Data Center Energy White Paper 05 — Functions of Isolation Transformer in the UPS

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Preface

There are transformer-based UPSs and transformer-less UPSs. The main difference between them is using the isolation transformer or not. In the industry, some people think that isolation transformers of transformer-based UPSs have the functions of reducing the neutral-ground voltage, restraining interference, and isolating outputs from inputs. Is this true? Why are transformer-based UPSs equipped with the isolation transformer? What are its real functions? This document provides in-depth analysis based on technical details, with a purpose of unraveling the mystery of isolation transformers.

1. Evolution of Transformer-based UPSs and Transformer-less UPSs

In the late 1960s, the first generation of UPSs equipped with semiconductor devices was borne. Such an UPS has five transformers in total. The autotransformer is used for input to the rectifier and it has a winding for recharging batteries. The remaining four isolation transformers are used for inversion. By stacking phases, the pulse-type stepwise inversion voltage is generated and the voltage wave is changed into the sine wave after passing through the LC filter. In China, such UPSs with isolation transformers are called transformer-based UPSs. After decades of development and improvement of semiconductor devices, in 1990s, the number of isolation transformers used in a transformer-based UPS was reduced to one. (See figure 2.) At the beginning of this century, various UPS vendors launched UPSs without the isolation transformer, which were called transformer-less UPSs.

Figure 1 First generation of UPSs equipped with semiconductor devices (excluding bypass)

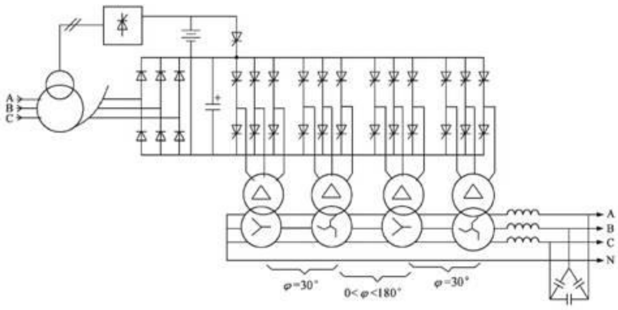
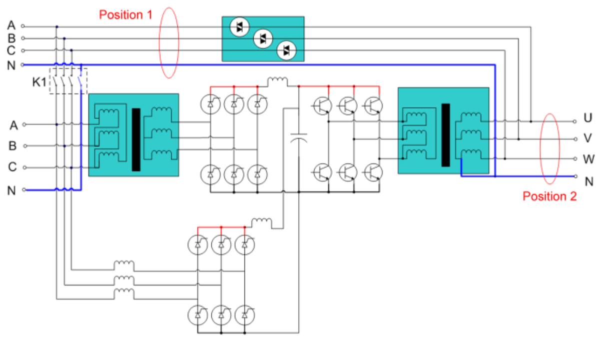


Figure 2 12-pluse transformer-based UPS with one isolation transformer



2. Analysis of Functions of Isolation Transformer in the UPS

Seeing from the architecture, the biggest difference between transformer-based UPSs and transformer-less UPSs is that transformer-less UPSs do not have the isolation transformer. Due to this, the weight and size of transformer-less UPSs become much smaller and their efficiency improves prominently. Compared with transformer-based UPSs, they have significant competitive advantages. However, as transformer-based UPSs have the history of decades of years, many UPS users doubt about the performance of transformer-less UPSs. They think that the following problems will occur without using the isolation transformer:

a. Outputs are not isolated from inputs.

b. Interference cannot be restrained.

