Understanding Delta Conversion Online™ "Output Power Factor Ratings" - Part 7

Introduction

This application note is the seventh in a series on delta conversion theory of operation. For complete understanding of the engineering benefits of this technology we recommend that you read all the series in order and any of the supplemental white papers found on the APC web site.

UPS Output Power Factor

In part 6 with respect to UPS input power factor we said: "Power factor is the percentage of electricity that is being used to do useful work. It is expressed as a ratio. For example, a power factor of 0.72 would mean only 72% of your power was being used to do useful work. Perfect power factor is 1.0, (unity), meaning 100% of the power is being used for useful work."

Power factor also applies to the UPS output, where we can say: "UPS output power factor rating is the percentage of electricity that is available to do useful work and its' also expressed as a ratio. For example, a power factor of 0.80 would mean only 80% of your power is available as real power to do useful work. Perfect output power factor is 1.0, (unity), meaning 100% of the power is available for useful work." However, like all things in life, there are some "caveat emptor's" . A lot depends on the size and type of inverter used in the UPS system.

The UPS Output Power Triangle

Although it may not be clear at this time, figures 1 & 2 show the difference in output ratings. Where the Delta Conversion Online™ output rating is at PF =1.0 (500kVA/500kW). This PF 1.0 rating is feasible because the main inverter is a IGBT PWM that is 100% kW rated at 500kW.

