Analysis and Suppression of Harmonics Generated on Offshore Oil Production Platform

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ABSTRACT

With the continuous development of offshore oil industry, an increasing number of offshore oil production platforms will appear in different large sea areas. For the offshore oil production platform grid, which is an independent and small power distribution system far away from land, its power quality is extremely crucial. Various kinds of electrical and instrumental equipments have increasingly higher demand on the security and reliability of the power distribution system’s operation. However, when some nonlinear electrical devices and high capacity equipments start, they will generate a great amount of harmonic in the power distribution system on the platform and bring hidden trouble to various kinds of electricity load operations. Since this issue has aroused wide attention, the present paper takes the power distribution system of a central offshore oil production platform in an area of China’s sea as an example. First, it discusses the harm of harmonic in the power distribution system on the offshore oil production platform. Then, it proves the effect of harmonic suppression on the basis of a combination use of passive power filter (PPF) and active power filter (APF).

INTRODUCTION

Offshore oil production platform grid is an independent and small power grid which is far away from land. During its normal operation, all the electric equipments are powered by the turbine generator. However, due to some limitations, like the space and costs of the platform, the unit capacity of the turbine generator is very limited. When the high-capacity equipment in the low voltage power grid of the platform starts directly, it will undoubtedly bring about great impact on the whole grid and even break the grid down. Therefore, variable frequency starting and silicon controlled soft starting are two popular ways to start high power equipments in the low voltage grid on the offshore oil production platform. But harmonics are often generated just at the very moment when these nonlinear electronic equipments and the heavy load equipments in the medium voltage system start. The following part will analyze and discuss the harm of harmonics in the power distribution system of a central offshore oil production platform in an area of China’s sea.
Harmonic Harm to the Platform Grid

When the current or voltage frequency surpasses 50 Hz in the power distribution system, the system will be affected and irregular sine wave will appear. This irregular sine wave is harmonic. It can cause great harm and impact to almost all kinds of transformers, circuit breakers, power cables, motors and uninterruptible power supplies (UPS) in the power distribution system, thus becoming the greatest threat to the grid pollution problem ([1]). The following part will analyze the harmonic impact on different electric equipments on the platform ([2-3]).

Impact on Transformer

There are many different types of transformers on the central offshore oil production platform, which are the lifeline of the platform’s power distribution and transmission. The harmonic in the grid will not only directly increase the transformer wear, but also bring electrical stress to the insulation materials of the transformer. These factors will cause abnormal heating and noise to the transformer, and also can result in the aging of some related insulation parts of the transformer, affecting the function as well as the life span of the transformer.

Impact on Circuit Breaker

Circuit breakers on the platform mainly include vacuum circuit breaker (VCB), air circuit breaker (ACB), and moulded case circuit breaker (MCCB). The first two kinds play an important role in linking all levels of bus ties, and the latter is widely used in the low-voltage grid. Their on-off capability is precisely designed according to the normal power frequency voltage and current. When a large amount of harmonic occurs, it is likely to result in malfunction of the relay protection device of VCB and ACB. This will seriously affect the regular work of the tripping and closing coils of different types of circuit breakers, and greatly reduce the arc extinguishing ability and blocking ability, thus seriously affecting the operation security of the grid system.

Impact on Power Cable

The existence of the harmonic in the grid will increase the dielectric loss of the cable, reduce the insulation performance of the cables at all levels, and increase the possibility of single phase ground fault during operation. For the new platform which is just put into production, the destructive effect of the harmonic will gradually expose as time goes on. The connection of the power supply between all the wellhead platforms and the central platform mainly relies on the submarine cable. The cable’s transmission length is relatively long, the diameter is comparatively large, and the skin effect is relatively obvious. When the harmonic current flows through the wire, the resistance under the harmonic frequency increases, and then the additional loss caused by the harmonic increases. Besides, the reactive power will increase accordingly, thus the loss will be further increased and the power supply efficiency will be decreased.
Impact on Motors of All Levels

The platform harmonic mainly comes from the frequency converter and the silicon controlled soft starter in the low voltage grid. The harmonic will be transmitted to the medium voltage grid via step-down transformer, and then exert some impact on the motor in the medium voltage grid. Certainly, it will have a more direct impact on the motor in the low-voltage grid because it will increase the wear and efficiency of motors of all levels, bring a temperature rise to the motor coil, and therefore affect the life span of the equipment.