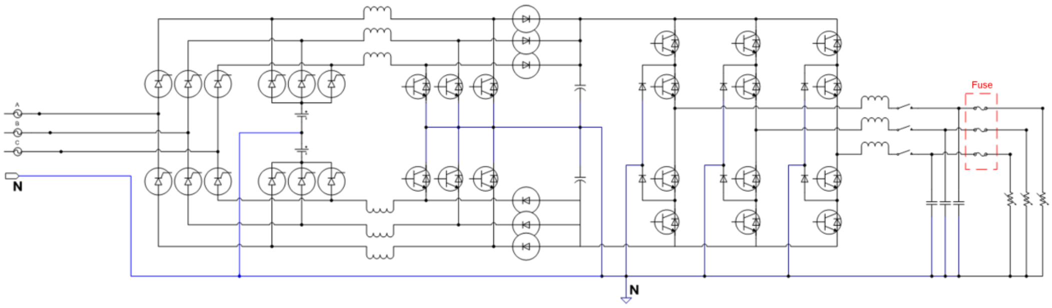
c. The neutral-ground voltage cannot be reduced.

d. Faults cannot be isolated.

e. Low-frequency 3n-order harmonics cannot be restrained.

In this document, through comparison based on principles, let us see whether transformer-less UPSs without the isolation transformer really have aforesaid problems compared with transformer-based UPSs with the isolation transformer.

Figure 3 Typical typology of the UPS without the isolation transformer



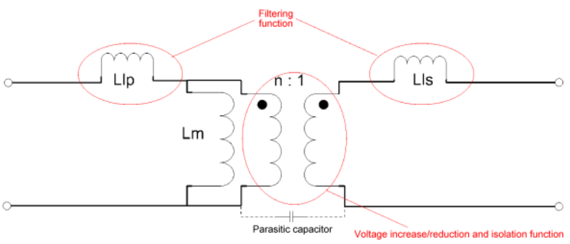
2.1 Isolate Outputs from Inputs

Under normal circumstances, the isolation transformer can isolate primary sides from secondary sides. However, in some scenarios, if primary sides have electrical connections with secondary sides, the isolation transformer loses its function of isolation. All of you know that transformer-less UPSs do not have the isolation transformer and therefore outputs are not isolated from inputs. However, do transformer-based UPSs really have the function of isolation? Figure 2 shows the transformer-based UPS including bypass. We can see that when main and bypass inputs use the same power source (K1 closed), main and bypass outputs are not isolated from main and bypass inputs. When main and bypass inputs use different power sources (K1 opened), main outputs are isolated from main inputs. However, bypass outputs are still not isolated from bypass inputs. In other words, outputs are not isolated from inputs. Transformer-based UPSs can isolate outputs from inputs only when another isolation transformer is installed on the bypass or at the output position (position 1 or 2) shown in figure 2. However, if another isolation transformer needs to be installed to realize isolation, transformer-less UPSs can also do this with the installation of one isolation transformer. Based on all these, we can draw the conclusion that the isolation transformers of transformer-based UPSs do not really isolate outputs from inputs for UPSs.

2.2 Restrain Interference

The UPS is a type of switch mode power supply. The LC filter needs to be installed on the output end to reduce harmonics of output voltage. Transformer-less UPSs have the extra inductor on the output end, such as L2 in figure 3. It, together with the filter capacitor, becomes the LC filter. In the actual isolation transformer, the flux on primary sides cannot be completely coupled to secondary sides. The part of flux that is not coupled forms the leakage inductance. Figure 4 is the equivalence principle diagram of the actual isolation transformer. Most of transformer-based UPSs do not have the output filter inductor. They just take the leakage inductance of the isolation transformer as the inductive reactance of the output filter for filtering. Both transformer-less UPSs and transformer-based UPSs need to output the filtering inductive reactance. The difference is that transformer-less UPSs have the independent inductor while transformer-based UPSs only utilizes the leakage inductance of the isolation transformer. Indeed, the two have no differences in nature. Costs are high if the leakage inductance of the isolation transformer is used as the filter inductor. However, for transformer-based UPSs, the isolation transformer must be installed at their inversion position. (Reasons will be introduced in the following text.) Therefore, using the leakage inductance of the isolation transformer as the filter inductor is an economical means for them. After analysis, we can see that both transformer-less UPSs and transformer-based UPSs can use the LC filter to restrain interference. The difference is that transformer-less UPSs use the independent inductor and transformer-based UPSs use the leakage inductance of the isolation transformer.

