Understanding Delta Conversion Online™ "Power Balance" - Part 4

Introduction

This application note is the fourth 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.

Delta Conversion Online™ UPS Power Balance

We have already touched briefly on the Power Balance concept in parts 1 through 3. However let's restate the basic rule for the power balance point, which also fit's Kirchhoff's first law of currents- "The algebraic sum of currents at any junction of conductors is zero". This can be put very simply as: "At the power balance point (PBP) there has to be as much current flowing away from the PBP as there is flowing toward it."

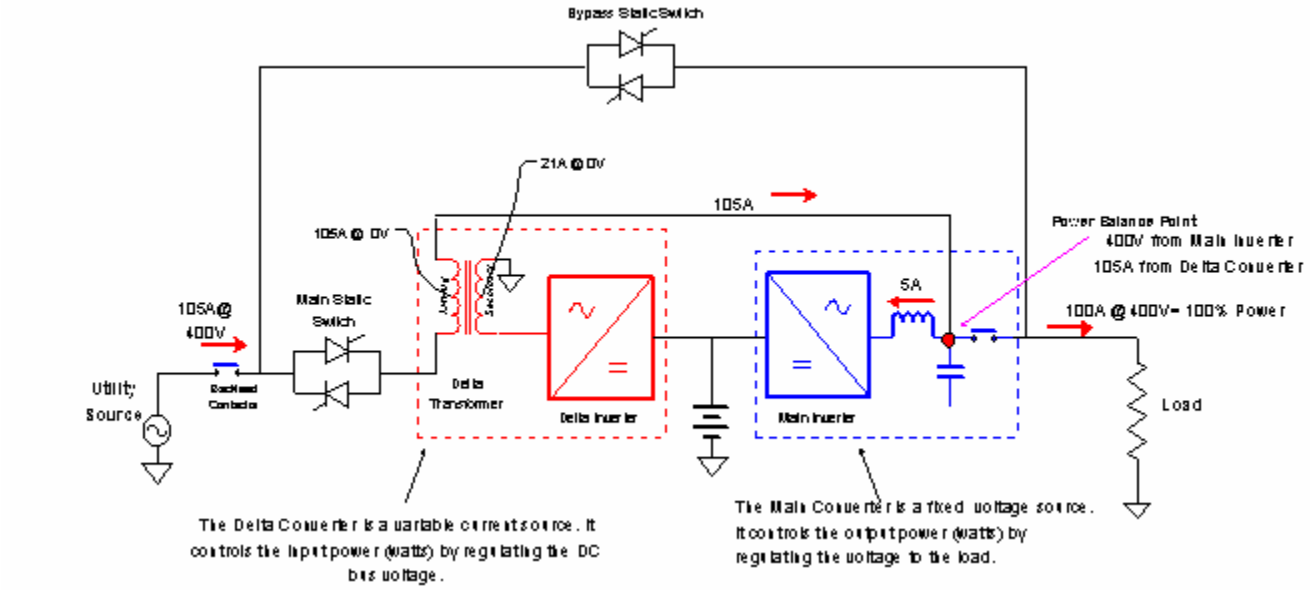

Figure 1: *Power Balance at Nominal Input Voltage*

Above is the same model we've used in previous discussions, i.e., 40kW system @400VAC. As we now have a good understanding of how the bi-directional power flow through the inverter and across the DC bus is possible, we are going to use this simplified diagram to save space. The above diagram is normal operation at 400V input with a 100A load. We are also assuming 5% losses for the system. This means the delta converter has to import 42kW of power. The load takes 40kW (400V * 100A = 40,000W), and the remaining 2kW (400V * 5A= 2,000W) flows backwards through the main inverter flyback diodes. The algebraic sum of current and the power at the PBP is zero. Now lets look at the entire system operation, including the +/- 15% input voltage window. Now it starts to get interesting.

Power Balance At -15% Input Voltage

To examine what happens, I have deliberately not rounded the current values to the nearest ampere. In this situation the delta converter has to still maintain the same 42kW of imported power. To do this it has to raise the input current to 123.52941A (42000/340 = 123.52941). Now at the PBP Kirchhoff's law still applies. We see the load takes 40kW (100A) the remainder of the current has to again take the same path as the losses in our previous example. But wait a minute! It appears we have more power going into the PBP than we have coming in from the Utility Source, i.e., 123.52941 * 400V = 49411.764W. But the real answer is that 100A is our load and 5A is our 2kW of losses. The remaining 18.52941A is control power flowing in the delta conversion power path, i.e. through the inverters. This power is not being consumed. It's probably easier to understand by looking at the actual power flow shown in Figure 3.

