Understanding Delta Conversion On-line "Power Regulation" - Part 2

Introduction

This application note is the second 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.

How do we regulate the power to the load?

Simple- The main inverter is a voltage controlled IGBT PWM inverter. It has the primary function of regulating the voltage at the Power Balance Point (PBP). It also provides a current path from the battery in the event of an AC source failure. So all we need to do is start the main inverter. Now the main inverter at +/- 1% regulates the voltage at the Power Balance Point (PBP). The current through the PBP is regulated by the delta inverter working through the delta transformer (see Part #1.). The PBP is a circuit node where all of Kirchhoff's Law's for voltage and current must be satisfied. Working together, the two converters form a very good power control system. One regulates input current (watt power from the AC source) and the other regulates output voltage (watt power to the load).

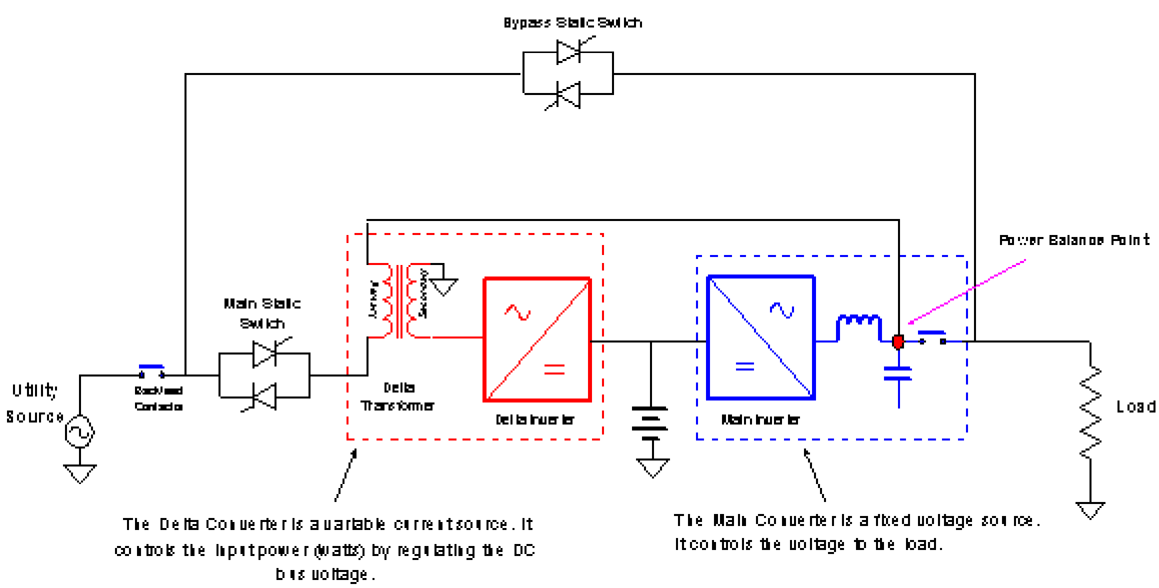

Figure 1 - *Delta Conversion power balance*

Going deeper: The output voltage is fixed at the PBP by the main inverter, and the voltage across the delta transformer primary will now be the difference between the PBP voltage and the AC Source voltage. For sake of discussion let's use 400V as our system voltage, and we are powering the same 100A load. We'll start with the AC source at 400V and examine what's happening in the entire system. This means our main inverter is set to regulate at 400V +/- 1%. If the source is 400V and the PBP is at 400V, there has to be zero (0) volts across the delta transformer primary. Now we have very unique situation. The impedance of the delta transformer primary winding now appears as very low impedance between the AC source and the load. In fact it appears to be loss-less, i.e., zero volts x 100A = zero resistance and zero power. There is also no phase shift across the primary winding. Clearly, the delta transformer primary winding is not behaving like a choke. This also means there is zero power transformation in the delta transformer itself, i.e., power exchange between the primary and secondary windings.

How do we make up for losses?

Of course there are some system losses, so the delta inverter is set to deliver the 100A load current + losses. For simplicity sake, we will assume 5% losses. Then we set the delta inverter current to be 21A, with a corresponding primary current of 105A. Now we have 105A flowing to the PBP. Once again we must satisfy Mr. Kirchhoff's law of current. The load can only consume 100A. Therefore the other 5A has to flow in the only other current path available, i.e., backwards through the main inverter flyback diodes to the DC bus where it's automatically redistributed to account for all the losses. The delta conversion pure power path gives us this capability of bi-directional power conversion.