Figure 4 Equivalence principle diagram of the actual isolation transformer

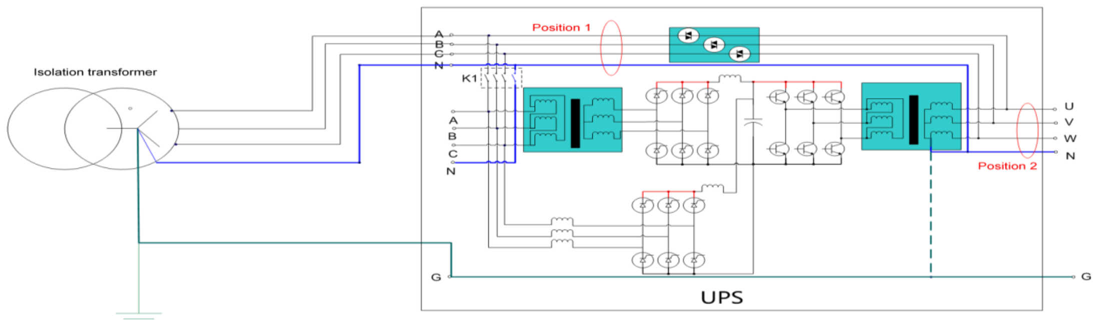


2.3 Reduce the Neutral-ground Voltage

Disputes about the neutral-ground voltage never stop. We always think that it is unscientific to overstate hazards of the neutral-zero voltage. For details, see the *Data Center Energy White Paper 04 — Causes of Generation of Neutral-ground Voltage and Related Misunderstandings*. Here I only conduct the technical analysis on the influence of the isolation transformer on the neutral-zero voltage. The isolation transformer itself does not reduce the neutral-ground voltage. Some users think that the neutral-ground voltage can be reduced to 0 by connecting the UPS output N to the ground (PE) in the isolation transformer of transformer-based UPSs. Actually, in transformer-less UPSs, the neutral-ground voltage can also be reduced to 0 by connecting N to PE. However, as the TN-S power distribution system is commonly used in China, N cannot connect to PE in transformer-based UPSs or transformer-less UPSs.

In the TN-S system, if a UPS does not have the isolation transformer on the bypass, its bypass input must include N and the input N shall be connected to the output N. Figure 5 shows connection of N to PE by virtue of the isolation transformer. In the figure, the ground wire connects to the middle point of the isolation transformer and to N through the dashed line. As a result, the N wire and PE wire on the input side of the UPS become parallel connection. PE wire is no longer a PE wire and becomes a PEN wire, with currents of the N wire flows through it. The TN-S system changes into the TN-C system. Such a connection is not allowed in power distribution systems outside China. However, in China, the *Code of Acceptance of Construction Quality of Electrical Installation in Building* (GB50303—2002) requires connection of N and PE of the UPS, which has been questioned by many power distribution experts. To realize connection of N and PE on the output end of the UPS in the TN-S system, the isolation transformer needs to be installed on the bypass or at the UPS output position, to separate the N wire from the PE wire.

Figure 5 Connection of N and PE by virtue of the isolation transformer in the TN-S power distribution system



We can see that the isolation transformer cannot reduce the neutral-ground voltage. For the TN-S system, if the isolation transformer is not installed on the bypass, N cannot be connected to PE on the output end of the isolation transformer, as this will change the TN-S system into the TN-C system. If users accept the TN-C system, PE can also be connected to N in transformer-less UPSs to reduce the neutral-ground voltage.

2.4 Realize Fault Isolation

After inverters fail, UPSs supply the power through the bypass. No matter UPSs are of power frequency or high frequency, output fuses are configured on the output end. (See figure 3.) If the inverter or bus bar capacitor fails, great energy enters into or is released by the bus bar capacitor. At this time, fuses burn out. Therefore, both transformer-based UPSs and transformer-less UPSs have the function of fault isolation.

