# Data Center Energy White Paper 01 — Development of the UPS Architecture

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## Preface

In recent years, with the rapid development of big data and cloud computing, traditional data centers face fast transformation. As a key part of the power supply and distribution system of a data center, the uninterruptible power supply (UPS) also changes. More and more UPS vendors pay attention to key features such as reliability, high-efficiency, usability, and simple maintenance.

Since its generation, what changes has the UPS experienced? What causes these changes? What are the mainstream products on market currently? This document answers these questions.

## 1. Classification of the UPS

The UPS can be classified in multiple modes. The UPS can be generally classified into dynamic UPS and static UPS by energy storage mode, and the dynamic and static UPSs can be classified into passive stand-by UPS, online interactive UPS, and online double conversion UPS. By technology, the UPS can be classified into transformer-based UPS and transformer-less UPS, and the transformer-less UPS can be classified into tower-mounted UPS and modular UPS.

### 1.1 Classification of the Dynamic UPS

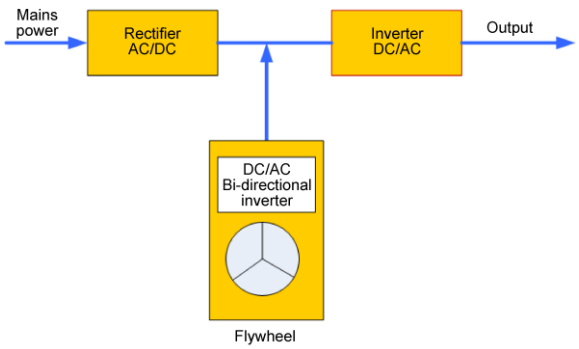
The dynamic UPS releases kinetic energy using its rotating part, while the static UPS uses the battery to store energy. The fly wheel UPS is a typical dynamic UPS. The online double conversion UPS is the most frequently applied static UPS in the current market.

Through decades of development and improvement, the fly wheel UPS occupies a unique position in the high-power UPS market. Fly wheel UPSs applied in the market are as follows:

**a). Online double conversion fly wheel UPS (Typical example: VYCON solution)**

This structure is exactly similar to the online double conversion UPS. The difference is that the online double conversion fly wheel UPS uses the flywheel rather than the battery to store energy and needs to cooperate with the traditional UPS. Therefore, the application of the online double conversion fly wheel UPS is limited.

Established in 2002, VYCON is a manufacturer of technologically advanced flywheel energy storage systems. VYCON products are mainly used in North America. The standby time of the fly wheel UPS ranges from 15 seconds to 90 seconds.



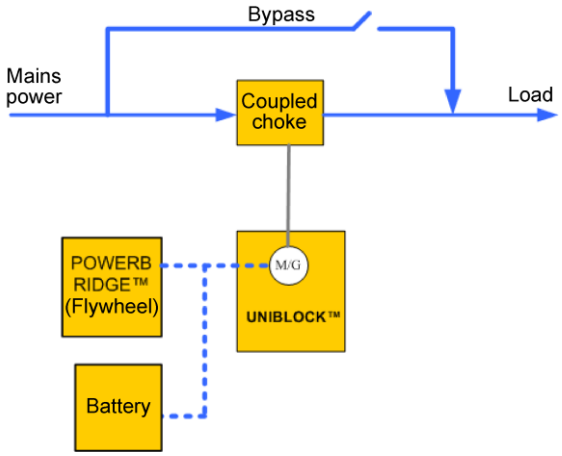

**b). Rotary online fly wheel UPS (typical example: Piller solution)**

Different from the VYCON solution, the Piller solution replaces the traditional UPS.

The main functions of the coupled choke are power conversion, compensation, and filtering.

The core component is the M/G (UNIBLOCK™), which functions as the motor to drive the flywheel (charge the flywheel) when the mains power supply is proper. When the mains power supply is abnormal, the flywheel discharges as a generator. The mechanical mode replaces the power electronics conversion. Without the accurate control of the power electronics conversion, the power grid adaptability and inversion quality are compromised.