Impact on the UPS

The main role of UPS on the offshore oil production platform is to provide clean power source to some important equipments. UPS itself has the filtering function, but since it includes a lot of AC and DC capacitances, the harmonic can cause resonance to the capacitor ([4]). Under the power frequency, the capacitive reactance of the UPS capacitance devices in the circuit is much larger than the inductive reactance in the system, which does not generate resonance. But under the harmonic frequency, the inductive reactance multiplies while the capacitive reactance decreases greatly, which may generate resonance. The resonance will magnify the harmonic current, burn down equipments like the capacitor, and then cause UPS malfunction and finally cause the platform to fail to produce.

HARMONIC PREVENTION AND SUPPRESSION

In the future, offshore oil development will become the main force of oil production, and more and more offshore oil production platforms will appear in different large sea areas. We will gain more experience in the development process and our technology in harmonic prevention and suppression will be more mature. In order to minimize the harmonic harm to the platform grid, great importance and enough attention must be attached to both its prevention and suppression. By comparing the situations before and after the installation of passive and active power filter on a central production platform in an area of China’s sea, and according to a series of experimental tests, the results are shown as follows.

Harmonic Prevention

Harmonic prevention should start mainly from the equipment selection about the frequency converter. Although the frequency converter is the main source of harmonic on the platform, an appropriate selection can suppress the formation of the harmonic, so as to reduce the generation of harmonic from the source of power supply. When selecting frequency converter, two aspects should be paid special attention to. On one hand, in order to reduce the harmonic impact on the grid devices, it should be ensured that the power supply of the converter system and that of some other equipment should be independent, or an isolation transformer should be installed on the input side of both the converter and some other electric equipment. On the other hand, the selected converter must be equipped with AC and DC reactors, so the converter itself can filter out some harmonics. Pay attention to the above two aspects when selecting frequency converter, and then harmonics under some frequencies can be prevented to a large extent.
Harmonic Suppression

*The use of passive power filter (PPF)*

Passive harmonic filtering is a passive filtering method that is designed for the harmonic under certain frequency in the system. PPF is composed of reactors and capacitors at a certain ratio ([3, 5]). It has low impedance, and the resonant frequency is close to the harmonic frequency, making it possible to filter out most of the harmonics ([4]). Its working principle is shown in Figure 1.

![Figure 1. Working principle of PPF.](image)

The central production platform in an area of China’s sea, on which the paper is based, totally has four electric submersible pumps: A1, A3, A4, and A7. The converter takes three-phase 380V electricity from the busbar, and then turns it into 35Hz step wave. After the voltage boosting by the transformer, it can be used by the electric submersible pump. At present, A4 and A7 electric submersible pumps are in use, so we carry out PPF suppression method on A4 and A7 transformers when they are on load.

*The suppression effect of PPF on A4*

We choose the high voltage output end of A4 transformer to start testing. The voltage waveform between phases A and B of the high voltage side of A4 transformer when loaded is shown in Figure 2.

![Figure 2. Voltage waveform of the Uab line on the high voltage side of A4 transformer when loaded, before / after using PPF.](image)
In Figure 2, the yellow waveform is the voltage waveform of the Uab line on the high voltage side of A4 transformer, and the green is the current waveform of phase A on the high voltage side of A4 transformer. After PPF is put into service, the higher harmonic voltage of the output end on the high voltage side of the transformer was filtered out. The peak voltage was reduced from 2.328KV to 1.948KV, a 344V decline, which reduced the harm of the higher harmonic voltage to the electric submersible pump.

The suppression effect of PPF on A7

We choose the high voltage output end of A7 transformer to test. The voltage waveform between phases A and B of the high voltage side of A7 transformer when loaded is shown in Figure 3.

Figure 3. Voltage waveform of the Uab line on the high voltage output end of A7 transformer, before / after using PPF.

In Figure 3, the bottom left and right show the voltage waveform of the Uab line on the high voltage output end of A7 transformer before and after using PPF respectively. It is evident that after PPF is put into service, the higher harmonic voltage disappeared, and the peak voltage was reduced from 2.47KV to 2.12KV, a 350V decline, which greatly reduced the harm of the higher harmonic voltage to the electric submersible pump.