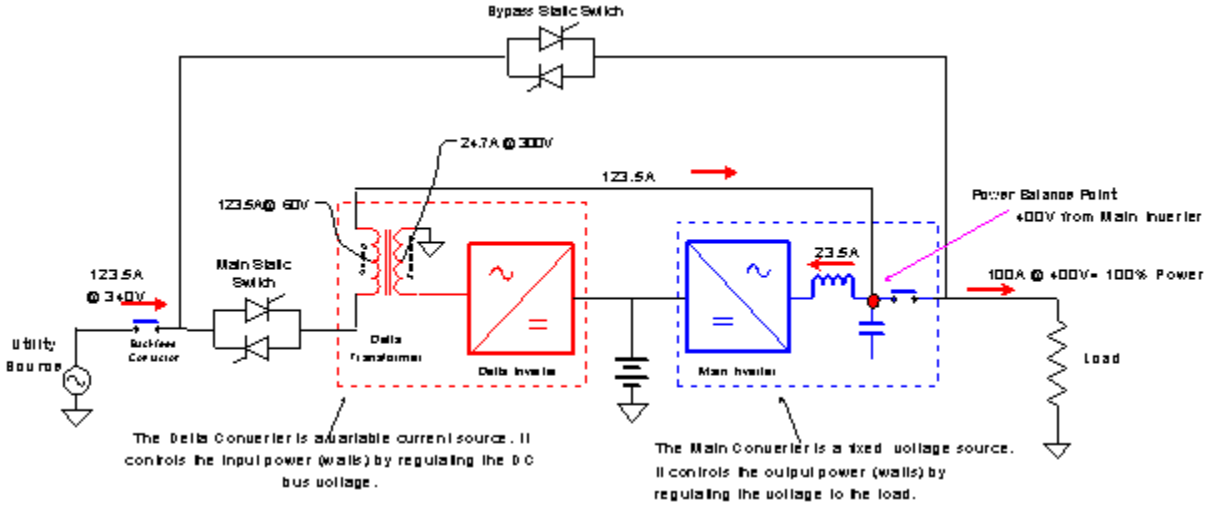

Figure 2: *Power Balance at -15% Input Voltage-Current Flow*

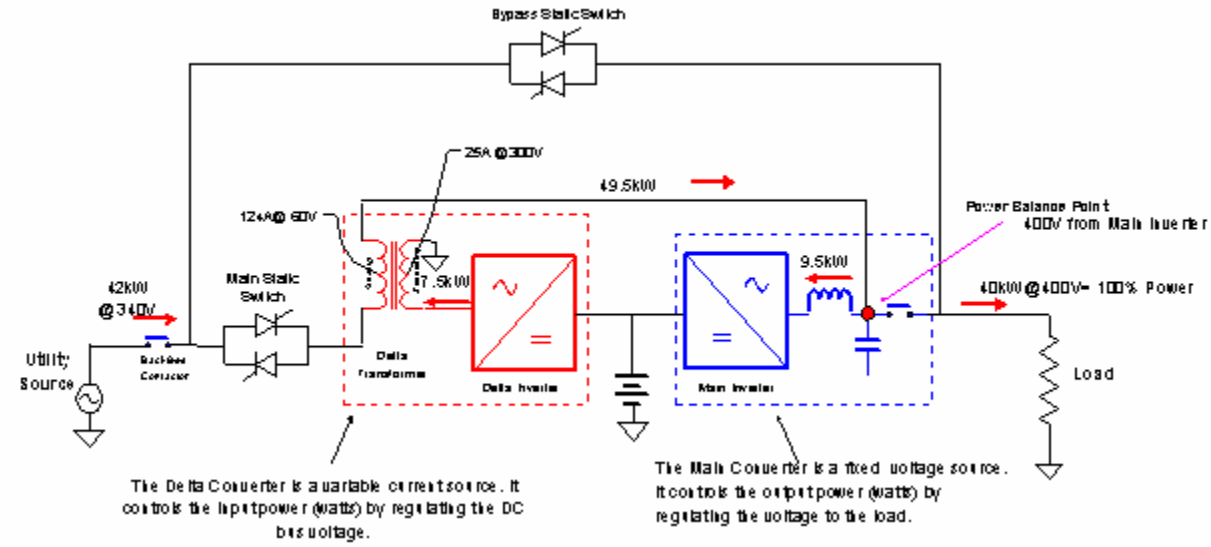

Figure 3: *Power Balance at -15% Input Voltage-Power Flow*

We also can see that now there is transformation in the delta transformer, because there is both voltage and current on the primary and secondary windings. This transformation is control power it is not consumed. The control power simply flows in the delta conversion power path, i.e., loop formed by the inverters, DC Bus, delta transformer, pure power path and the PBP, see Figure 4 (green arrows). In this case the power transformation in the delta transformer is from secondary to primary. Which is exactly the