Medium Voltage UPS Solutions -

When and Why?

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1 Scope

The tendency towards Mega Data Centres in the internet and IT business requires an increasing demand of high reliability power at single locations. More and more large critical industrial processes rely on a power quality level which can not be provided by the public grid. The distribution of the electrical power within those installations is realized in medium voltage (MV) technology because a low voltage (LV) distribution with its high current levels is physically and economically limited. Likewise a centralized high power uninterruptible power supply (UPS) system represents a reasonable technological solution, particularly if designed as a medium voltage UPS or integrated Diesel-rotary-UPS (DRUPS).

Medium voltage UPS technology reduces distribution losses downstream of the UPS and reduces space due to the lower number of transformers required. Short circuit currents are limited to a manageable value while the reliability of the power distribution is kept on a high level when using a high quality UPS system.

The MV distribution allows paralleling of several high power UPS or DRUPS systems on one common output bus in an N+x configuration and thus avoiding the use of an extensive number of low voltage switching devices to create redundancy.

The modular design of a line interactive UPS simply allows a replacement of the grid-to-load interface from low voltage to medium voltage components, keeping the basic parts of the UPS and the storage the same as for LV applications. In this way the good and familiar experience with the functionality and maintainability of a reliable LV UPS is maintained.

The paper describes the design of a MV UPS unit and its integration into a redundant MV UPS system. Space and electrical loss aspects are presented as well as configurations realized in the field for a Data Centre, an Airport and a Semiconductor Fab.

2 Power Demand and Distribution in today’s Mission Critical Applications

Fast growing E-commerce over the last decade forced a rapid rise both in space and electrical power required to operate data centres. The power density in kilowatt per square metre then gets higher and cooling power becomes a critical issue. Operators and customers of those data centres expect a safe and reliable power supply covered by an uninterruptible power supply (UPS) system. Often, dictated by the risk of thermal runaway, the entire electrical
power needed is covered by UPS. Whereas a typical data centre in the early nineties required some one to three megawatts, today ten to twenty megawatts per installation is not rare. Also industrial enterprises like semiconductor fabrication, chemical and food industry require more often a safe power supply because major production losses caused by mains interruptions can not be tolerated. Single locations have grown larger with a demand on a safe power supply up to 40 MVA. In addition the production area is often wide spread and distribution of a high amount of electrical power throughout the location is necessary. Long distances in the power distribution also have to be overcome in applications like airport, runway lighting.

3 Limits of LV Distribution in High Power Applications and the Solution

At low voltage system levels of 400 volts or 480 volts a maximum capacity of approximately 5 MVA at the common bus is reached very soon. The limitation to 5 MVA is given by the current capability of bus bars and breakers of about 6000 amps on one side and the short circuit capability of the switchboards of typically 100 kA on the other side. Higher ratings of both will let the costs and the dimensions of the switchgear increase dramatically while the component availability in the market is very limited. Additionally, high currents require high copper cross sections and cause rather high resistive losses, both resulting in increasing costs for power transmission.

A way to reduce the currents and to enable a further increase of the power is the move to a medium voltage (MV) system level. At a typical MV level of 13.2 kV, which is quite common in the US, the maximum system power rises up to 27 MVA using a standard MV breaker size of 1200 amps and up to 57 MVA with a breaker size of 2500 amps. Medium voltage levels go up as high as 34.5 kV, allowing a system power rating of up to 70 MVA.

Power distribution using UPSs follow the same electrical rules: Paralleling of UPS modules at a low voltage level on a common bus is subject to exactly the same limitations. Figure 1 illustrates a possible situation:

- The left side shows a group of paralleled UPS modules. The addition of a 4th module results in an overload situation (shown in red) of the secondary winding of the supply transformer and the downstream bus work.

- In the middle the UPS group has been moved to the MV side of the transformer, eliminating the overload situation at the bus work attached to the UPS modules.
staying with one MV-transformer only this will still overload its secondary winding and the LV bus work.

- On the right side also parts of the distribution have been moved to the MV side and there are three separate transformers used to supply the load. Splitting the LV distribution into three separated paths eliminates the overload situation for the transformer and the LV bus work.

![Figure 1](image1.png)

**Figure 1** Paralleling of UPS modules in a high power distribution

## 4 Integration of UPS-Systems in the MV-Distribution

An obvious way for integrating one or more standard low voltage UPS modules into a MV distribution is adding a transformer both at the input and at the output side. These additional step-up and step-down transformers increase the total number of components, require additional space and reduce the efficiency of the entire power supply system.

By using an integrated MV-UPS both transformers can be omitted. As shown in **Figure 2** further components can be saved if a high power UPS replaces four or five standard dual conversion LV UPS modules. This configuration offers space savings around the power supply system and operates at higher efficiency.