The use of active power filter (APF)

In order to prevent an instantaneous shock from the grid on the DC bus capacitor after power on, APF firstly charges up the DC bus capacitor via the soft starting resistance, which usually lasts for about dozens of seconds. When the busbar voltage Udc reaches a desired value, the main contactor closes. The DC capacitor, as a power storage device, outputs compensating current via IGBT inverter and internal reactor so as to provide power. APF collects the real-time current signal via an external CT, sends it to signal modulation circuit, and then sends it to the FPGA controller. The controller then separates the components of the fundamental wave, extracts all harmonics, and then compares the gathered harmonic components with the compensating current provided by APF to get the
difference. The difference value is output to the drive circuit as a real-time compensating signal, which triggers the IGBT converter to inject the compensating harmonic current into the grid; thus the filtering function is realized. The internal control schematic of APF is shown in Figure 4.

![The internal control schematic of APF.](image)

**The suppression effect of APF**

The central production platform involved in the present paper has two main step-down transformers, one for use and the other for backup. The transformer on the upper end of the LA segment is put into service, and the transformer on the upper end of the LB segment is for backup. The bus coupler between LA and LB segments are closed. This production platform has four electric submersible pumps. Since the frequency converter on the upper end of the pump is the main source of harmonic, we choose point A - the output end of the transformer which is on the upper end of the LA segment - to test. Only A4 and A7 are put into use on the site and their testing results are shown from Table 1 to Table 3.

It can be observed from Table 1 that the system current waveform changed into a standard sine wave, and the system voltage waveform also turned into a better situation after using APF. Meanwhile, the phase difference between the current waveform and the voltage waveform decreased.

**Table 1.** The system voltage waveform and current waveform, before / after the APF suppression.
Table 2. The system voltage parameters, before / after the APF suppression.

| Before APF suppression | After APF suppression |
|------------------------|-----------------------|
| 384.82V                | 389.18V               |
| 3.31%                  | 1.17%                 |

According to the data in Table 2, it is found that after using APF, the effective value of the system voltage increased from 384.82V up to 389.18V, and the voltage distortion rate reduced from 3.31% to 1.17% (phase A as an example).

Table 3. The system current parameters, before / after the APF suppression.

| Before APF suppression | After APF suppression |
|------------------------|-----------------------|
| 1.7954KA               | 1.6853KA              |
| 6.48%                  | 0.64%                 |

According to the data in Table 3, it is found that after using APF, the effective value of the system current reduced from 1.7954KA to 1.6853KA, a decline of 110.1A, and the current distortion rate reduced from 6.48% to 0.64% (phase A as an example).

We observed the changes of system voltage and current of phases A, B, and C before and after the use of APF, and found that the 5th, 7th, 11th, and 13th voltage harmonics obviously reduced and the corresponding current harmonics all disappeared in these three phases. We also observed and compared the system power parameters before and after the use of APF, and found that the three phase apparent power reduced from 1.2056MVA to 1.1223MVA, the three phase reactive power reduced from 0.7643MVA to 0.4987MVA, and the three phase power factor increased from 0.7732 to 0.8958.

On the basis of all the above data, we can draw a conclusion that a combination use of PPF and APF can obviously improve the power supply quality of the platform grid, and remarkably decrease the chance and level of being affected by harmonics.
CONCLUSION

Harmonic has considerably great harm to the platform grid system. It not only affects the power supply efficiency of the voltage system of all levels, but also impacts the related electrical equipments. More seriously, it can even affect the service efficiency and life span of the electrical equipments. This paper makes an analysis about the harm, prevention and suppression of harmonics on a central offshore oil production platform in an area of China’s sea. If the electrical workers in offshore oil production industry have a clear understanding and in-depth study about the harm and the comprehensive treatment measures on harmonics appeared in the platform grid system, it is of course quite useful for both improving the suppression effect about harmonic problems and reducing the harmonic harm as much as possible. As a result, it can guarantee a regular, safe and stable operation of the offshore oil production platform grid, and provide a powerful support for the security of offshore oil production.

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