Application Note #41

Understanding Delta Conversion On-line "DC Bus Power Exchange" – Part 3

This application note is the third 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.

The DC BUS Components

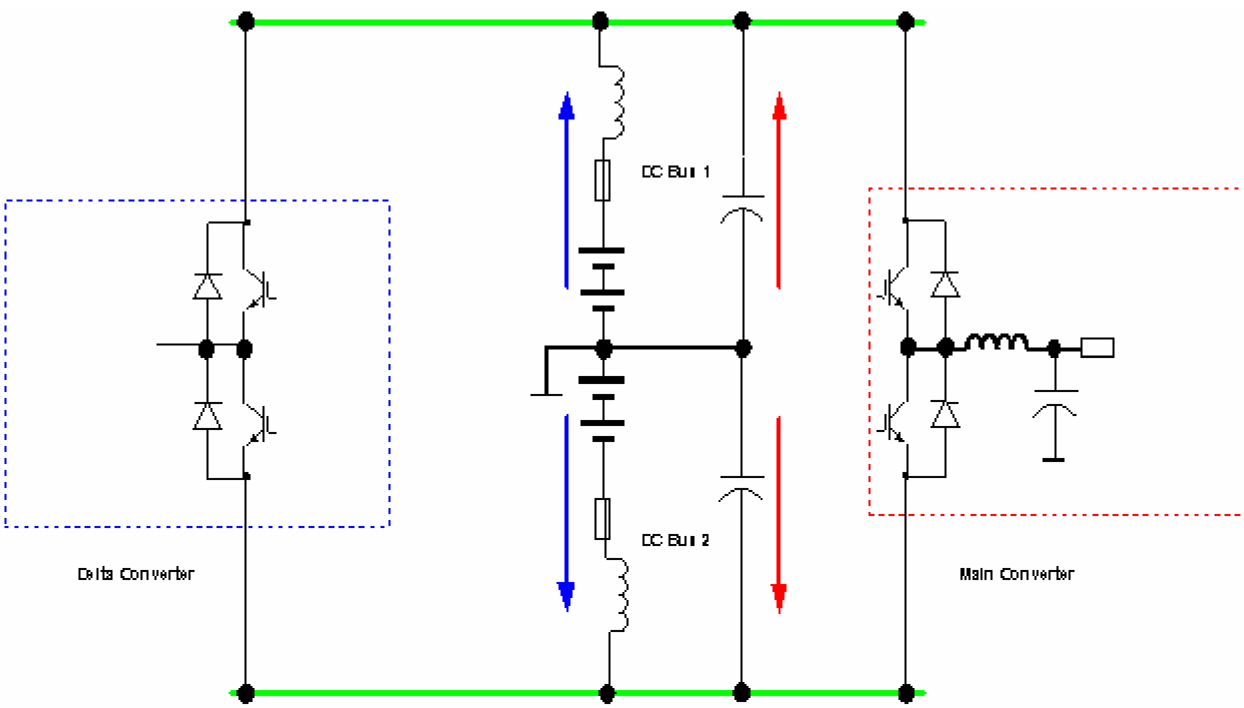

Figure 1: *Delta Conversion Online™ UPS DC Bus*

From the above we can see that we have a center tapped DC bus. This has some distinct advantages that will be discussed later. The important components in understanding how the DC bus works are the DC filter capacitors and the battery strings with their series chokes. These two energy storage components, i.e., the battery, and the DC filter capacitors behave very differently. Their actual DC operation is no different from a well-designed traditional double conversion DC bus. By design, the DC capacitors with their inherently lower source impedance, provide current for reactive power loads and instantaneous watt power for step loads, etc (Red Arrows). Whereas, the battery with its series choke impedances provides watt power for the longer duration needs (Blue Arrows).

How the two work together is best understood by examining the DC bus voltage levels and what they mean as far as what's happening to the DC bus. First the DC bus for our system is 2 x 384V. This means we will have two (2) battery strings of 192 cells each connected as shown above. The nominal voltage across the entire bus is 768VDC, i.e., between the bright green lines. We know the actual bus operating voltage across the bus at float will be 2 x 436 = ~872VDC (if float =2.27V/cell) and we also know the battery open circuit voltage is 2 x 406 = 812V (2.12V/cell).