![Figure 2](image2.png)

**Figure 2** MV-UPS technology reduces the total number of components
From the different UPS configurations on the market, the line interactive UPS offers the best choice for integration into a MV system. Figure 3 provides an overview:

- The MV breakers and the coupling choke as the link between mains and load replace the corresponding LV parts and will fit into the MV switchboard.
- The MV-transformer is an additional part and represents the interface to the remaining standard LV UPS components.

These standard LV UPS components consist of a synchronous motor-generator which provides continuous and stabilized power for the load, a frequency converter which connects the energy storage and an optional Diesel engine attached via a mechanical clutch. The energy storage may be a chemical battery or a space saving flywheel (POWERBRIDGE) for bridging short mains interruptions, until the Diesel engine has taken over the load.

A major advantage of such a configuration is the fact that all low voltage components including the entire control electronic and the operation software are taken from standard and long term proven LV units.

Figure 3  Design of an integrated MV Diesel Rotary UPS (DRUPS) Type UBTD, showing the electrical (single line diagram) and the physical (grey boxes) arrangement of the systems components.

5 Redundancy Concepts

A high quality power supply for mission critical applications presumes a redundancy concept. For LV designs there are some well known and proven concepts like the N+1 parallel redundant concept or the N+N system redundant configuration with two redundant A and B feeders where dual corded loads can be connected to. Without major effort, these concepts can directly be adapted to a MV layout. They represent simple and clearly arranged
installations, keeping the systems manageable for operators and maintenance personnel. Figure 4 shows single line diagrams of such systems. Again, the power distribution from the UPS location to the load transformers is done in medium voltage.

![Figure 4: MV-UPS modules in redundant system configurations](image)

A new modern concept to achieve redundancy while limiting the short circuit power is the Isolated Parallel System (IP-System). The loads are individually fed by separate UPS modules loaded to a certain degree below full load. A module failure will cause the assigned load to be fed from a common IP-bus, which is contributed by each of the UPS modules via an IP-Choke. Figure 5 shows the basic layout of a Medium Voltage IP-System, which allows the realization of a highly reliable power supply system that offers some benefits compared to the above two systems [1].

![Figure 5: MV-UPS modules integrated in an IP-System](image)

6 Space and Losses are Key Factors for large Systems

One of the major cost issues in a data centre or a production facility is floor space. Reducing the space for infrastructure equipment like power supplies results in additional space for IT or manufacturing equipment. Often the available area for the UPS system is given and limited, particularly in existing buildings, but the required power is increasing. High power UPS modules with kinetic energy storage in LV or MV technology are well suited to overcome this challenge.
In Table 1 a space comparison between various LV and MV redundant concepts is shown. These comparisons are based on a load requirement of 10 MVA in total and a feeding voltage level of 13.2 kV. Typical values for the footprint for static and rotary UPS modules, 5 minute batteries and switchgear cabinets are taken from manufacturer brochures. MV transformer and choke are of cast resin dry type with footprints taken from real projects. The entire system consists of 7 groups of 1670 kVA each, realized with 3 static UPS units in parallel or 1 rotary unit per group. Each static unit is equipped with a 5 minute battery, the rotary unit with flywheel storage. Redundancy is achieved by the 7th group, so the configuration is 6+1.

<table>
<thead>
<tr>
<th>Distribution</th>
<th>UPS Type</th>
<th>Power</th>
<th>Energy Store</th>
<th>Groups</th>
<th>Space Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV static</td>
<td>LV</td>
<td>600 kVA</td>
<td>Battery</td>
<td>3</td>
<td>2267 ft²</td>
</tr>
<tr>
<td>MV static</td>
<td>LV</td>
<td>600 kVA</td>
<td>Battery</td>
<td>3</td>
<td>3021 ft²</td>
</tr>
<tr>
<td>MV rotary</td>
<td>LV</td>
<td>1670 kVA</td>
<td>kinetic</td>
<td>1</td>
<td>1628 ft²</td>
</tr>
<tr>
<td>MV rotary</td>
<td>MV</td>
<td>1670 kVA</td>
<td>kinetic</td>
<td>1</td>
<td>1656 ft²</td>
</tr>
</tbody>
</table>

Table 1  Comparison of space required of a 10 MVA, 13.2 kV, N+1 redundant UPS system in different design concepts

A comparison of the 1st and the 2nd line in Table 1 shows, that the total space required by the system increases by approximately 33% if the static LV UPS units are arranged between a step-up and a step-down transformer. A drastic reduction in space is achieved by using a rotary UPS both in LV and MV, as shown in lines 3 and 4.