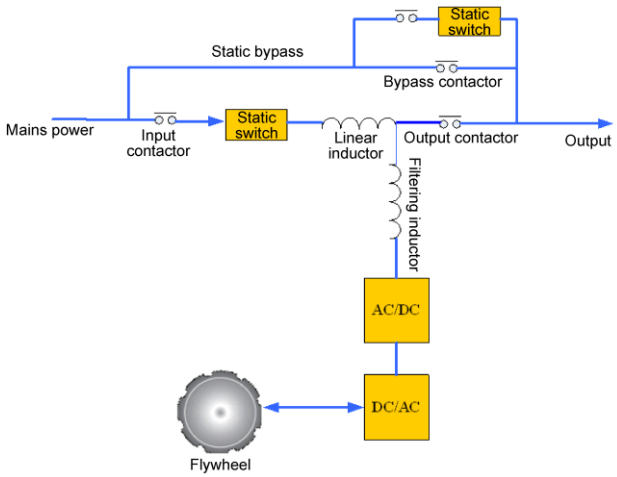
Piller is a century-old company in the UPS field, with the mainstay product UNIBLOCK-T. Piller is headquartered in Germany. Currently, Piller products are applied in Europe and North America.




**c). Online interactive fly wheel UPS (typical example: Active Power solution)**

This solution replaces the traditional solution of UPS+battery.

The online interactive fly wheel UPS is the most frequently used solution in China. The operating principle is the same as that of the online interactive UPS. The online interactive fly wheel UPS is similar to a filter, which can implement simple filtering and voltage stabilization, with a simple topology and high efficiency. However, the power grid adaptability and output performance indicator are significantly poor.




### 1.2 Comparison of Anti-Grid Interference Capabilities of Three Dynamic UPSs

The preceding UPSs are typical dynamic UPSs. Table 1 compares the anti-grid interference capabilities of the three dynamic UPSs.

**Table 1** Comparison of anti-grid interference capabilities of three dynamic UPSs

| Quality Issue of the Battery | Double Conversion | Rotary | Online Interactive |
|---|---|---|---|
| **Voltage dips (DIP)** | Output voltage steady state: ±0.5%; dynamic state: ±5% (a power cycle, 40 ms). | Output voltage steady state: ±1%; dynamic state: ±5% (200 ms). | Output voltage DIP directly affects the load. |
| **Voltage jump** | Output voltage steady state: ±0.5%; dynamic state: ±5% (three power cycles). | Output voltage steady state: ±1%; dynamic state: ±5% (200 ms). | In a power cycle, the voltage surge exceeds 14%. |
| **Frequency variation** | The output frequency variation is limited within ±0.5%. | The frequency variation from the grid cannot be controlled. | The frequency variation from the grid cannot be controlled. |
| **Wave form distortion** | Line voltage distortion does not affect the output waveform. | Line voltage distortion is corrected on the output end by the synchronous generator. | Line voltage distortion cannot be corrected. |
| **Voltage imbalance** | The voltage imbalance of the mains power supply does not affect the load. | Some voltage imbalance of the mains power supply is corrected by the synchronous generator, and some directly impacts the load. | The voltage imbalance of the mains power supply directly affects the load. |

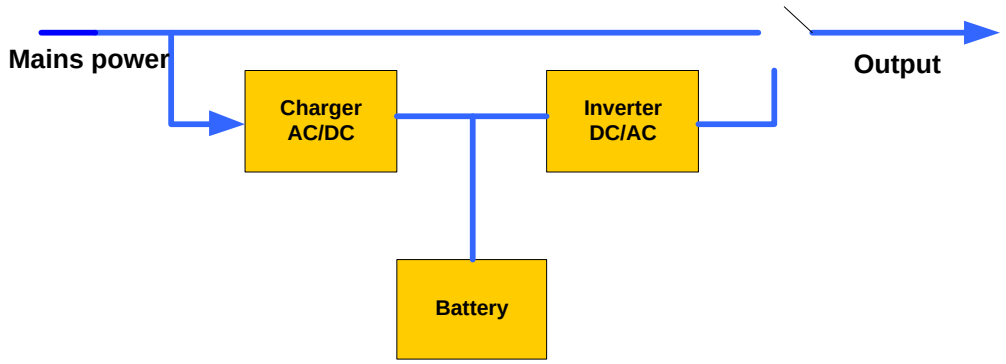
According to Table 1, the online double conversion fly wheel UPS has the strongest anti-interference capability. However, fly wheel UPSs of this type must cooperate with the traditional UPS to work. Therefore, the application is limited. Currently, the online interactive UPS is the most frequently used UPS in China.

