Power network quality analysis and harmonic control of large electric drive test station

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Abstract. During the operation of large-scale electric drive test-bed, the driving and loading frequency conversion equipment will produce many different frequency harmonic currents due to their nonlinear characteristics, which will not only affect each other, but also interfere with other transmission and distribution equipment, resulting in current and voltage waveform distortion. In this paper, the operation conditions of a large power drive test bench are analyzed and studied, and the power quality control solution is proposed. The test results prove the effectiveness of the control measures.

1. Introduction
At present, the high-power test-bed is generally electric drive loading system. The test product is driven by a frequency conversion motor, and the loading equipment is an energy feedback dynamometer running in four quadrants. The tester obtains the product test data by controlling the driving motor and loading motor, such as acceleration and deceleration, loading and unloading, etc.

In the power system, the distortion of voltage and current waveform is more and more serious due to the use of various high-power loads and the non-linear components of the system itself. It is very important to effectively suppress the harmonic and eliminate the governance.

In this paper, the measured power grid data of a high-power power drive test-bed is analyzed and studied. The new active harmonic suppression measures are used to improve the power quality of power system and strengthen the security and stability of power grid.

2. Harmfulness of Harmonics
Due to its nonlinear characteristics, the drive and load inverter in the test bench will produce many harmonic currents with different frequencies in the operation process. In addition to increasing the loss of transmission lines and transformers and interfering with the control and communication systems, the mutual influence and interference between harmonics under specific conditions will also cause misoperation of relay protection devices, and then affect the security of power grid.

The harm of harmonics is mainly manifested in the following aspects:
1) Harmonics cause additional loss of public network components and reduce the efficiency of power generation, transmission and consumption equipment.
2) Due to skin effect, harmonics will overheat cables and accelerate insulation aging.
3) Harmonic will produce local series and parallel resonance, which endangers the safety of power equipment, especially the safety of power capacitor.
4) A large number of harmonic current will make the neutral line current too large, even burn the neutral line, causing fire.

5) The harmonic will make the relay protection device malfunction and make the electrical instrument measurement inaccurate.

6) Harmonics can interfere with nearby communication signals.

According to the national GB / T 14549-1993 power quality harmonics of public power grid, the limits of harmonic voltage (phase voltage) of public power grid at all voltage levels of power supply system are shown in Table 1, and the allowable values of harmonic current component injected into the point by all users of public connection point are shown in Table 2.

Table 1. harmonic voltage (phase voltage) of public power grid

| Nominal grid voltage kV | Voltage total harmonic distortion rate % | Each harmonic voltage content rate % |
|-------------------------|----------------------------------------|-----------------------------------|
|                         |                                       | Odd times | Even times   |
| 0.38                    | 5.0                                    | 4.0       | 2.0          |
| 6                       | 4.0                                    | 3.2       | 1.6          |
| 10                      | 3.0                                    | 2.4       | 1.2          |
| 35                      | 2.0                                    | 1.6       | 0.8          |
| 66                      |                                        |           |              |
| 110                     |                                        |           |              |

Table 2 allowable value of harmonic current injected into common connection point

| Standard Voltage kV | Base short-circuit capacity MVA | Harmonic order harmonic current allowable value, A |
|--------------------|--------------------------------|---------------------------------------------------|
|                    |                                | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  | 13  | 14  | 15  | 16  | 17  | 18  | 19  | 20  |
| 0.38               |                                | 78  | 62  | 29  | 62  | 26  | 44  | 19  | 21  | 16  | 28  | 13  | 24  | 11  | 12  | 9.7 | 18  | 8.6 | 16  | 7.8 |
| 6                  |                                | 100 | 43  | 34  | 21  | 34  | 14  | 24  | 11  | 8.5 | 16  | 7.1 | 13  | 6.1 | 6.8 | 5.3 | 10  | 9.0 | 3.4 | 4.7 |
| 10                 |                                | 100 | 26  | 20  | 13  | 20  | 8.5 | 15  | 6.4 | 6.8 | 5.1 | 9.3 | 4.3 | 7.9 | 3.7 | 4.1 | 3.2 | 6.0 | 2.8 | 4.4 | 2.6 |
| 35                 |                                | 250 | 15  | 12  | 7.7 | 12  | 5.1 | 6.8 | 3.8 | 4.1 | 3.1 | 5.6 | 2.8 | 4.7 | 2.2 | 2.6 | 1.9 | 16  | 7.1 | 13  | 6.1 | 6.8 | 5.3 | 10  | 9.0 | 3.4 |
| 66                 |                                | 500 | 16  | 13  | 4.1 | 3.1 | 5.6 | 2.6 | 4.7 | 2.2 | 2.6 | 1.9 | 16  | 7.1 | 13  | 6.1 | 6.8 | 5.3 | 10  | 9.0 | 3.4 | 2.5 | 1.5 | 2.8 | 1.3 | 2.5 | 1.2 |
| 110                |                                | 750 | 12  | 9.6 | 16  | 7.1 | 13  | 6.1 | 6.8 | 5.3 | 10  | 9.0 | 2.0 | 3.7 | 1.7 | 1.9 | 1.5 | 2.8 | 1.3 | 2.5 | 1.2 |