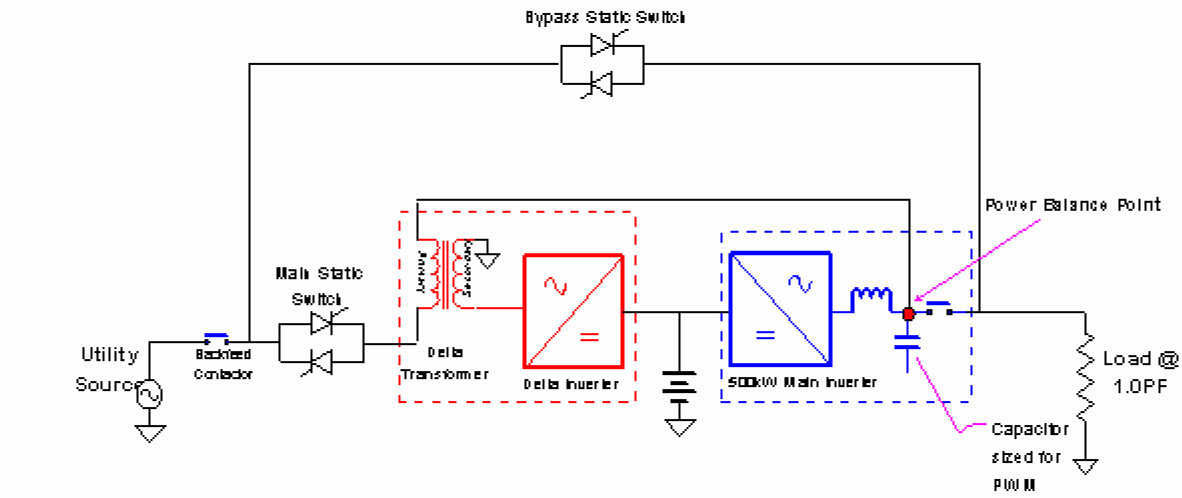

Figure 1 - *Delta Conversion Online™ 500kVA/500kW*

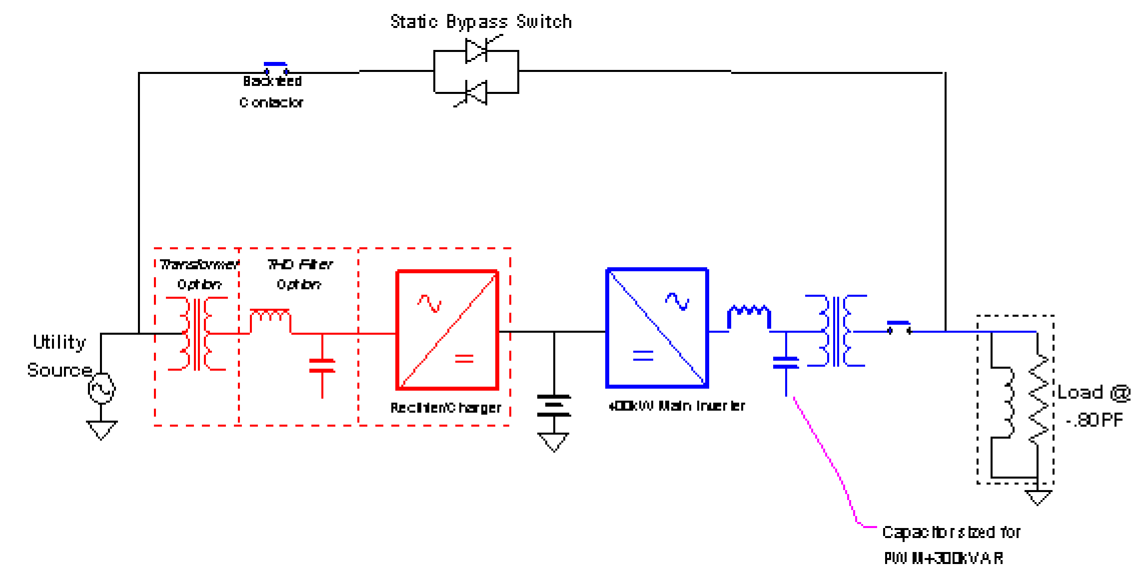

Figure 2 - *Double Conversion 500kVA/400kW*

The double conversion system shown in figure 2, is an old design that is output rated at PF = -.80 (500kVA/400kW). This is feasible because the main inverter is 80% kW rated at 400kW and they either use an IGBT H-bridge inverter and flyback diodes or they have to add 300kVAR to the inverter filter capacitor. The flyback diodes or the capacitor supplies the reactive power (Q) and the main inverter supplies the real power (P).

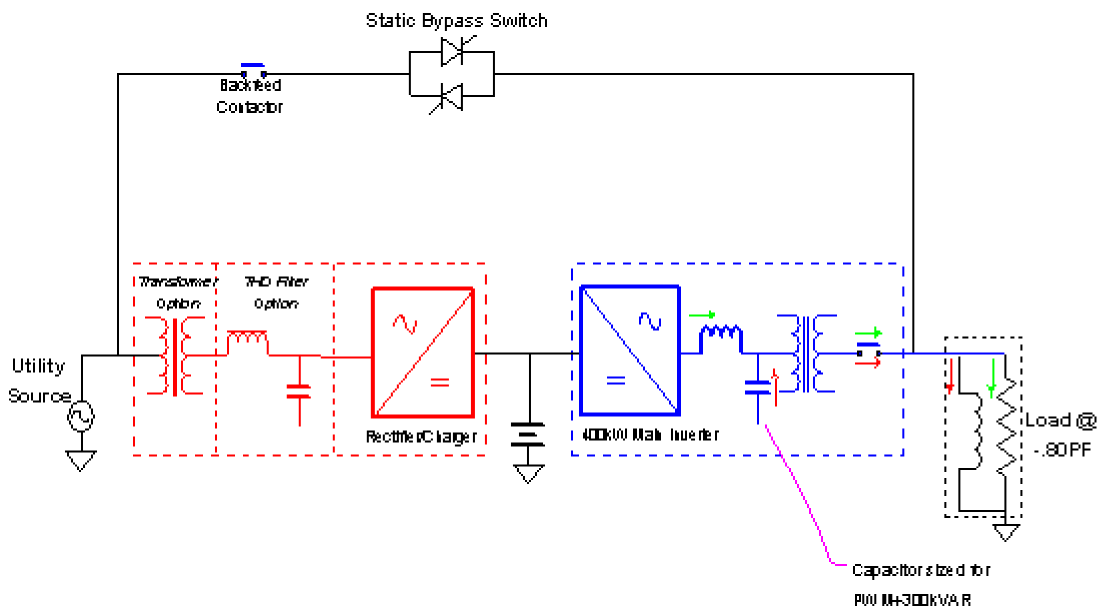

***Figure 3 -** Double Conversion Real Power & Reactive Power Paths @ -.8PF Load*

Using some of the information about power factor from part 6 of this series, i.e., if you reviewed the bibliography. We can best understand this via understanding the trigonometric relationship, i.e., "power triangle". If we take our DPF equation from Part 6.