**1.3 Classification of the Static UPS**

The preceding content describes some common structures of the dynamic UPS. The following describes some static UPSs. Different from the dynamic UPS, the static UPS uses the battery to store energy. By operating principle, common static UPSs can be classified into passive stand-by UPS, online interactive UPS, Delta conversion UPS, and online double conversion UPS.

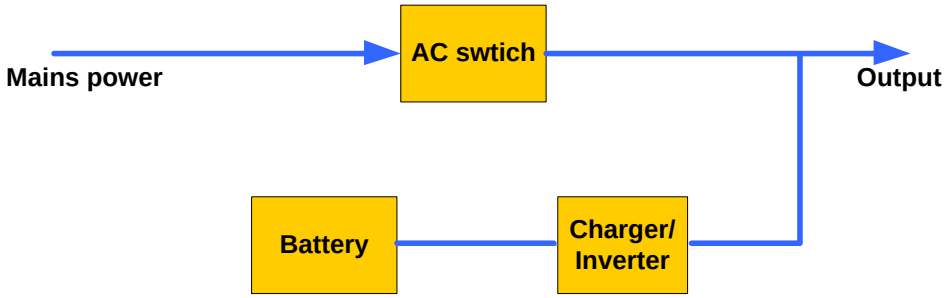
**a). Passive stand-by UPS**

A passive stand-by UPS only starts the inverter when the power supply is abnormal. When the power supply is proper, the problems on the mains power supply grid cannot be regulated. Therefore, the power supply quality is relatively poor, but the efficiency is high. This structure is generally applied to the UPS with the power capacity lower than 3 kVA. The structure of UPSs of this type is simple; the backup time is about 10 minutes; and the rectangular wave output is adopted. Passive stand-by UPSs are mainly applied to PCs.




**b). Online interactive UPS**

Compared with the passive stand-by UPS, the online interactive UPS is configured with the voltage stabilization function to supply optimized mains power to the load. The cost is low and the circuits are simple. However, the input distortion and interference cannot be removed. In addition, switching takes a period of time. This structure is applied to small-capacity UPSs with the power capacity lower than 5 kVA. The structure of UPSs of this type is simple; and the output is rectangular wave or simulated sine wave. Online interactive UPSs are mainly applied to PCs or office equipment to provide protection.

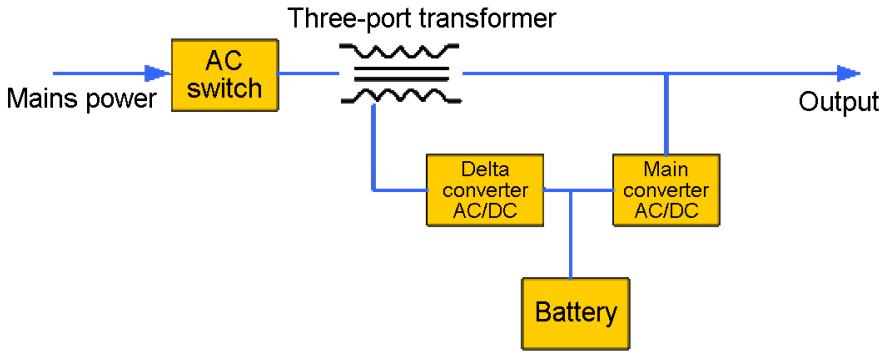


**c). Delta conversion UPS**

The core of a Delta conversion UPS is the Delta converter and main converter.

