CHLORIDE

Secure Power Always

Leading power factor loads and their impact on UPS capacity and performance

Server technology has rapidly advanced in response to market needs, delivering high density, highly reliable computing without the massive harmonics issues inherent with older power supplies. One unintended consequence of this advance is a shift in load power factor characteristics in data centers from a range of 0.6-0.9 lagging to a range of 0.9 leading to 0.9 lagging. UPS's of older designs cannot deliver their full rated power to these new loads and must be de-rated or retrofitted. Therefore, data center designers and operators must be vigilant in order to avoid problems including insufficient capacity, nuisance alarms, and even downtime due to overloads. Fortunately, new UPS designs can avoid these issues while delivering more real power available to the load.

Power supply evolution leads to harmonics issues

For many years, systems powered by switch mode power supplies had power factors ranging from 0.6 to 0.9 lagging. These designs had many advantages, but produced high input current harmonics in addition to the poor power factor. Eventually regulatory pressure led to standards such as EN/IEC 61000-3-2 standard in the European Union which forced power supply manufacturers to address this issue. The server industry response was to add large input filter capacitors to the power supply. These were optimized for full load but at the time servers routinely had a single power supply typically loaded at 40-50% of capacity. None the less, they were effective in reducing harmonics while load power factors remained predominantly lagging (inductive).

The demand for high availability

As server technology became more powerful, servers assumed more of the mission-critical computing tasks. In order to achieve the higher reliability required for these applications, servers were equipped with hot-swappable redundant power supplies. This reduced typical power supply loading from approximately 50% to approximately 25%, while the filter capacitor was still typically optimized for 100% loading.

In modern "blade" server systems, multiple server cards are supported by a common set of redundant power supplies. This reduces the number of components, especially fans, and thus increases reliability. However, this further reduces the loading of power supplies, while leaving the filtering capacitors sized for the highest load scenario should one power supply fail. Additionally, many blade chassis are not fully populated or utilized. With these changes, load server power factors now fall into a range from 0.9 leading (capacitive) to 0.9 lagging (inductive), depending on design and loading at any particular moment.

The challenge for UPS's

Most large UPS module designs were not ready for this development. In order to understand why not, it is important to consider the key UPS subsystems and how they operate. A double conversion UPS has two major subsystems, a DC subsystem (rectifier and battery or other energy storage device) and an AC subsystem (the inverter). Each has a limit in terms of how much power it can deliver. The DC system limit is defined in kW and the AC system limit is defined in kVA. Overloading either of these systems overloads the UPS.

Older inverter designs have large output filters based largely on capacitance. If the load power factor is lagging (inductive), the reactance of the load and the filter offset each other and the UPS can deliver all or most of its rated kW to the inductive load. However, if the load power factor is capacitive (leading), the capacitive reactance of the filter and the load become additive, and the UPS uses more of its kVA capacity to overcome this capacitive reactance.

Figure 1 is a power output diagram for a typical UPS optimized for 0.7-0.9 lagging power factor loads. This illustrates the constraints on UPS power delivery at various load power factors. The vertical axis "A" represents active or true power, measured in watts, while the horizontal axis "B" represents reactive power in VAR's or kVARS. The lengths of the vectors originating at point "AB" equal kVA. The vertical height of any point on a vector indicates the kW. The horizontal distance from axis A to any point on a vector represents the kVAR of a load at that point.

The relationship of the vectors and axis is defined by the geometry of a right triangle:

$$kVA = \sqrt{(kW)^2 + (kVAR)^2}$$

The angle between the vector and the vertical axis "A" is θ, the angle of deflection of the current wave form from the voltage waveform; the cosine of θ is the power factor.

The constraints on UPS power delivery are represented by lines "C", "D", and "E".