Equation 1

$$PF = \frac{P}{S} = \frac{P}{VI} = \cos\theta_1$$

First we represent these output rating relationships mathematically. Then we can diagram the double conversion output rating, i.e., apparent power (S), real power (P), and reactive power (Q) relationships via a power triangle.

Equation 2

$$\text{If: } PF = \frac{P}{S} = \frac{400kW}{500kVA} = .80\ PF$$

Equation 3

$$\text{Therefore: } S = \frac{P}{\cos\theta_1} = \frac{400kW}{.80} = 500kVA$$

Equation 4

$P = S \cos \theta_1 = 500 * .80 = 400kW$

Given we know S and P , we can calculate the reactive power (Q) and show their relationship to each other.

Equation 5

$Q = \sqrt{S^2 - P^2} = \sqrt{500^2 - 400^2} = 300kVAR$

Equation 6

$P = \sqrt{S^2 - Q^2} = \sqrt{500^2 - 300^2} = 400kW$

Equation 7

$S = \sqrt{P^2 + Q^2} = \sqrt{400^2 + 300^2} = 500kVA$

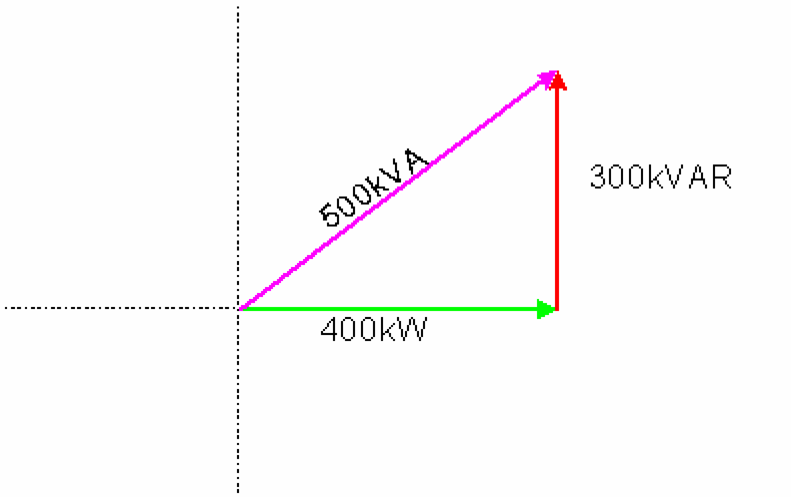

Figure 4 - *Double Conversion 500kVA/400kW Power Triangle*

We can also calculate the system output currents by converting the power quantities to amperes of current at a specific voltage. If we use 400V three-phase as our system voltage, the results are as follows:

Equation 8

If: $S = V * I * \sqrt{3}$

Then: $I_S = S/V* \sqrt{3} = 500000/692.8 = 721.7A$

Equation 9

If: $P= VI * \sqrt{3} * \cos \theta$

Then: $I_P = P/(V\sqrt{3}/ \cos\theta) = 500000/(692.8/.80) = 577.4A$

Equation 10

$I_Q = \sqrt{I_S^2 - I_P^2} = \sqrt{721.7^2 - 577.4^2} = 432.9A$

Now we can see the system output bus supplies 721.7A per/phase of apparent power (S) to the load. Of that apparent power (S), 577.4A per/phase is supplied by the main inverter as real power (P), and 432.9A per/phase is supplied by The flyback diodes or the 300kVAR capacitor as reactive power (Q). Neat trick! If they use a capacitor, can it handle additional heating from a harmonic PF load?

The Double Conversion -.80PF Output Rating Problem

To simplify all the above. A 500kVA/400kW double conversion system with it's output rating at -.80 PF, uses the 400kW main inverter combined with either flyback diodes or a 300kVAR of capacitor to boost the output apparent power (S) to 500kVA. The inverter supplies the real power (P) from the DC bus and the reactive power (Q) comes from the flyback diodes or capacitor. The combined effect at the output bus is 500kVA of available apparent power (S).

For older designs where capacitors are used and the load power factor increases above .80PF, the capacitors become an increasing reactive load on the main inverter, rather than a reactive current source for the output. The capacitor's reactive power (car's) is fixed and the inverter power rating (kW) is also fixed. Therefore, if the actual UPS output load power factor increases above .80, it affects the overall available system kW output rating by lowering the amount of kW load the system can support.