The functions of the Delta converter are as follows:

- Control the input current, a high ohmic sine wave current source.
- Control current charging.
- Compensate the input voltage to ensure the output voltage is stable.
- Control and adjust the input power factor.



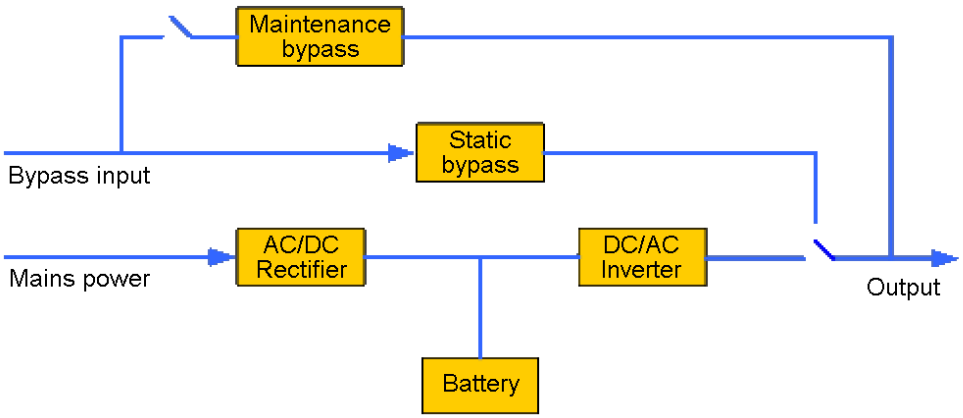

The functions of the main converter are as follows:

- Control and stabilize the output voltage, a low internal resistance sine wave voltage source.
- Charge the battery.
- Supply power to the load when the mains power supply fails.
- Compensate the reactive power and harmonic in the load current when the mains power supply is proper.

According to the functions of the Delta converter and main converter, the Delta conversion UPS has a stronger capability in regulating the input voltage and a more complex structure than the online interactive UPS. This structure is applied to UPSs with the power capacity ranging from 20 kVA to 200 kVA and the output is sine wave.

**d). Online double conversion UPS**

The online double conversion UPS provides perfect protection for the load and filters out nearly all interference and harmonics. However, the structure is complex and the cost is generally high. This structure is applied to UPSs with the power capacity ranging from 1 kVA to 1200 kVA, has the highest stability compared with other structures, and the output is standard sine wave. Currently, 80% UPSs adopt this structure. This structure provides protection for the IT load or other important industry load.




An UPS has multiple working states including the normal mode, static bypass mode, battery mode, and maintenance bypass. The online double conversion UPS can be classified into the transformer-less UPS and transformer-based UPS by structure, which will be described in this document.

### 1.4 Comparison of Anti-Grid Interference Capabilities of Four Static UPSs

Table 2 compares the anti-grid interference capabilities of four static UPSs.

**Table 2** Comparison of anti-grid interference capabilities of four static UPSs

| Item | Passive Stand-by | Online Interactive | Delta Conversion | Online |
|---|---|---|---|---|
| **Power off** | ○ | ○ | ○ | ○ |
| **Transient voltage falling** | x | Δ | ○ | ○ |
| **Transient voltage rising** | x | Δ | x | ○ |
| **Low voltage** | x | Δ | ○ | ○ |
| **Overvoltage** | x | Δ | x | ○ |
| **Power supply noise** | ○ | ○ | ○ | ○ |
| **Frequency variation** | x | x | x | ○ |
| **Switching transient** | ○ | ○ | ○ | ○ |
| **Harmonic distortion** | x | x | x | ○ |
| **Power factor correction** | x | x | ○ | ○ |

Note: Symbols in Table 2 are described as follows:

○: resistible

x: partially resistible

Δ: irresistible

**According to the comparison, the online double conversion UPS has the strongest anti-grid interference capability.**

### 1.5 Comparison of Dynamic and Static UPSs

The preceding content describes some basic topologies of dynamic and static UPSs. However, what advantages and disadvantages do the dynamic and static UPSs have?

The most significant difference between the dynamic and static UPSs is the energy storage mode. A static UPS uses the battery to store energy, while a dynamic UPS uses the flywheel to store energy. Table 3 compares the two energy storage modes.

