![Fig.5 Simulation results of two-phase short circuit fault](image3)

![Fig.6 Simulation results of single-phase ground fault](image4)

According to the definition of voltage sag, compare the residual voltage results of voltage sag during the above simulation process as shown in Table 3.
### Table 3: Comparative results of BPA and PSCAD in fault

| Fault Type                        | BPA   | PSCAD | Error  |
|-----------------------------------|-------|-------|--------|
| Three-phase short-circuit fault   | 30.97 | 30.99 | 0.06%  |
| Two-phase ground fault            | 27.74 | 27.99 | 0.50%  |
| Two-phase short-circuit fault     | 65.58 | 65.79 | 0.31%  |
| Single-phase short-circuit fault  | 1.748 | 1.744 | 0.22%  |

#### 4.2. Influence of different fault removal time

In order to further verify the impact of different fault removal times, that is, the impact of different voltage sag durations on the simulation results, four types of faults (three-phase grounding, two-phase grounding, two-phase short-circuit, and single-phase short-circuit) were analyzed and changed the duration of the fault, and the simulation results are shown in Figure 7 below.

It can be seen from Figure 7 that as the duration of the fault changes, the sag residual voltage rms does not change, so the time scale has no effect on the simulation and error results, that is, the lowest amplitude of the voltage drop after the fault is mainly related to the fault type and location, and basically has nothing to do with the duration of the fault.

#### 5. Applicability analysis of two kinds of software

This paper compares and analyzes the difference between the electromagnetic transient simulation result (PSCAD) and the electromechanical transient simulation result (BPA) in the typical voltage sag caused by the line short-circuit fault. It can be seen from Figure 3 to Figure 6 that the difference is mainly reflected in the switching process caused by the fault. In the electromagnetic transient simulation, the current has a very short period of time from the steady-state current to the steady-state short-circuit current level after the fault occurs. The corresponding voltage also presents a gradual decrease process, while the BPA simulation is a sudden change in the voltage switching moment, which directly transitions from the fundamental state before the fault to the voltage after the fault. Therefore, according to the different application scenarios of voltage sag analysis, BPA or PSCAD can be selected for simulation calculation, which can be specifically considered from the following four aspects:

1) Causes of sag: short-circuit faults, large-scale induction motor starting and transformer excitation are the main causes of voltage sags. The voltage sag events caused by the three causes have different waveform characteristics\(^{[14]}\), and the voltage sag can be identified by waveform classification.
In the simulation of cause identification, the voltage waveform obtained through BPA simulation will weaken this feature, so it is recommended to select electromagnetic transient simulation tools such as PSCAD for simulation.

2) Duration: if it is necessary to determine the duration of the voltage sag event based on the voltage waveform, the waveform is preferably obtained by PSCAD simulation. At the same time, the situation is similar when it is necessary to calculate the voltage sag severity index involving duration, such as the duration severity index (DSI), the combined magnitude duration severity index (CMDSI), and so on.

3) Calculation scale: the voltage sag amplitude refers to the lowest voltage rms during the sag. Since domestic power grid data is generally stored in the format required by electromechanical transient software, the data in the electromagnetic transient simulation software format is lacking, and large-area measurement cannot be carried out in engineering. Therefore, when the voltage sag amplitude is used to evaluate the severity of the voltage sag of each node of the large power grid, the BPA simulation calculation is a method with sufficient accuracy and feasible engineering.

4) Dynamic time scale: the dynamic time scale of electromechanical transients is generally on the second level, while the dynamic time scale of electromagnetic transients is on the millisecond level. Because of the large inertia of the power supply in the traditional power grid, the impedance of the network is based on static circuits and transformer loops with inductive properties. Therefore, the time scale of the main dynamic characteristics of the system is sufficient to simulate the electromechanical transient simulation. For microgrids and local power grids mainly composed of new energy sources, since the response speed of power electronic equipment is comparable to the time scale of the electromagnetic transient transition process, electromechanical simulation is used in this scenario to replace detailed electromagnetic simulation. There may be errors.

In summary, according to the different application demand scenarios of voltage sag analysis, corresponding reasonable simulation tools should be adopted, and the results obtained can be considered reasonable and effective.

6. Conclusion
Based on actual power grid parameters, this paper uses electromagnetic transient simulation software (PSCAD) and electromechanical transient simulation software (BPA) to analyze the voltage sag under typical fault conditions, compare the difference in voltage characteristic values in the curve, and comprehensively consider different sags. Analyze the requirements of the scenario and draw the following conclusion:

1) In the traditional power grid, when considering the analysis of the severity of voltage sag in the case of network failures, the use of electromechanical simulation tools such as BPA can greatly reduce the calculation cost while meeting the engineering accuracy requirements.

2) In the new power grid where new energy power generation with fast dynamic response speed of the system is widely connected, since the fluctuation speed and amplitude of the voltage amplitude may change greatly during the fault process, it is necessary to further study the application of BPA simulation analysis based on the specific situation method.

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