The important point to understand is that voltage difference between open circuit voltage and float voltage is where the capacitors really provide power. Until the DC bus drops to 2 x 406V or ~ 812V across the bus, the battery is not providing any power and as DC bus voltage goes lower than 812V, the battery starts providing proportionally more power until nominal voltage where the battery is providing 100% of the power.

Remember our discussion about DSP control accuracy. The DC bus can be regulated in .1 V increments with extremely fast response times. The secret to making a robust system is to design the DC capacitor to be robust. Meaning, the capacitors have a very high-energy capability in this 60V window. As an example let look an actual 100% step load with the system running in normal operation.

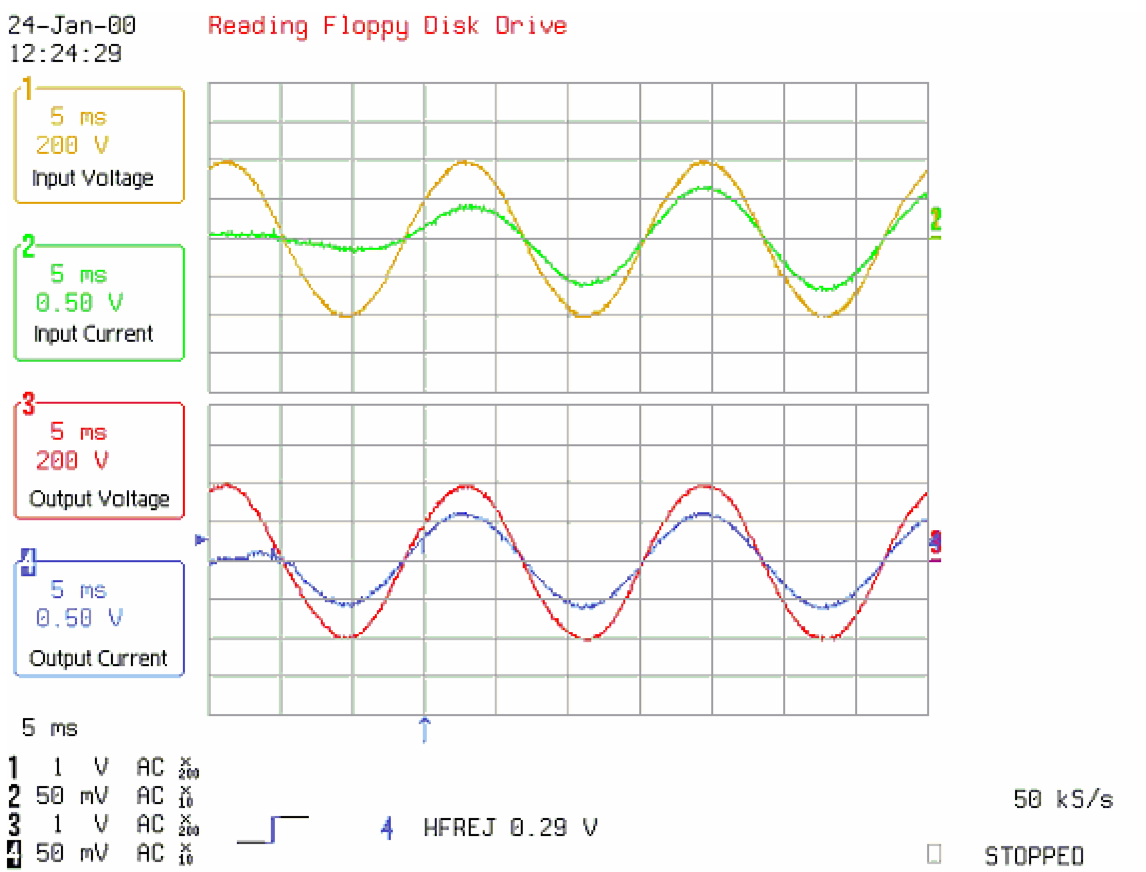

Figure 2: *Delta Conversion Online™ 100% step-load*

We see the step load on the output current waveform (blue). We also see that the output voltage is not even affected by this event (red), because the capacitors are a low impedance source providing very high energy to aid the inverter regulation. We can also see the delta inverter starting to adjust the input current within the first half cycle and is fully adjusted within 1.5 cycles (green). In fact a very reliable measure of how robust the DC capacitor energy capability for any UPS is to do a 100% step-load in normal operation with the DC battery circuit breaker(s) open.

