The UPS system has become a vital component in managing the critical power infrastructure and to guarantee the availability of power for the critical loads. Now the key question is what topology of UPS has to be used.

a) Transformer based
b) Transformer less UPS
c) Transformer less UPS with external input/output transformer

The answer to this key question depends on the design requirements of downstream electrical infrastructure which is based on taking into consideration the following points:

i. Flexibility to connect two independent sources for increased availability
ii. Galvanic isolation of DC (Battery) from the AC output
iii. Short Circuit Characteristics of UPS
iv. Safety Margin in design
v. Local grounding of neutral
vi. Efficiency

TRANSFORMER BASED AND TRANSFORMERLESS UPS
Flexibility To Connect Two Independent Sources

The possibility to connect two independent sources for the rectifier and bypass mains input is primarily to have a redundancy of power at the UPS point to the loads and to have the possibility of concurrent maintenance of the sources.

Redundancy: When the rectifier mains and the bypass mains are separated and are connected to two independent sources, the power continuity is guaranteed to the loads; either through the UPS system or through the independent source connected to the bypass mains.

Concurrent Maintenance: It is possible to shutdown one complete source as the distribution system is through separate independent paths/sources and to perform the maintenance activity without disturbing the loads.

Transformer-Based UPS

In a transformer-based UPS, the transformer is inbuilt at the output of the inverter, this transformer provides a galvanic isolation between the rectifier and the output of the UPS. This gives the flexibility to connect two different sources to the rectifier and bypass without any change or disturbance to the existing earthing system.

Transformerless UPS

In a transformerless UPS, as there is no galvanic isolation transformer between the rectifier input and output, an external isolation transformer is required either at the rectifier input or at the bypass input (refer figure 2 or 3) to have the flexibility to connect two different sources to the rectifier and bypass without any change or disturbance to the existing earthing system.

It is forbidden to connect two different sources for rectifier mains and bypass due to the fact the neutrals of both sources gets connected together and will lead to:

- Nuisance tripping of ELCB's upstream of the UPS
- Inactiveness of ground fault detectors
- EMC's issue due to circulating current on the neutral of both sources

When a transformer is connected to the bypass of the UPS, the coordination of the downstream safety systems is disturbed and has to be co-ordinated based on the short circuit current capacity of the transformer.
Short Circuit Characteristic Of UPS

In the event of an short circuit at the output of an UPS(without bypass), the output voltage of the UPS becomes almost Zero and the output current will start to raise until it reaches the current limit setting of the inverter bridge and will last for 5-6 cycles after which the inverter will trip (Figure 5).

![Figure 4 Short Circuit Current in Inverter Mode](image)

The fault clearing is possible if the selected UPS system is able to deliver a higher short circuit current and the breakers are co-ordinated such that the breaker feeding the short circuit is first cleared before any of the upstream breakers in the output distribution of the UPS.

**a. Transformer-based UPS**
Transformer-based UPS exhibit a better short circuit characteristic as the short circuit current is based on the devices and impedance of the transformer. Transformer based UPS will have a better phase to neutral short circuit current as two winding of the primary side of the transformer will support this fault.

**b. In transformerless UPS** the short-circuit characteristic is purely based on the electronic current limiting circuits of the UPS. The amplitude and the duration of the short circuit current is purely based on the characteristic of the devices selected. To have the same characteristic of transformer based UPS, higher rating of IGBT has to be selected. In some Transformer less UPS, the UPS may also transfer to bypass to clear the fault thereby putting the connected loads at risk without any power protection.
Galvanic Isolation of DC (Battery) From the AC Output
In the event of short circuit in any one of the IGBT’s in the inverter bridge, the DC will flow through to the loads and will disturb the smooth operation of the loads.

a. Transformer-Based UPS
In a transformer-based UPS (as shown in Figure 1), the transformer which is at the output of the inverter provides a galvanic isolation between the DC bus and the output AC power. This transformer will not allow the DC to flow through the loads.

b. Transformerless UPS
In a transformerless UPS, there are additional electronic circuits to detect the DC component in the output but will require an output transformer as shown in figure 4 if a galvanic isolation is desired.

When the transformer is connected to the output of the UPS, the output voltage regulation of the UPS is no more controlled by the UPS but will be based on the regulation of the transformer which is generally ±4-5% as against the ±1% of UPS. Also the coordination of the downstream is disturbed and has to be coordinated based on the short circuit current capacity of the transformer which depends on the impedance of the transformer.

Galvanic Isolation of Neutral
Galvanic isolation of neutral is indeed an important requirement to ensure the right quality of power to ensure that
• Input neutral coming from the mains is galvanically isolated from the output neutral
• Reduces the problem of common-mode noise induced through “ground loops” or multiple-current paths.
• Can reduce the harmonic currents fed back to the source by single-phase nonlinear loads.

a. Transformer-Based UPS
In a transformer-based UPS, the output neutral generated by the transformer can be grounded to earth so that the UPS can act as a separately derived source. However to achieve this, the bypass has to be disabled.
An additional transformer at the bypass is required to have a galvanic isolation if the bypass of the UPS system is enabled as shown in Figure 6.