**Table 3** Comparison of the battery energy storage mode and the flywheel energy storage mode

| Energy Storage Mode | Battery | Flywheel |
|---|---|---|
| **Advantage** | ✓ Reliable battery backup technology and mature application.<br>✓ Flexible configured back time, ranging from 5 minutes to 1 hour.<br>✓ Relative low purchase cost in the initial stage.<br>✓ Easy to monitor. | ✓ Core component flywheel with 20 years useful life.<br>✓ Compared with the traditional battery, the floor area is reduced by 70%.<br>✓ Environment friendly. |
| **Disadvantage** | ✓ The performance degrades with the time, and the integrated replacement is required every 5 or 10 years.<br>✓ The A/B circuits of the battery are required to be deployed in different battery rooms; the floor area is large and the weight bearing requirement on the floor is high.<br>✓ Battery leakage or scrapping will pollute the environment. | ✓ Generally, the back time is 15s; and longer back time is not supported.<br>✓ The diesel generator must be started within 15s.<br>✓ Relative high purchase cost in the initial stage (30%).<br>✓ Periodic inspection is required and the bearing, capacitor, and vacuum pump needs to be replaced periodically.<br>✓ Small number of vendors, leading to the risk of insufficient spare parts. |

According to Table 3, the battery and flywheel energy storage modes have advantages and disadvantages respectively. However, the back time of the flywheel energy storage mode is only 15 seconds, which greatly restricts its application.

Table 4 compares the online double conversion UPS and online interactive flywheel

UPS, which are current mainstream static and dynamic UPSs. Huawei UPS5000 is used as an example of the online double conversion UPS, and Active Power is used as an example of the online interactive UPS.

**Table 4** Comparison of the online double conversion UPS and the fly wheel UPS

| | Indicator | Online Double Conversion (Huawei UPS5000) | Fly Wheel UPS Active Power |
|---|---|---|---|
| **Input performance** | Input voltage range | –64% to +22% | –15% to +10% |
| | Input frequency range | 40–70 Hz, convertible | 45–55 Hz, inconvertible |
| | Input power factor | 0.99 | 0.99 |
| | Input harmonic current | < 3% | < 3% |
| **Output performance** | Output voltage regulation | –1% to +1% | The output voltage is regulated to ±2% when the input voltage ranges from –10% to +10%.<br>The output voltage is regulated to ±8% when the input voltage is out of the range of ±10%. |
| | Output frequency regulation | ±6 Hz, configurable; the frequency accuracy is 0.1% | Inconvertible; the frequency accuracy is 0.2% |
| | Output voltage distortion | Linear load < 1%<br>Non-linear load < 3% | Linear load < 3%<br>Non-linear load < 5% |
| | Dynamic voltage recovery | 20 ms<br>(Jump when the load reaches 100%) | 50 ms<br>(Jump when the load reaches 100%.) |
| | Overload capability | In inverter mode: 110% load/60 minutes, 125% load/10 minutes, 150% load/1 minutes<br>Long-period operation with a load of 135% in bypass mode<br>1000% load/100 ms | In inverter mode:125% load/60s, 200% load/30s, 500% load/1s<br>1000% load/10 ms |
| | Output power factor | The output PF is 1; when the input PF of the load ranges from –0.5 to +0.5, the UPS output does not need to be derated. | When the input PF of the load ranges from 0.7 to 0.9, the UPS output does not need to be derated. |
| **Overall efficiency** | System efficiency | A maximum of 96% when the load is 40% | Efficiency of 96% when the load is 40%.<br>Efficiency of 97% when the load is 70%.<br>Efficiency of 98% when the load |

| | | | |
|---|---|---|---|
| | | | is 100%. |

According to Table 4, except the efficiency, other parameters of the UPS5000 are better than that of the fly wheel UPS of Active Power, and the efficiency of the UPS5000 in the low-load period (40% load) is at the similar level of the fly wheel UPS.