If the main inverter is rated to deliver 400kW from the DC bus, obviously it cannot support a continuous load greater than 400kW. In fact for the older step-wave and SCR technologies, if the load power factor is unity, i.e., PF = 1.0, the main inverter may have a hard time supporting more than ~ 265kW of real power (P) at the output bus load. This is shown below in figure 5.

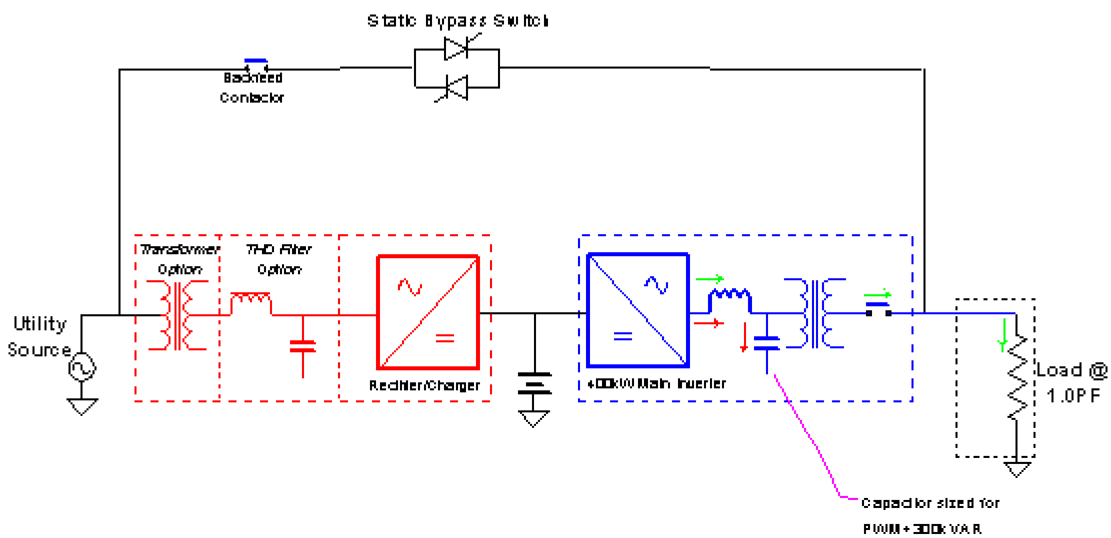

Figure 5 - *Double Conversion Real Power & Reactive Power Paths @ 1.0PF Load*

Now our challenge is to figure out how much real power (P) can the older step-wave or SCR UPS support with an output load at PF 1.0? Calculating the effect is identical to solving the power triangle for kW when kVA & kVAR's are known. However, the inverter kW rating becomes the hypotenuse of our power triangle (right triangle), the maximum output kW load becomes the base, and the capacitor kVAR's remains as the altitude.

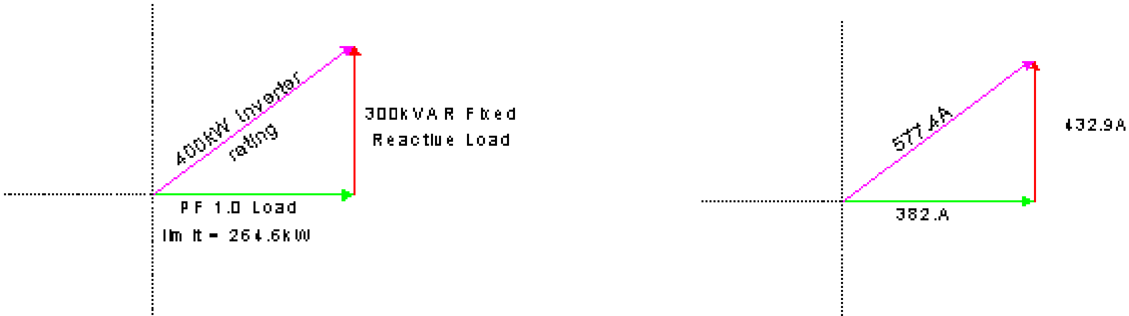

Figure 6 - *Double Conversion Power & Current Triangles @ 1.0PF Load*

Therefore, maximum allowable PF 1.0 load w/o overloading the inverter is easily found by either of the following equations:

$P_{max} = \sqrt{} P_{Inv}^2 - Q^2 = \sqrt{} 400^2 - 300^2 = 264.6kW$ or $I_{P\ max} = \sqrt{} I_{Inv}^2 - I_Q^2 =$ Ö 577.42 - 432.92 = 382A

This means if the inverter is rated to take 400kW of current from the DC bus, it can now only supply 66% of the system kW load rating (265/400 = .66) to the system output bus. Because the inverter is going into overload, a older design double conversion system will probably switch to static bypass if this 66% PF 1.0 load level is exceeded. If they don't switch to static bypass immediately, they will eventually be forced too, because of inverter over-temperature.

What Does It Really Mean To the CE or Customer?

The effect of loads with power factor greater than -.80PF, is usually transparent to most users and a great many CE's. That is until they experience the problem with older double conversion UPS designs. What are the potential risks? Some examples:

- CE designs system for small data center based on customer specified Watts/sq ft, and total calculations come to maximum of 350kW. CE selects a 500kVA/400kW system because he likes a little comfort zone. After facility is completed customer begins installing all large PFC servers. When actual load hits ~ 265kW, the UPS alarms on inverter overload, and transfers to static bypass. UPS vendor blames load PF, and customer blames CE.

- CE designs same small data center with distributed redundant design, 2 - 500kVA/400kW UPS systems using same 350kW facility maximum load. For redundancy each UPS system is feeding a separate output bus that feeds separate inputs to dual input static switch PDU's. After facility is completed, data center customers begin installing large PFC servers. The design is for each UPS to handle no greater than 50% load. After some time actual total connected load is ~300kW (150kW/ UPS system). Again what appears to be well within rating of the UPS system capacity? Major power failure, one module has inverter or battery failure. Remaining good module takes the 300kW load and shuts down on inverter overload. . UPS vendor blames load PF, and customer blames CE.

The real problem is the CE can't control the loads or their power factor. The load in a data center changes daily as new equipment is installed. The typical data center load today has a combined PF better than .90, with many of them at .95 or above. This is because of the huge influx in power factor corrected (PFC) power supplies in the servers, routers and other data center equipment.

The CE has a couple of choices:

- Use next higher rated double conversion UPS. This would be 625kVA to 750kVA depending on the vendor. However, this also has huge impact on rest of the facility infrastructure. The service transformer, engine generator, generator transfer switch, feeder circuit breakers and feeder conductors are now oversized by ~ 100 to 200kW or +25 to +50% of actual design kW load, depending on the vendors available UPS ratings. Clearly the customer is paying for a compromised design caused by the UPS output rating @ -.80PF limitations.
- Use a UPS system that's not load power factor limited and can deliver its full power to any PF load. That's an APC's Delta Conversion Online™ 400kVA/400kW system with PF 1.0 output rating. By using a 400kVA/400kW unit we further reduce infrastructure cost by ~20% versus the original competitor's 500kVA/400kW unit, (400/500 = 80%) and ~ 36% versus oversized competitor's 625kVA/500kW (400/625= 64%). Clearly the CE can deliver a design that meets the performance requirements, at the lowest capital expense. He can also sleep at night and not worry about the future load PF. The customer will benefit from the UPS output power factor rating because he can safely connect any load within the UPS's output current rating.

How much horsepower do you want?

The easiest analogy to describe this difference in UPS output power factor rating is to compare two trucks. f. ex. You need a new truck to pull the brand new bass boat your wife just bought you. This sounds like a fantasy. Well actually the part about her buying you the bass boat is fantasy!

Truck #1 has a 5.0L engine rated at 400HP, and Truck #2 has a 5.0L engine rated at 500HP. Which truck can pull more load? Oh yes truck #2 also has better fuel economy! The engine displacement in liters equates to our apparent power rating (S) in kVA and the horsepower rating equates to our real power (P) rating in kW. Oh yes, they both have ~ same price! Which truck do you want?

This is only one of the advantages of using a fully rated inverter for power factor 1.0 output rating. This concludes Part 7 of our series..

Bibliography

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