- "C" is the kW limit of the DC subsystem of the UPS (rectifier and battery)
- "D" represents the kVA limit of the UPS inverter; it is offset because of the capacitive nature of the output filter, causing it to favor lagging (inductive) loads.
- "E" represents the range of real loads, or practical VA

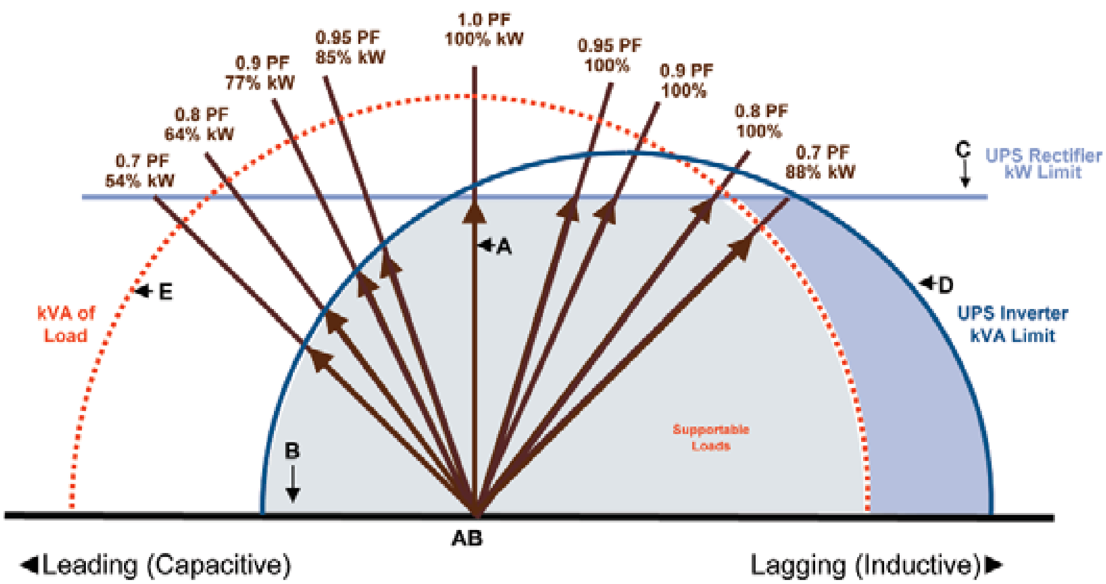

Figure 1. Power output diagram for UPS rated at 0.8 power factor, optimized for 0.7 - 0.9 lagging

Table 1: UPS power delivery*

Load power factor	Delivered kVA	% of unit kVA rating	Delivered kW	% of unit kW rating	Limit
0.7 lagging	500 kVA	100%	350 kW	87.5%	load demand
0.8 lagging	500 kVA	100%	400 kW	100%	rectifier kW
0.9 lagging	444 kVA	88.8%	400 kW	100%	rectifier kW
0.95 lagging	421 kVA	84.2%	400 kW	100%	rectifier kW
1.0 (utility)	400 kVA	80%	400 kW	100%	rectifier kW
0.95 leading	358 kVA	71.6%	340 kW	85%	inverter kVA
0.9 leading	342 kVA	68.4%	308 kW	77%	inverter kVA
0.81 leading	320 kVA	64%	256 kW	64%	inverter kVA
0.7 leading	309 kVA	61.8%	216 kW	54%	inverter kVA

** This table is for 500 kVA/400 kW UPS (0.8 PF) optimized for lagging power factor loads.*

The effects of these constraints can be seen in Table 1. The vectors extend from the center point until they meet a constraint. The light blue shaded area represents the range of loads that can be supported. On the leading side, the UPS inverter kVA limit is the binding constraint in this example. On the lagging side, the constraint is the rectifier kW until you reach a region (darker blue area) where the load does not demand all of the kVA or kW that the UPS can supply.

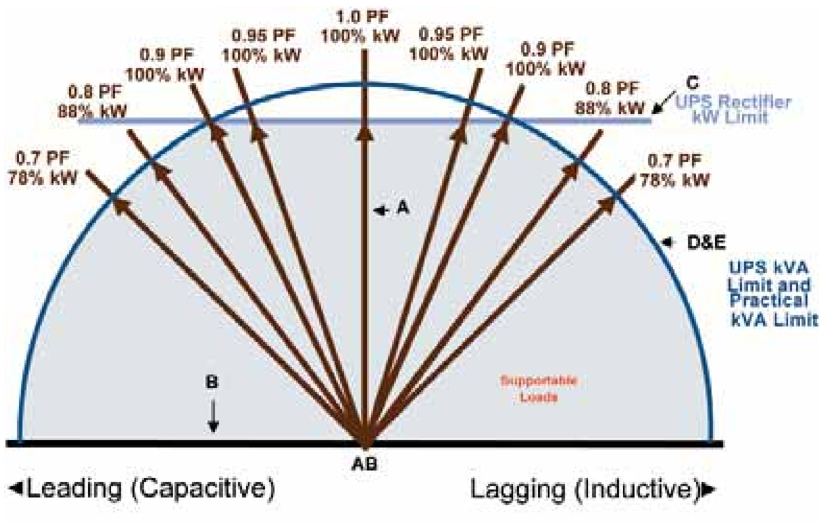

Figure 2. Power output diagram for UPS rated at 0.9 power factor, optimized for 0.9 leading - 0.9 lagging