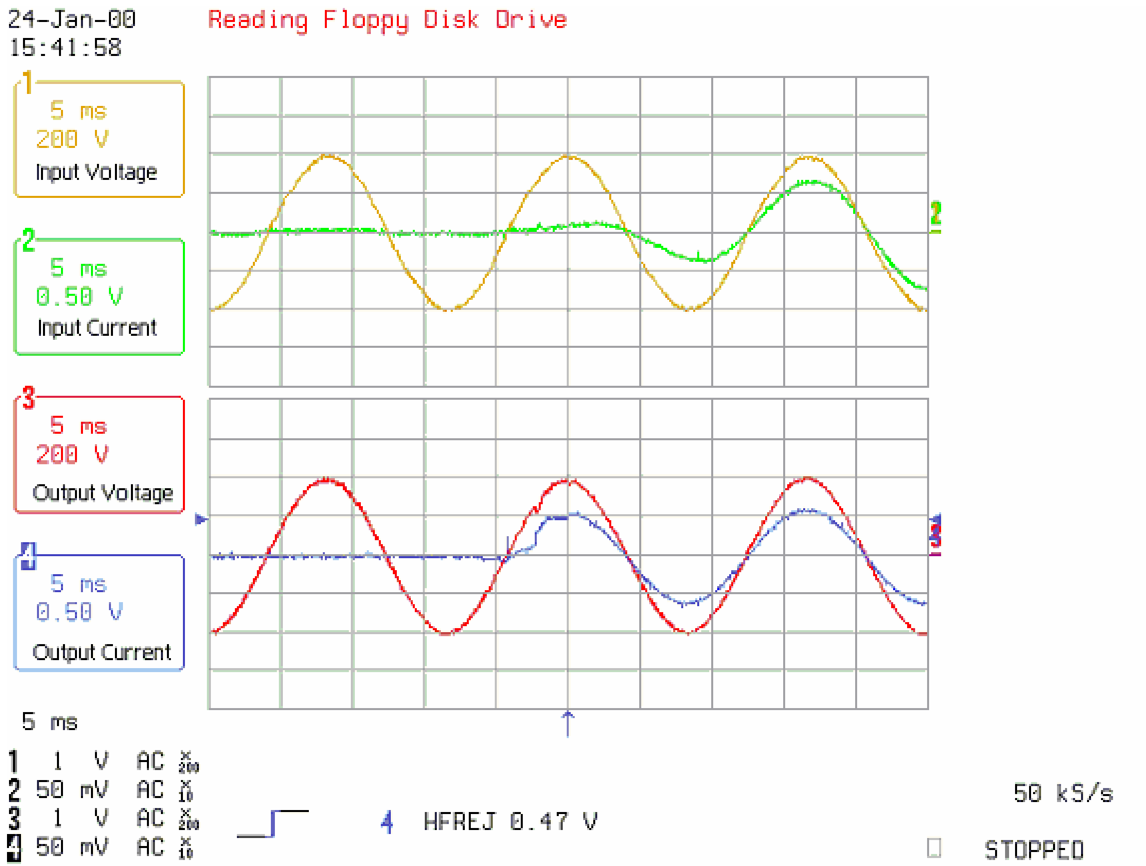

Figure 3: *Delta Conversion Online™ 100% step-load Without Battery*

Here again we can see the response of both the main inverter and the delta inverter to the step load event. This shows that the energy storage in the capacitors protects the batteries from unnecessary discharge when the system is in normal operation.

Whereas, in a poorly designed DC bus with this same test you may see output voltage deviation and/or inverter shutdown and/or static bypass operation. A output voltage sag is an indicator that the system probably will use some battery energy to support step loads. Below in figure 3 is a competitors' system with DC breaker open and 100% kW step load and we can see the response of the rectifier/charger control circuit. It takes about 2.5 cycles to reach full power on the input current, i.e., channel 2 (green waveform). Also we can see the response of the inverter and the DC capacitor energy. There is a sag in the peak voltage of the third positive peak from the left, i.e., channel 3 (red waveform). This indicates the DC capacitors were running out of energy before the rectifier could catch up.