opposite of the classic power transformation. Why? No one had explored this side of transformer physics before, i.e. a source and load simultaneously connected to both primary and secondary windings. That's the stuff that Patent's are made of!

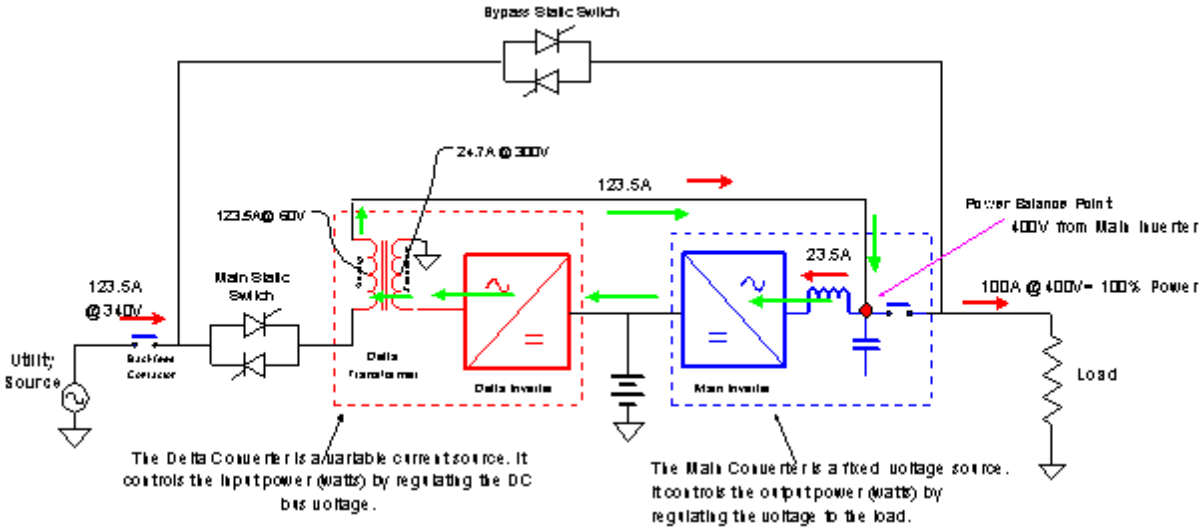

Figure 4: *Power Balance at -15% Input Voltage-Control Power*

Power Balance at +15% Input Voltage

If you thought the above example was interesting, lets look at the opposite condition, i.e., +15% voltage at the input. Now the delta inverter has to lower the input current, i.e., to maintain the power balance. The most interesting aspect is what happens in the delta transformer, pure power path and delta conversion power path.