Figure 6 Transformer based UPS with bypass Transformer

b. Transformerless UPS
In a transformerless UPS, If the UPS has to act as a separately derived source, a common transformer has to be connected to the input of both rectifier and bypass mains (Figure 8). This will decrease the overall efficiency of the UPS by atleast 2-3%.

Figure 7 Schematic of Transformerless UPS with input transformer
Efficiency is a function of the technology and choice of components used in the UPS. Also the efficiency of the UPS specified by the manufacturer is usually under a conditioned environment with linear loads. Actual site requirements maybe different and this should be factored when comparing the energy efficiency of UPS from different manufacturers.

Also the efficiency of the UPS under different loading levels from 25 – 50% is more important than the energy efficiency at 100% loading.

A Transformer based UPS, in general, will be about 2-3% lower in efficiency than a transformerless UPS when no isolation is required. This external transformer energy loss must not be forgotten and must be accounted for when comparing the overall energy efficiency of the transformerless UPS.

A summary of efficiency comparison is tabulated below

<table>
<thead>
<tr>
<th>Load %</th>
<th>Transformer-Based UPS</th>
<th>Transformerless UPS with external Transformer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>UPS Efficiency</td>
<td>UPS Efficiency</td>
</tr>
<tr>
<td>Full Load</td>
<td>No Isolation</td>
<td>92-94%</td>
</tr>
<tr>
<td></td>
<td>Two Different Sources</td>
<td>92-94%</td>
</tr>
<tr>
<td></td>
<td>Full Isolation</td>
<td>92-94%</td>
</tr>
<tr>
<td>50% Load</td>
<td>No Isolation</td>
<td>91-93%</td>
</tr>
<tr>
<td></td>
<td>Two Different Sources</td>
<td>91-93%</td>
</tr>
<tr>
<td></td>
<td>Full Isolation</td>
<td>91-93%</td>
</tr>
<tr>
<td>25% Load</td>
<td>No Isolation</td>
<td>89-91%</td>
</tr>
<tr>
<td></td>
<td>Two Different Sources</td>
<td>89-91%</td>
</tr>
<tr>
<td></td>
<td>Full Isolation</td>
<td>89-91%</td>
</tr>
</tbody>
</table>
A summary of both topologies of UPS is tabulated as follows:

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>Description</th>
<th>Transformer-Based UPS</th>
<th>Transformer-less UPS</th>
<th>Transformerless UPS with external Transformer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Flexibility to connect two independent sources for increased availability</td>
<td>Possible</td>
<td>Not Possible</td>
<td>Possible with transformer at input / bypass</td>
</tr>
<tr>
<td>2</td>
<td>Galvanic isolation of DC-output AC</td>
<td>Possible</td>
<td>Not Possible</td>
<td>Possible with transformer at global output</td>
</tr>
<tr>
<td>3</td>
<td>Short Circuit Characteristics of UPS</td>
<td>Best</td>
<td>Better</td>
<td>Better</td>
</tr>
<tr>
<td>4</td>
<td>Local grounding of neutral</td>
<td>Possible</td>
<td>Not Possible</td>
<td>Possible</td>
</tr>
<tr>
<td>5</td>
<td>Efficiency</td>
<td>Better</td>
<td>Better</td>
<td>Not good, as 3% efficiency is lost on account of transformer</td>
</tr>
<tr>
<td>6</td>
<td>Footprint and Weight</td>
<td>Better</td>
<td>Best</td>
<td>Higher compared to transformer based UPS</td>
</tr>
<tr>
<td>7</td>
<td>Low Component Count</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>8</td>
<td>Handling of triplen harmonics</td>
<td>The Zig-Zag winding of the transformer cancels the triplen harmonic current in the secondary windings of the transformer</td>
<td>The triplen harmonics are managed by the inverter bridge, which requires higher rating of IGBT to handle these harmonic current</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Reliability</td>
<td>Higher mean time before failure (MTBF). Because this UPS use traditional electrical engineering principles instead of a high concentration of electronic components, they are inherently more reliable by design than a corresponding electronic circuit board assembly.</td>
<td>Employs sophisticated electronic circuitry to mimic the online characteristics of a transformer-based device, as well as providing suitable standards of mains filtering. As such, transformerless UPS are more prone to failure on sites where there is a high degree of mains borne pollution such as transients, spikes and electrical noise</td>
<td></td>
</tr>
</tbody>
</table>

UPS with built-in isolation transformers are more suitable for industrial applications:

- Gives better reliability for fully inductive and half controlled thyristor based loads which draws unequal current in both the halves of sine wave with 3ph 4 wire inputs
- The loads such as motors, fans, isolation transformers in the customer facility are protected even if there is a failure of the inverter IGBT as there will no flow of DC voltage to the motors which could have damaged the motors.

UPS which are transformer free are suitable for IT applications where there are downstream PDUs with isolation transformer.