According to the preceding comparison, we can conclude as follows:

- Compared with the traditional UPS, the fly wheel UPS has advantages in energy saving and environment protection.
- The fly wheel UPS has inherent defects and some restrictions:
  - ✓ The backup time is only 15 seconds; if the diesel generator fails to be started, serious power failure occurs.
  - ✓ The price is high and the initial investment is increased because the fly wheel UPS must cooperate with the diesel generator.
  - ✓ The complex system requires professional maintenance of the original factory; therefore, the maintenance cost is high.
  - ✓ The power grid adaptability is poor; the input and output performance indicators are all poorer than those of the online double conversion UPS.

**Based on the preceding analysis, the fly wheel UPS is only applicable to the following scenarios:**

- ✓ Environment friendly power supply systems that support new technologies.
- ✓ Scenarios with the high quality grid, few power-off accidents, and low requirement on the system reliability.

## 2. Comparison of the Transformer-less UPS and the transformer-based UPS

Currently, the static UPS is the most frequently used online double conversion UPS; in addition, the static UPS has the strongest anti-interference capability. From generation to now, the online double conversion UPS experiences the change from the transformer-based UPS to the transformer-less UPS. What is a transformer-based UPS? Why is the transformer-less created?

### 2.1 Introduction to transformer-based and transformer-less UPSs

A transformer-based UPS is UPS with output transformer and transformer-less UPS is UPS without output transformer.

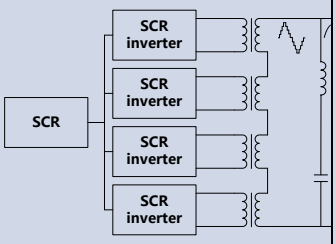
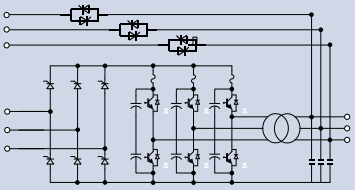
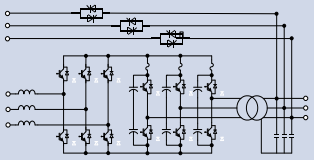
During the development process of the transformer-based UPS, the adopted rectifier changes from the SCR to the insulated gate bipolar transistor (IGBT) rectifier, and the output transformer is no longer used. Therefore, usually the two types of UPSs are distinguished by checking whether the transformer is used in the industry.

### 2.2 Development of the transformer-based UPS

Since its generation, the transformer-based UPS has experienced the development and changes in Table 5.

**Table 5** Development of the transformer-based UPS

| | Early-Stage Transformer-based UPS | Traditional Transformer-based UPS | Modern Transformer-based UPS |
|---|---|---|---|

| | | | |
|---|---|---|---|
| **Rectification unit** | SCR, power frequency | SCR, power frequency | IGBT rectifier, high frequency |
| **Inversion unit** | SCR inverter, power frequency, transformer mandatory | IGBT inverter, high frequency | IGBT inverter, high frequency |
| **Architecture** |  |  |  |
| **Feature** | High harmonic pollution and extremely large size inverter and filter | High harmonic pollution and the inverter size greatly reduced using the high-frequency technology | Low harmonic pollution |

The modern transformer-based UPS is the Transformer-less UPS using the IGBT rectifier and isolation transformer.

**2.2 Reasons of the Development from the transformer-based UPS to the transformer-less UPS**

The reasons why the UPS develops from transformer-based to transformer-less are as follows:

1. Market requirement: As the requirements on energy saving, emission reduction, and environment protection are raised, the UPS must deliver higher efficiency and be easier to install and maintain.

2. Technology evolution: On the one hand, the component technology improves. "Silicon" replaces "copper". Through the generational shift of power components such as the metal-oxide semiconductor field-effect transistor (MOSFET) and IGBT, widely application of the digital signal processor (DSP) and digital circuit, and gradual maturity of the logical link control (LLC), soft switch, and tri-level inverter, the high-frequency, digital, and intelligent electronic products become the main trend. Traditional analog circuit components such as the transformer and filter inductor that the "copper" stands for are gradually replaced by various digital circuit components such as the single-chip microcomputer, control chip, and new semiconductor power component that the "silicon" stands for. On the other hand, the rapid development of software enables the digital circuit technology to replace some functions of the analog technology.