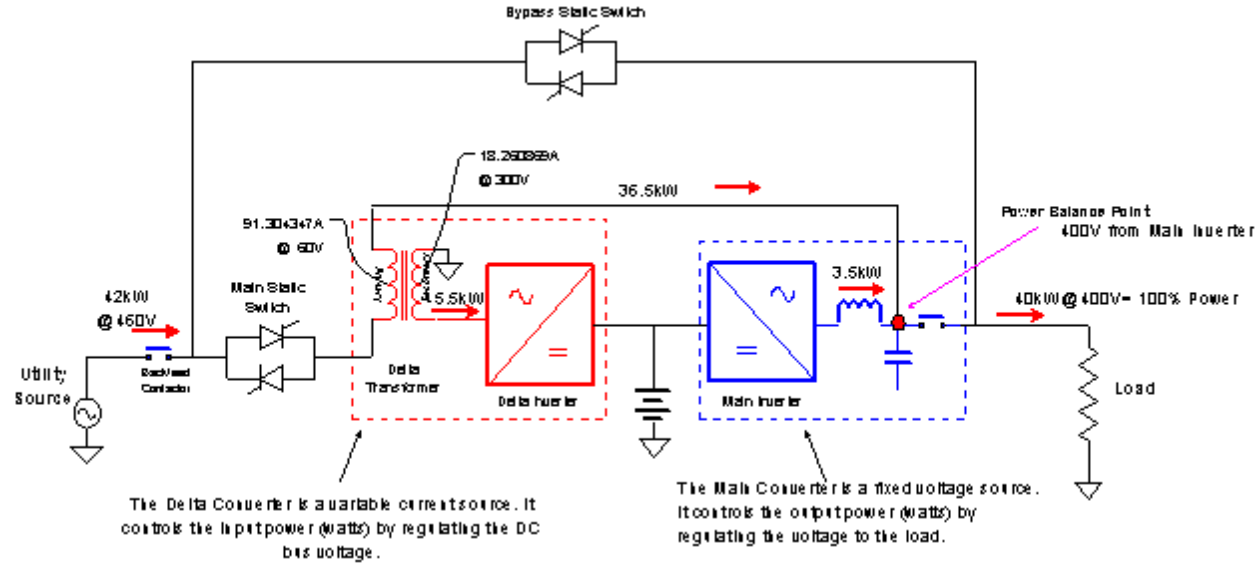

Figure 5: *Power Balance at +15% Input Voltage-Power Flow*

The power flow in the delta conversion power path has reversed and we now have power flowing to the PBP in the two parallel paths formed by the pure power path and the delta conversion power path. The utility voltage controls the power flow reversal. As we have seen previously, at nominal input voltage there was zero power in the transformer and only losses flowing in the inverters. At minus voltage there was reverse power flow in the transformer, i.e., secondary to primary. Now with positive voltage the power flow in the transformer is primary to secondary. All the delta inverter has to do is maintain the power balance, i.e., power imported by maintaining the DC bus at float voltage. Again we have satisfied Kirchhoff's law of current at the PBP, see Figure 6.