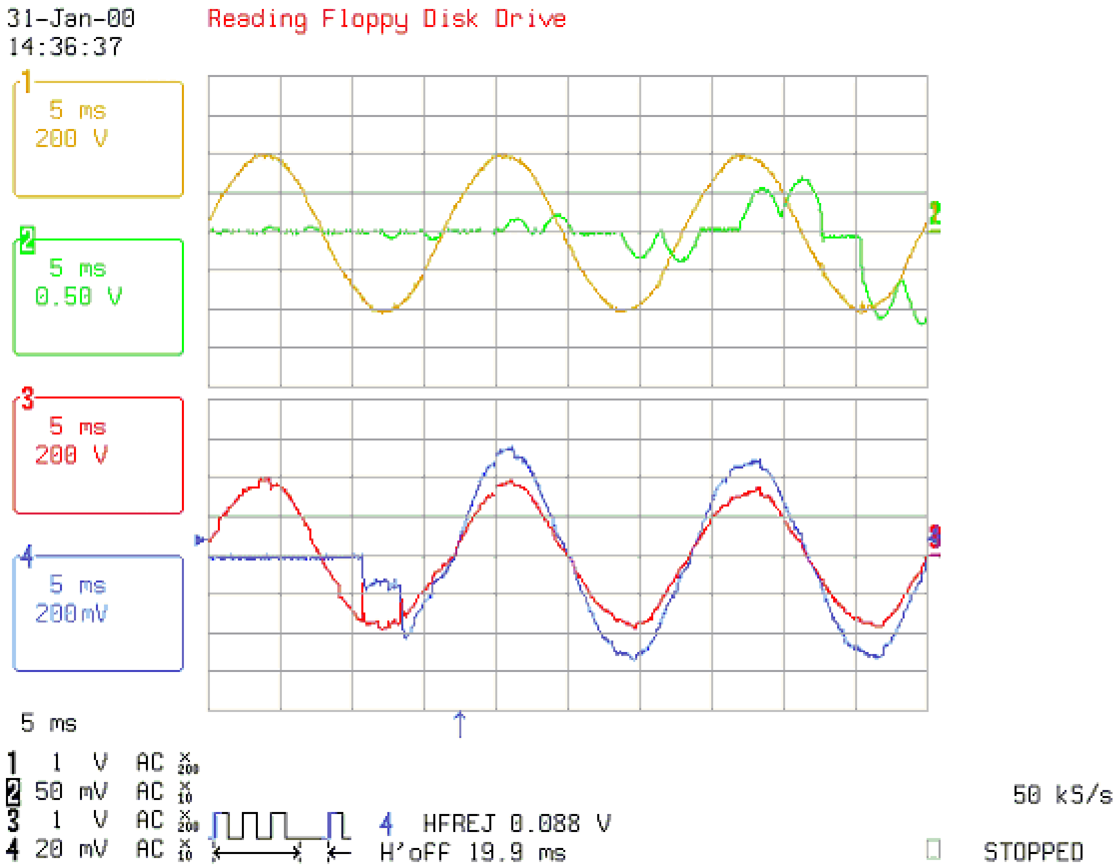

Figure 4: *Double Conversion 100% step-load Without Battery*

The DC Power Exchange

As we said in Part 1 of this series, a conventional double conversion system DC bus is a one-way path, i.e., from the rectifier/charger to the main inverter. The DC bus in the Delta Conversion OnLineTM is a bi-directional power path between the two inverters. If we look at it from the perspective that the delta inverter as the source, i.e., fed from the delta transformer. We see the flyback diodes can rectify the power and feed it to the DC bus. The main inverter can take the power through its IGBT's and feed the power to the load as shown in figure 5.