Table 2: UPS power delivery comparison*

	Current UPS with symmetrical output 0.9 PF				**Legacy design UPS 0.8 PF** (from table 1)				
Load power factor	**Delivered kVA**	**% of unit kVA rating**	**Delivered kW**	**% of unit kW rating**	**Limit**	**Delivered kVA**	**% of unit kVA rating**	**Delivered kW**	**% of unit kW rating**
0.7 lagging	500 kVA	100%	351 kW	78%	load demand & inverter kVA	500 kVA	100%	350 kW	87.5%
0.8 lagging	500 kVA	100%	396 kW	88%	load demand & inverter kVA	500 kVA	100%	400 kW	100%
0.9 lagging	450 kVA	100%	450 kW	100%	rectifier kW	444 kVA	88.8%	400 kW	100%
0.95 lagging	474 kVA	94.8%	450 kW	100%	rectifier kW	421 kVA	84.2%	400 kW	100%
1.0 (unity)	450 kVA	90%	450 kW	100%	rectifier kW	400 kVA	80%	400 kW	100%
0.95 leading	474 kVA	94.8%	450 kW	100%	rectifier kW	358 kVA	71.6%	340 kW	85%
0.9 leading	500 kVA	100%	450 kW	100%	rectifier kW	342 kVA	68.4%	308 kW	77%
0.8 leading	500 kVA	100%	396 kW	88%	load demand & inverter kVA	320 kVA	64%	256 kW	64%
0.7 leading	500 kVA	100%	351 kW	78%	load demand & inverter kVA	309 kVA	61.8%	216 kW	54%

** This table compares a 500 kVA/450 kW UPS (0.9 PF) optimized for 0.9 leading - 0.9 lagging with a legacy design 500 kVA/400 kW UPS UPS (0.8 PF) optimized for 0.9 - 0.7 lagging.*

Chloride recognized this shift in power factor early on and has developed more modern designs that are compatible with leading power factor loads. Output filters in these designs incorporate a balance of capacitive and inductive characteristics which gives the UPS a symmetrical output as seen in Figure 2. Note that the UPS kVA limit ("B") is now concurrent with the practical VA limit shown in Figure 1. Additionally, the latest designs for North America incorporate a kW/kVA rating based delivery of full kVA and kW at a 0.9 power factor.

The range of supportable loads is shown by the shaded area in Figure 2. Note that a larger percentage of targeted loads can be supported, and that de-rating is not necessary anywhere within this range. Table 2 shows the kVA and kW that the UPS can deliver at various load power factors, and provides a comparison with the UPS described in Figure 1 and Table 1.

Conclusion

The new UPS designs with symmetrical output characteristics, such as Chloride's UPSs, offers significant advantages to the data center designer and operator:

The UPS can be specified easily based on its kW/kVA rating subject only to normal practice of 80% maximum loading for safety factor. De-rating is NOT required for modern loads nor for any likely to develop over the next several years;

The operator will know that dynamic changes of load level or power factor within the specified kW/kVA rating of the UPS will not cause overloading and the resultant nuisance alarms or downtime.

Therefore, the logical choice for designers and operators of data centers is to select UPS's with symmetrical output characteristics that can handle leading as well as lagging loads without de-rating. They provide the best assurance against issues that may arise due to the dynamic variation of load in the modern data center under current conditions and in the foreseeable future.

Bibliography

(1) *Leading Power Factors*, John Taplin, published in Building Services & environment Engineer, October 2007.

About the author

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Chuck Heller is currently product manager for three-phase UPS sytems at Chloride North America. He has over 18 years of experience in the UPS industry and holds an MBA from the University of Chicago.

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