3. Analysis of Power quality

A 35KV substation with two main transformers, one for use and one for standby, is set up on site. Three sections of 6kV bus are set, and all bus couplers are in closing state. The operation mode is as follows: in summer, due to the large air conditioning load, the total load exceeds the capacity of one main transformer, so two main transformers are operated in parallel; one is not in use and one is standby in other time. Each section of 6kV system is equipped with fixed capacitor bank for reactive power compensation. The 0.4kV side is installed with automatic switching capacitor bank to compensate the reactive power required by the low voltage system.

The feeder cabinet of 1# test bench, 2# test bench and 3# test bench are installed on 6kV bus.

As shown in Fig. 1 and Fig.2, when the test bench is put into operation, the harmonic content of the system is high, which leads to the mal operation of the comprehensive protection of 6kV capacitor bank, which makes the power factor of the system unable to reach the required value.

Figure 1 grid side voltage harmonics
When the test-bed is put into operation, the harmonic generated by the nonlinear load characteristics of the test-bed greatly pollutes the original good power supply quality, making the voltage distortion rate far beyond the requirements of the national standard. The impact of the system makes the protection of the system malfunction, so that the equipment can not run normally.

4. Method of Power Management

At present, the application measures of harmonic control in power system are mainly divided into two types: one is active control, starting from the harmonic source, optimizing and upgrading it, so as to produce less low order harmonics or no harmonics. The second is passive control, by adding harmonic compensation device to prevent harmonics from entering the power grid or load side.

In this paper, the active power filter (APF) is discussed. APF is developed on the basis of passive filter, which can effectively compensate the harmonics with varying frequency and amplitude. Its working principle is similar to that of harmonic generator, and the harmonic current is injected into the power grid. By controlling the frequency, amplitude and phase of the current, the harmonic current injected into the power grid will counteract the original harmonic current in the system, thus achieving the goal of harmonic control. According to the access mode, APF can be divided into series type, parallel type and series parallel type. Figure 3 shows the series APF topologies. The series device can be used as a controlled voltage source. Its main function is to eliminate the voltage type harmonics in the power grid, improve the voltage fluctuation and other common quality problems, and improve the stability of the power grid. Series APF needs all the current in the load circuit in the working process, and the power damage will be more serious. In addition, its switching, protection and other actions are relatively complex, so the application range is very small now. Figure 3 shows the effect of harmonic compensation. Compared with the series APF, the switching and protection of the parallel APF are more safe and convenient, and can compensate the reactive power of the power grid.

5. Experimental verification

Since the main transformer on site is one for use and one for standby, the outgoing line at 6.3kV side of low voltage side of main transformer is treated by local compensation.

Compensation capacity required for parallel operation of single 4000kVA transformer:
\[ Q = SN \times THD_{\text{max}}\% = 480 \text{kvar} \]

However, considering the voltage rise of the power treatment device and the regenerative harmonics of the frequency conversion equipment, the calculated capacity should be divided by:

\[ \frac{Q}{0.6} \times 1.2 = 960 \text{kvar} \]

According to the site understanding, due to the increase of air conditioning load in summer and the need to increase the experimental platform project in the later stage, the reactive load of the system will be increased, and the harmonic current will be amplified. Considering the long-term planning, it is necessary to increase part of the capacity:

\[ Q \times 1.2 = 1152 \text{kvar} \]

The calculated capacity of the device is 1152kvar. Considering the fluctuation of system load, 1200kvar power treatment device is selected for the project.

6. Conclusion
In this paper, the large-scale electric drive test-bed is analyzed and studied. The new active filter is used to improve the power quality of the power system and strengthen the security and stability of the power grid. The test results show that the voltage and current harmonics of the system can be effectively suppressed by adding the designed power quality control device, and the power grid quality can meet the requirements of the national standard.

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