Besides the footprint the electrical losses are an important point to look at, too. Particularly at long distribution distances in large industry facilities or wide spread airport areas distribution losses become an issue. A comparison with the above configurations including a cable of 100 meters (328 ft) between UPS and load is shown in Figure 6. The typical losses for UPSs and transformers are taken from brochures. The losses for the cable have been calculated by using an adequate type of cable suitable for the current. The LV cable in this example generates 1.5% losses (line 1) whereas the MV cable has 0.1% losses only. The step-up step-down solution requires another 2.4% losses for the transformers (line 2), so this is not the ideal way. The high power one module rotary UPS generates 0.5% less losses (line 3) but by removing the step-up step-down transformers the losses decrease substantially (line 4). Accumulated to losses per year the difference between the last two examples is more than 1 million kilowatt-hours or approx. 100,000 US$.  

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[86x45]8
For longer distribution lengths the influence of the cable will rise, which again would give a better result for the MV distribution.

Figure 6  Comparison of losses of a 10 MVA, 13.2 kV UPS distribution in different design concepts

Regarding investment costs the MV UPS and the MV switchgear need to be balanced against transmission cabling and distribution. MV UPS modules and MV switchgear are obviously more cost intensive than LV components. These higher costs can partially be compensated by utilising less copper for the distribution, especially in case of long and complex distribution networks.

If a MV solution is required for technical reasons, the usage of real MV UPS modules is more cost effective and more efficient than any integration of standard LV UPS modules in a MV distribution.

7 A MV-UPS serving Air Field Lighting

Classic applications for high reliability power supplies are safety relevant installations at airports like airfield lighting, radar systems and control towers. These critical loads are spread over a wide area across the airfield and the electrical distribution is often realized in medium voltage.

An example is shown in Figure 7, where a total load of 3.8 MW is served by a MV supply system at a voltage level of 20 kV consisting of four 1670 kVA Diesel UPS modules in a parallel redundant configuration. The total length of the MV network is 56 kilometres (35 miles). The UPS is inserted in series in the existing network. The four DRUPS are arranged in two groups of two paralleled units each. Depending on the load requirements the switchgear allows operation as n+1 or as system-system redundant.
8 Power Supply of a 35 MW Semiconductor Fab

The second example shows the power supply system of a semiconductor fab [2] which includes a cogeneration plant of nine generator sets with natural gas engines, 3.9 MW each. Both electricity and heat power is transported over several hundred meters from the energy plant to the production facility. The voltage level is entirely 20 kV. The role of the UPS system is interfacing the high quality supply bus with the raw utility bus in order to provide back up from utility while blocking all grid born disturbances. As a second task the UPS with its flywheel storage provides stabilisation power for a constant voltage and frequency level during transient conditions. The unique mode of operation of the flywheel storage allows delivery and absorption of full power unlike other UPS systems. The ability of bi-directional power flow enables an excellent frequency control especially under transient conditions, keeping the whole systems frequency within tight limits. A single line diagram of the principal layout is shown in Figure 8.
9 Redundant MV-UPS at a High Rise Data Centre

The third example, to be seen in Figure 9, explains the power supply of a large data centre. The entire load is almost 40 MVA, split into 28.8 MVA no break and 10.8 MVA short break load. The supply system is configured as isolated redundant at a voltage level of 11 kV. The UPS units are arranged in six primary groups of three modules each plus one redundant group of four modules to provide back up power in case of a failure of one of the six primary groups. So the total number of UPS units is 22, each of them laid out as a MV Diesel UPS, providing 1600 kVA of no break and 600 kVA of short break power.

The further down stream distribution is performed in medium voltage to the individual floors of the data centre and ends in supply transformers complemented by static transfer switches close to the IT equipment. The isolated redundant back up line is realized with two alternative power supply paths to the loads: First on the MV level with automatic transfer switches (ATS) upfront the supply transformers and second on the LV level directly feeding the static transfer switches (STS) connected to the loads.

Figure 9  Single line of a redundant 40 MVA high quality power supply system for an internet data centre

10 Conclusion

Increasing power density and increasing total power demand at single sites combined with rising requirement for high reliability power in IT business and production facilities are today’s trends. The power supply system has to respond with suitable UPS and distribution designs. As on the one hand, high power low voltage systems lead to current limitation in the distribution and as on the other hand often long distances need to be bridged, the step to medium voltage level is a suitable technical solution. MV systems reduce cable size and
losses which increases the efficiency of the distribution network. Additionally, the utilization of integrated high power MV UPS modules reduces the number of components to a minimum. Basic parts of those modules are taken from standard and proven low voltage equipment, including control hard- and software. The MV UPS enable a clearly laid out high power system configuration, keeping its complexity within manageable limits.

11 References

[1] Frank Herbener
   Iso-Parallel UPS Configuration
   http://www.piller.com/

[2] Stephan Schroeter
   Präzisions Power (German language)
   E&M Magazine, 15th February 2007