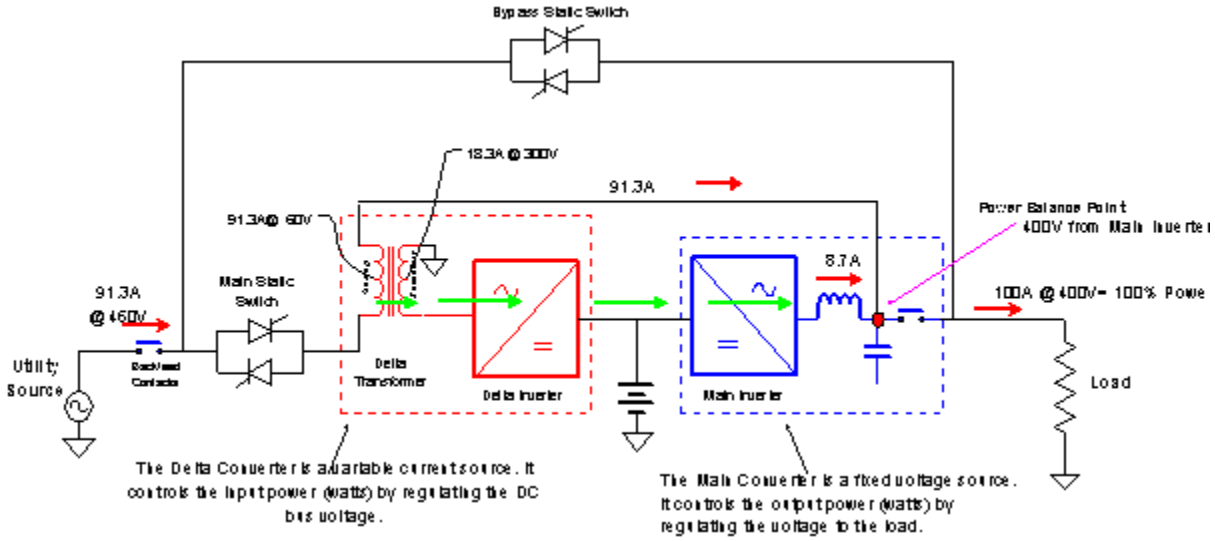

Figure 6: *Power Balance a +15% Input Voltage-Current Flow*

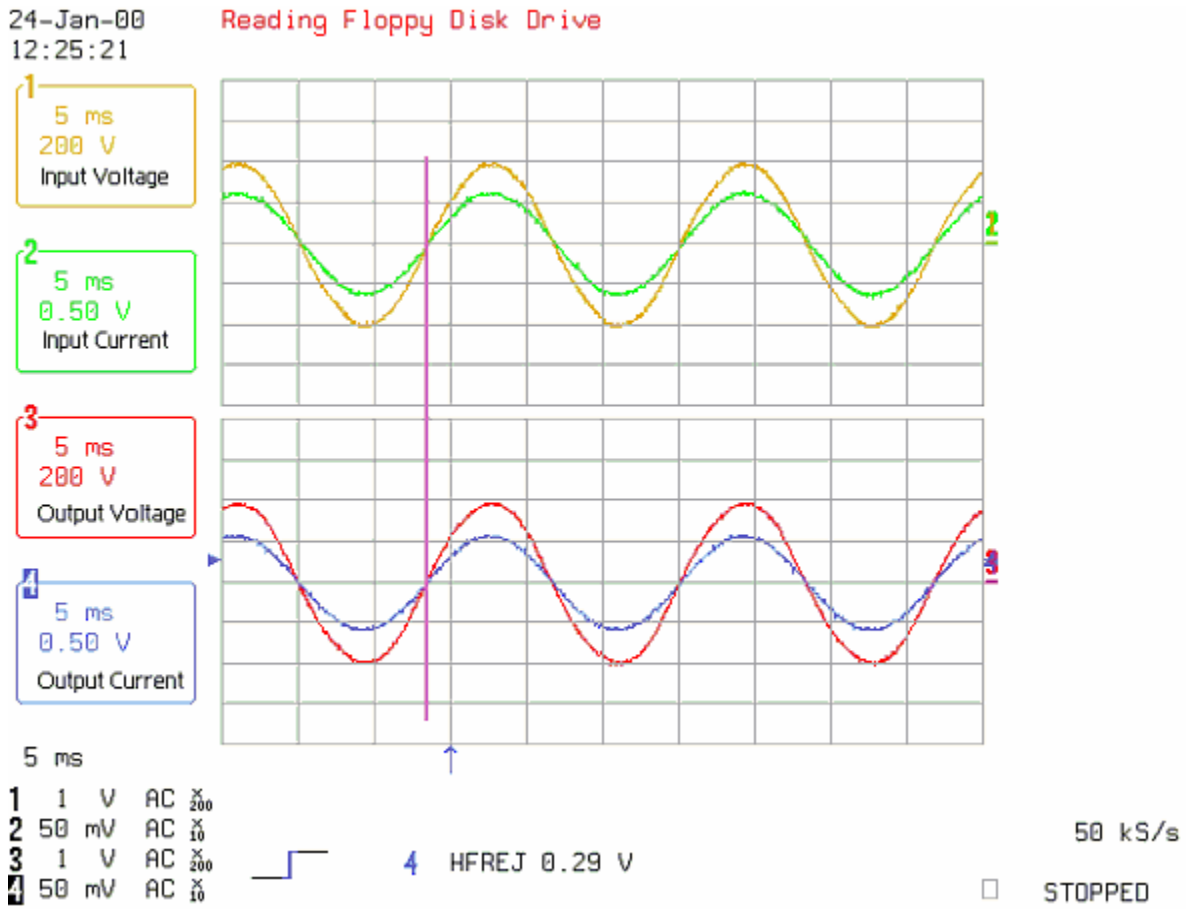

Figure 7: *Power Balance Delta Inverter-Main Inverter Synchronization*

Because the delta inverter current and the main inverter output voltage are precisely synchronized to the input voltage waveform, the power flowing in both the pure power path and the delta conversion power path arrives at the PBP at the same instant in time. The load only sees 100% power at the PBP, and the load doesn't care how it got there. This concludes Part #4.