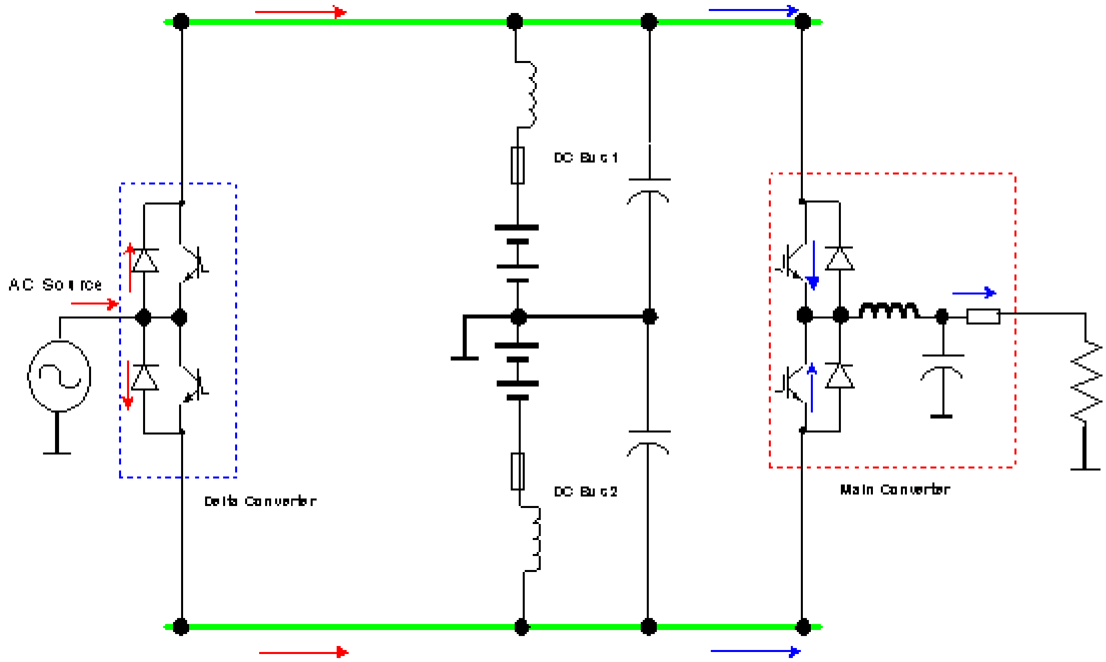

Figure 5: *Delta Inverter to Main Inverter DC Power Path.*

Now if we swap the load and the source, we can see how the main inverter can feed current to the DC bus via its flyback diodes and the delta inverter can take current from the DC bus via its IGBT's. We can do this because the Power Balance Point is a current node where the excess current will take the path shown in Figure 6.

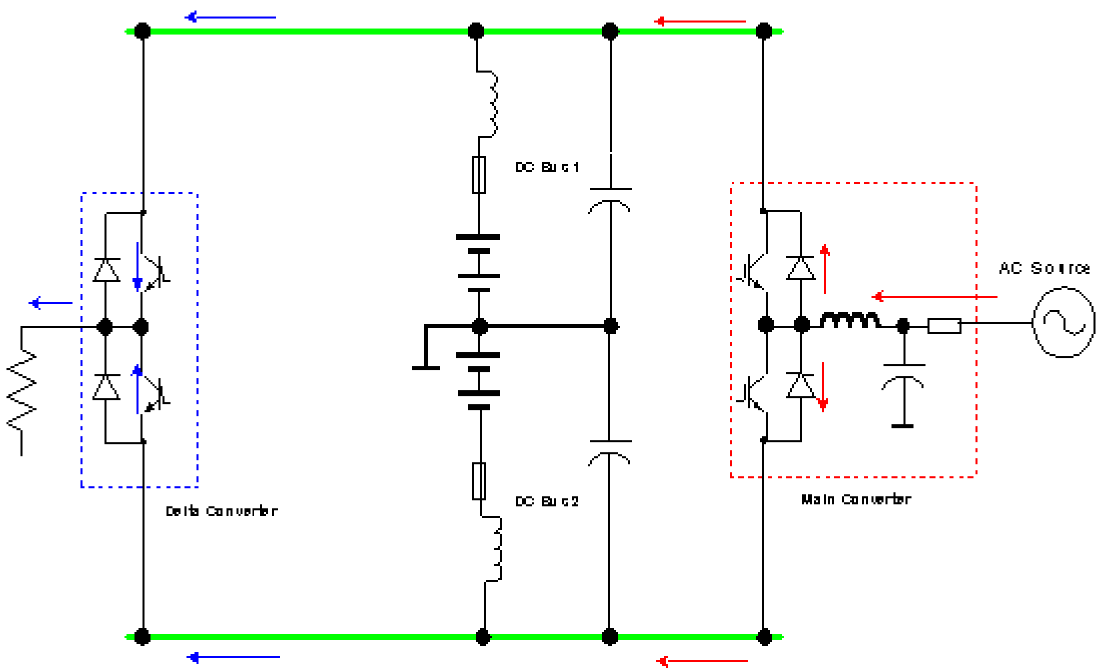

***Figure 6:** Main Inverter to Delta Inverter DC Power Path.*

How this all ties together is the next step in understanding Delta Conversion OnlineTM. This concludes Part #3.