**2.3 Comparison of the transformer-based UPS to the transformer-less UPS**

The transformer-based UPS and the transformer-less UPS can be compared in the following aspects:

**Reliability: The reliability of a transformer-less UPS is not poorer than that of a transformer-based UPS.**

The reliability of a transformer-less UPS is even better than that of a transformer-based UPS.

**Table 6** Comparison of the reliability of the transformer-based UPS and the transformer-less UPS

| | Rectifier | Inverter | Rectifier Topology | Inverter Topology |
|---|---|---|---|---|
| **Traditional transformer-based UPS** | SCR, low voltage stress, high current stress | IGBT | Phase-control rectifier | Full bridge |
| **Transformer-less UPS** | IGBT or SCR+IGBT, high voltage stress, low current stress | IG BT | High-frequency rectifier or phase-control rectifier+power factor correction (PFC) | Half bridge |
| **Comparison** | Both the SCR and IGBT are mature components and the reliability is similar. | | Both topologies are mature; the transformer-less UPS can implement wider voltage and frequency input range. | Both topologies are mature. |

**Environment adaptability: A transformer-less UPS has better environment adaptability than a transformer-based UPS.**

A transformer-less UPS uses the microprocessor as the processing control center. The complex hardware analog circuits are burnt to the microprocessor to control the operation of the UPS in the form of a software program. Therefore, the volume and weight are significantly reduced, the noise is relatively low, and the impact on the space and environment is low.

**Investment: In terms of the investment, a transformer-less UPS is superior to a transformer-based UPS.**

According to the investment in the device, the difference is insignificant (the price of some vendors' transformer-less UPSs is competitive, and the price of some vendors' transformer-based UPSs is competitive). However, comprehensively considering the efficiency of the two UPSs and the ratio of the diesel generator, the transformer-less UPS is superior to the transformer-based UPS. \

Take a well-known vendor as an example. In the situation of adopting the 12 pulse+11$^{th}$ harmonic filter, the recommended lowest ratio of the transformer-based UPS and the diesel generator unit is 1:1.4. However, the ideal ratio of the transformer-less UPS of the same vendor and the diesel generator unit is 1:1 (generally, 1:1.1).

**Energy saving: In terms of the energy saving, a transformer-less UPS is superior to a transformer-based UPS.**

In the current market, the half-load efficiency of a transformer-less UPS is superior to that of a transformer-based UPS. Generally, the half-load efficiency of a transformer-less UPS reaches 94%, while the half-load efficiency of a transformer-based UPS is about 88%.

**Volume and weight: A transformer-based UPS is in large size and heavy weight, which is difficult to install.**

As the transformer is equipped, the floor area of a transformer-based UPS is large and the weight is much heavier than a transformer-less UPS with the same power. Therefore, the installation is difficult and the installation cost is high.

Note: This document does not discuss the neutral-ground voltage problem of the transformer-less UPS as described by some transformer-based UPS vendors. For details, see the *Data Center Energy White Paper 04 — Causes of Generation of Neutral-ground Voltage and Related Misunderstandings.*

According to the preceding comparison, the performance of a transformer-less UPS in various aspects is better than that of a transformer-based UPS. We believe that the transformer-less UPS will gradually replace the existing transformer-based UPS in the market.

## 3. Conclusion

According to the whole development process of the UPS, the UPS is generally developing toward higher efficiency and easy installation and maintenance based on the high reliability. After the transformer-based UPS develops to the transformer-less UPS, a lot of types of the transformer-less UPS are created, such as the tower-mounted UPS, quasi-modular UPS, and modular UPS. In terms of the whole trend of the UPS, the transformer-less modular UPS is the main trend. What are the differences between a transformer-less modular UPS and a transformer-less tower-mounted UPS? How to choose a modular UPS? The *Data Center Energy White Paper 02 - How to Choose a Modular UPS* answers these questions.

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