2.5 Restrain Low-frequency 3n-order Harmonics

THDv is an indicator for measuring quality of the output voltage. Twentieth to fiftieth harmonics with frequency from 100 Hz to 2.5 kHz need to be calculated. The higher frequency of these harmonics, the higher the THDv is and the lower the quality of the UPS output voltage is. At present, most of transformer-based UPSs use the IGBT for inversion. The switching frequency of transformer-based UPSs ranges from 1 kHz to 3 kHz, while the frequency of mains power supply is 50 Hz. That is, the switching frequency is 20 to 60 times as high as the frequency of mains power supply. As a result, a lot of low-order harmonics (50 Hz, 100 Hz, and 150 Hz…) will be generated. Isolation transformers whose inputs on primary sides are delta, such as DY and DZ model isolation transformers, do not have the neutral wire. Therefore, third harmonics cannot pass through them. In this way, 3n-order harmonics are reduced and THDv is reduced. The switching frequency of transformer-less UPSs is usually above 15 kHz, 300 times as high as the frequency of mains power supply. With such high switching frequency, the output voltage of transformer-less UPSs includes few low-order harmonics. Even without the isolation transformer, THDv can be low. For example, the output THDv of Huawei transformer-less UPSs can be below 1%. We can see that transformer-less UPSs with high switching frequency themselves have the capability of restraining low-order harmonics. Without the isolation transformer, they can still ensure the low THDv.

3. Functions of Isolation Transformer in Transformer-based UPSs

Through aforesaid analysis, we find that the isolation transformer does not play an irreplaceable role in UPSs. Then, why are transformer-based UPSs still equipped with the isolation transformer? Actually, due to characteristics of transformer-based UPSs, the isolation transformer is really irreplaceable for them. The isolation transformer increases the voltage, which is an irreplaceable function, and filters out third harmonics, which is an important function.

3.1 Increase the Voltage

As shown in figure 2, the rectifier of the 12-pluse transformer-based UPS consists of thyristors. (For the 6-pluse transformer-based UPS, the situation is the same.) The highest DC voltage of 380 V mains power supply after rectification is 380*√2, 538.8 V. In the actual situation, the value is lower, usually 432 V. The DC 432 V bus bar passes through the inversion circuit. Considering the 1.2 modulation ratio, the 380 V AC wire voltage cannot be generated indeed. Actually, the voltage generated by transformer-based UPSs is 190 V wire voltage without the neutral wire. However, for inversion, 220 V phase voltage with the neutral wire is needed. Transformer-based UPSs can only increase the voltage by utilizing the isolation transformer.

3.2 Filter out Third Harmonics

As preceding analysis, transformer-based UPSs cannot filter out low-order harmonics due to low switching frequency. As 3n-order harmonics cannot enter into the delta input transformer, the isolation transformer plays an important role in improving voltage quality of power-frequency transformers. For transformer-less UPSs, as their switching frequency is high, the inverter can reduce low-order harmonics to a very low level through PWM modulation. Without the isolation transformer, they can still ensure the low output voltage THDv.

4. Conclusion

Isolation transformers play an irreplaceable role in transformer-based UPSs in an early stage. With the technical development, isolation transformers in UPSs become fewer and fewer. At first, the number of isolation transformers in a transformer-based UPS is four.

Now, the number of isolation transformers in the most advanced transformer-based UPS is only one. Due to architecture characteristics of transformer-based UPSs, the isolation transformer must be installed. While transformer-less UPSs do not require an isolation transformer by virtue of advanced technologies. By removing the isolation transformer, transformer-less UPSs have many advantages, small size and weight and high efficiency. However, users doubt about the performance of transformer-less UPSs as they do not have the isolation transformer. Moreover, as some transformer-based UPS vendors intentionally misguide users, many users doubt whether a UPS without the isolation transformer can reliably operate. However, as analysis in this document, we can find that, compared with transformer-based UPSs with the isolation transformer, without the isolation transformer, performance and reliability of transformer-less UPS are still high. At present, some traditional transformer-based UPS vendors that occupy good markets overstate functions of the isolation transformer, with a purpose of preventing the pace of transformer-less UPSs to replace transformer-based UPSs. Over the long term, their efforts are useless.

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