Modeling and Simulation of Power Quality for EAST

Xiaofeng Li\textsuperscript{1,a}, Yiyun Huang\textsuperscript{a2,b}

\textsuperscript{1}Institute of Plasma Physics, Hefei Institutes of Physical Science, Chinese Academy of Sciences University of Science and Technology of China Hefei, China

\textsuperscript{2}Institute of Plasma Physics, Hefei Institutes of Physical Science, Chinese Academy of Sciences Hefei, China

\textsuperscript{a}sheafli@mail.ustc.edu.cn

\textsuperscript{b}yyhuang@ipp.ac.cn

Abstract—To ensure the safety and efficiency of EAST nuclear fusion devices, the power quality has to be considered. The loads of EAST device are complex and diverse, especially the special loads with high power impact, volatility, randomness and nonlinear characteristic, which causes power quality problems such as voltage sag, harmonic and three-phase imbalance in power network. This paper analyzes the load characteristics of EAST devices and divides them into impulsive loads and conventional loads. The above two types of loads are modeled and simulated respectively, and the effects of loads with different properties on the system are discussed. The results of simulation analysis are of great significance to the next step of formulating corresponding compensation measures and developing control equipment. Therefore, the importance of power quality problems modeling and simulation for power system analysis and control is self-evident.

1. Introduction

Fusion energy is the ultimate energy of human beings and an effective way to solve the energy crisis of human society. China is also actively involved in the research of nuclear fusion. The former Soviet Union's T7 was changed to HT-7 in 1991, and now EAST is built and operated autonomously. Some important progress has been made in magnetic confinement fusion in China [1,2]. The safe and stable operation of the nuclear fusion device is closely related to the power quality of the distribution network. With the development of science and technology, more and more attention is paid to power quality. In EAST, the units based on computer, microprocessor, induction motor and other power quality sensitive equipment distributed in the whole device. At the same time, a large number of nonlinear devices composed of power electronic devices such as thyristor diodes are widely used, and the harmonic, reactive power generated by them will seriously affect the power quality of the distribution network. Therefore, on the one hand, the extensive use of power quality sensitive equipment promotes stricter requirements on power quality; On the other hand, the factors causing the decline of power quality are increasing.

The loads in EAST device are complex and diverse, especially the special loads have particularly prominent influence on the power quality of the power system, and even threaten the safe and stable operation of the whole EAST device. The analysis of loads with different properties on the EAST device and their impact on the system is the prerequisite for subsequent targeted solutions, while the modeling and simulation of load with different properties is an effective way to analyze the power quality. In this
paper, starting from the load classification of EAST device, there are mainly divided into two types: impulsive loads and conventional loads, and their modeling and simulation are respectively conducted to analyze the impact to the distribution network.

2. Load characteristic analysis of EAST device
The main loads of the distribution network of EAST device include: various power supply systems, low-temperature system, vacuum system, water-cooling system, control system, lighting system, etc., as shown in Figure 1.

![Main loads of EAST distribution network](image)

Figure 1. Main loads of EAST distribution network

The power supply systems are based on full-control or semi-control power electronic devices, which are mainly divided into neutral particle injection power system, magnet power system and auxiliary heating power system. The magnet power system consists of a longitudinal field coil power supply and a polar field coil power supply. The main functions of the magnet power supply systems are as follows: through AC/DC rectifier, controllable large current is excited in the circumferential field coil and polar field coil to generate the helical magnetic field required by the constraint plasma [4]. All kinds of auxiliary heating power supply mainly provide high-power non-inductive current heating energy, which provides energy support for plasma injected energy and is used for heating or driving plasma [5]. Auxiliary heating power supply system includes neutral beam injection heating (NBI), ion cyclotron heating (ICRF), electron cyclotron heating (ECRH) and low clutter current drive (LHCD).

The impulsive loads include magnet power supply system and PSM auxiliary heating power supply system. The conventional loads are data processing system, control system, low-temperature system, vacuum system and water-cooled system. The pole-field magnet power supply system as the impulsive load is changeable, has a great impact on the power grid. For the conventional load, the large capacity induction motor in each systems will also bring huge impact to the power grid when they are started.

The voltage stability of EAST distribution network not only has a great impact on the normal and stable operation of various types of equipment, but also the impulsive and impact loads of the experimental equipments may have an impact and harm on the power grid and cause damage to other equipment. The next step is to classify the different types of loads.

2.1. The impulsive load
The largest power consumption load in the EAST device is the magnet power supply system, which is mainly composed of multiple sets of rectifiers, and it is a impulsive load. It’s characteristic is: mutability, randomness, strong pulse power and duration is indeterminate. Compared with the conventional industrial impact loads such as electric arc furnace and rolling mill, EAST magnet power supply has larger impulse power and installation capacity, greater reactive power volatility, stronger randomness in operation, and greater impact on the power grid.
The impulsive load is a load with a fast rate of power change. The transient voltage sag will occur when the power system breaks the original equilibrium state because the impulsive load is put in. At the same time, the large part of the magnet power supply is the nonlinear load composed of power electronic devices. When put into operation, a large amount of harmonic current will be generated, which will cause serious distortion of bus voltage, may lead to overheating of the motor, vibration, failure of electronic control equipment and so on.

For example, the pole-field coil power with the largest power is based on thyristor phase control technology, which consists of positive and negative four three-phase full-control bridges to form a four-quadrant operation. The large active power fluctuation and reactive power consumption during operation will cause the bus voltage to drop greatly, and a large number of harmonics will be generated when the nonlinear device is in operation. If the compensation filter device is not added, it will have an impact on the entire distribution network of EAST device, and will affect the operation of other loads and rectifiers under the bus, or even damage the equipments, affecting the safety of the nuclear fusion experiment.

2.2. The conventional load

The induction motors in other systems such as low temperature system and vacuum system are typical conventional loads. For large-capacity induction motors, dynamic sensitive loads are not only sensitive to power quality, but also bring impact to power system when the motor is started.

Assuming that the reactance of the motor remains unchanged when the motor is started, $U_{st m}$ is the bus voltage when the motor is directly started, $U_{2 n}$ is the rated voltage of the transformer’s low-voltage side, $X_c$ is the reactance of the power system, $X_T$ is the transformer reactance, $X_{fh}$ is the reactance of pre-connected reactive load, and $X_L$ is the motor’s distribution line impedance, then:

$$U_{st m} = \frac{U_{2 n}}{X_c + X_T + X_3} X_3.$$

And:

$$X_3 = \frac{X_{st} X_{fh}}{X_{st} + X_{fh}}; \quad X_{st} = X_L + X_{st M}.$$

From the above equation, obviously $U_{st m} < U_{2 n}$, Therefore, there is a voltage sag in the bus voltage during the motor starting.

3. Simulation and analysis

Modeling is a prerequisite for power quality analysis and an important tool for solution research. Simulation results determine the formulation of various solutions of the system, and the accuracy of simulation results is closely related to the model adopted. The modeling and simulation of various special loads in EAST device is of great significance for the safe operation of the whole system.

3.1. Simulation of impulsive load

The impulsive load in EAST device has a strong randomness because the power fluctuation period and duty ratio are uncertain and vary randomly. In order to further study the impact of impulsive load on the power system, a simulation model is established in Simulink, as shown in the figure below:
Figure 2. The model of impulsive load

Assume that the load is connected to the system at 0.03 seconds and disconnected at 0.07 seconds; The power supply voltage is 10KV; The transformer variable ratio is 10KV/500V; The current source is controlled to simulate the impulse impact of the large current from the impulsive load. The following figures are the simulation results.
Based on the model and simulation results above, it can be found that when the impulsive load is connected to the system, it will bring a large amount of active power and reactive power, which will have a severe impact on the power grid. As a result, the voltage and current waveform is distorted, and the system voltage sag occurs with a transient amplitude of about 22%. When the impulsive load is cut off, the grid voltage returns to the initial value. Thus, it can be seen that the impulsive load has a great impact on the power quality of the system, and even threatens the safe and stable operation of the EAST device. It is of great significance to study the impact of the impulsive load on the system for the development of corresponding compensation measures.

3.2. Simulation of conventional load
When the large-capacity induction motor starts, it will absorb 5~6 times higher current value from the grid than the normal operation current value. At start, it takes a certain time for the motor speed to rise from 0 to the rated speed, during this time the current of the motor is maintained at a very high value. A strong starting current can cause a large line voltage sag. The simulation model is established in Simulink as follows:

Assume that the power supply voltage is 11KV, frequency is 50Hz, short circuit capacity of 10^5 KVA; The three-phase load has 20KW active power and 5KVar reactive power. The transformer T1 variable ratio is 10.5KV/120KV, and the secondary side winding is earthed at the neutral point. The transformer T2 variable ratio is 110KV/400V, and the original side winding is earthed at the neutral point; The working voltage of the large-capacity motor is 400V, and the power is 150KW. The motor is started directly in 0.2 seconds. The following are the simulation results.
Figure 5. Simulation results of large-capacity motor starting

It can be seen from the simulation results in the figures above that the voltage sag of power grid is caused by the fluctuating current flowing through the impedance of power supply line when the large-capacity induction motor is started. The lowest grid voltage is 67% of the original voltage during the motor starting, and reaches the maximum voltage sag at the startup moment, then the bus voltage gradually climbs up, and reaches the steady state after 0.5s. Therefore, the direct start of the motor has a great impact on the bus voltage, which will leads to voltage sag exceeding the voltage quality standard. It is necessary to further study the appropriate starting mode to meet the requirements of voltage quality standard, motor starting time and economic benefits.

4. Conclusions
This paper analyzed the loads of EAST device in detail. The particularity of the loads was explained. The loads were divided into two types: conventional loads and impulsive loads. The influences of different loads on power quality were modeled and simulated.
The simulation results show that the impact of impulsive load on power system is different from that of large capacity motor starting. During impulsive load connected at the system, the load will continue to affect the power system until the load is removed. In order to eliminate the influence of the impulsive load on the system, a compensation filter should be added.

When the large capacity induction motor is started directly, the network voltage will fluctuate greatly and the voltage sag will be caused. However, after a period of voltage sag, the grid voltage will gradually recover and become stable. It is necessary to further study the appropriate starting mode to meet other requirements under the premise of conforming to voltage quality standards.

To sum up, the establishment of EAST loads model and the simulation of their influence on power quality are of great significance to further study their influence on the whole device system, formulate corresponding compensation measures, develop control equipment, and ensure the safe and stable operation of the EAST device.

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