If we examine the system in a little more detail as in Figure 2, we will see how the two inverters, or more correctly "converters", because they are now capable of bi-directional power conversion, are able to share and regulate the power to the load. These two converters are linked together in the same manner as a double conversion system charger/rectifier and main inverter, i.e., via a common DC bus. This DC bus is shown in bright green. This provides a power path for the two converters to exchange power between each other in a bi-directional manner, without taking power from the battery. The AC-AC "Pure Power Path" is in dark green.

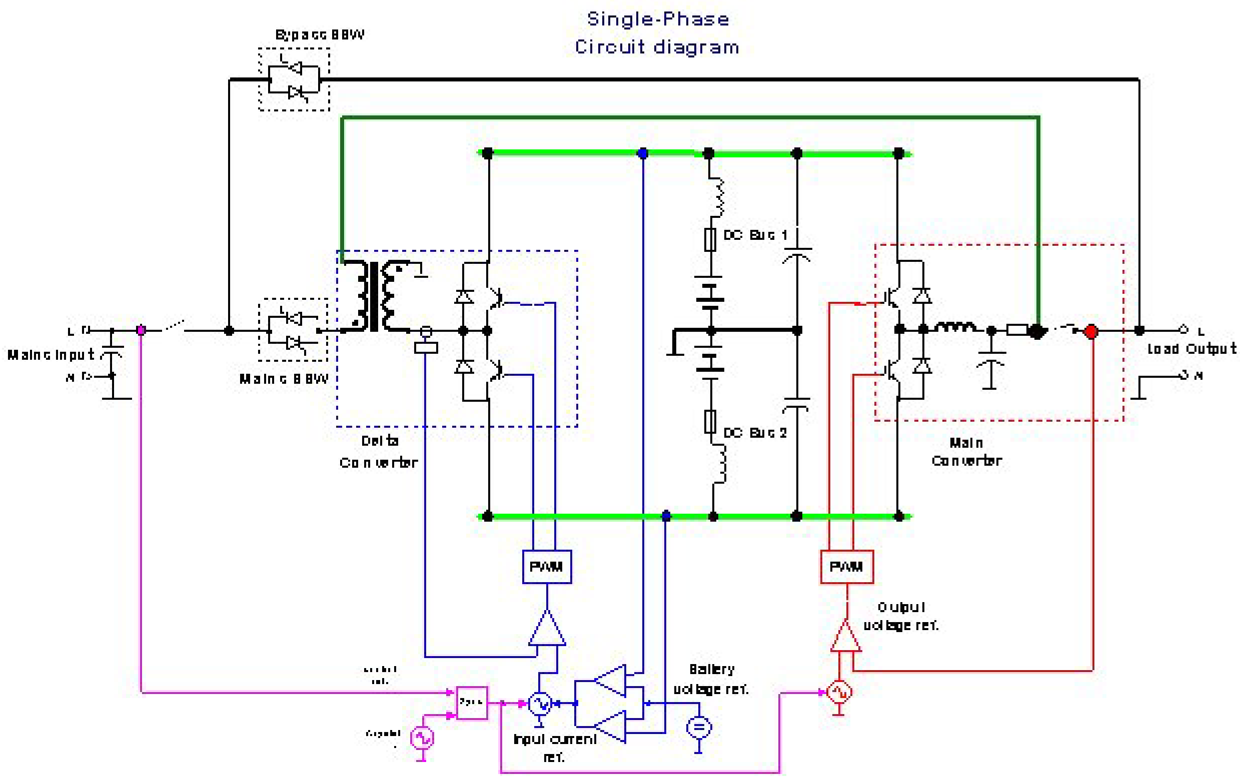

Figure 2 - *Single-Phase of Delta Conversion Online™*

Now lets take this same diagram and look at our example for the load power flow + losses in normal operation. See Figure 3 below. We have the delta inverter set at 21A. This forces the AC source to give us 105A through the delta transformer primary and we now have 105A flowing to the power balance point. The load takes 100A and the remaining 5A of power for system losses has to flow in the only power path available, i.e., back through the main inverter flyback diodes to the DC bus. Then across the DC bus through the delta inverter IGBT's and finally to the delta transformer. This shows us that even while the main inverter IGBT's are producing AC output voltage at +/- 1% for the load, our flyback diodes are simultaneously rectifying the excess power from the PBP and feeding it to the DC bus to account for all the system losses.

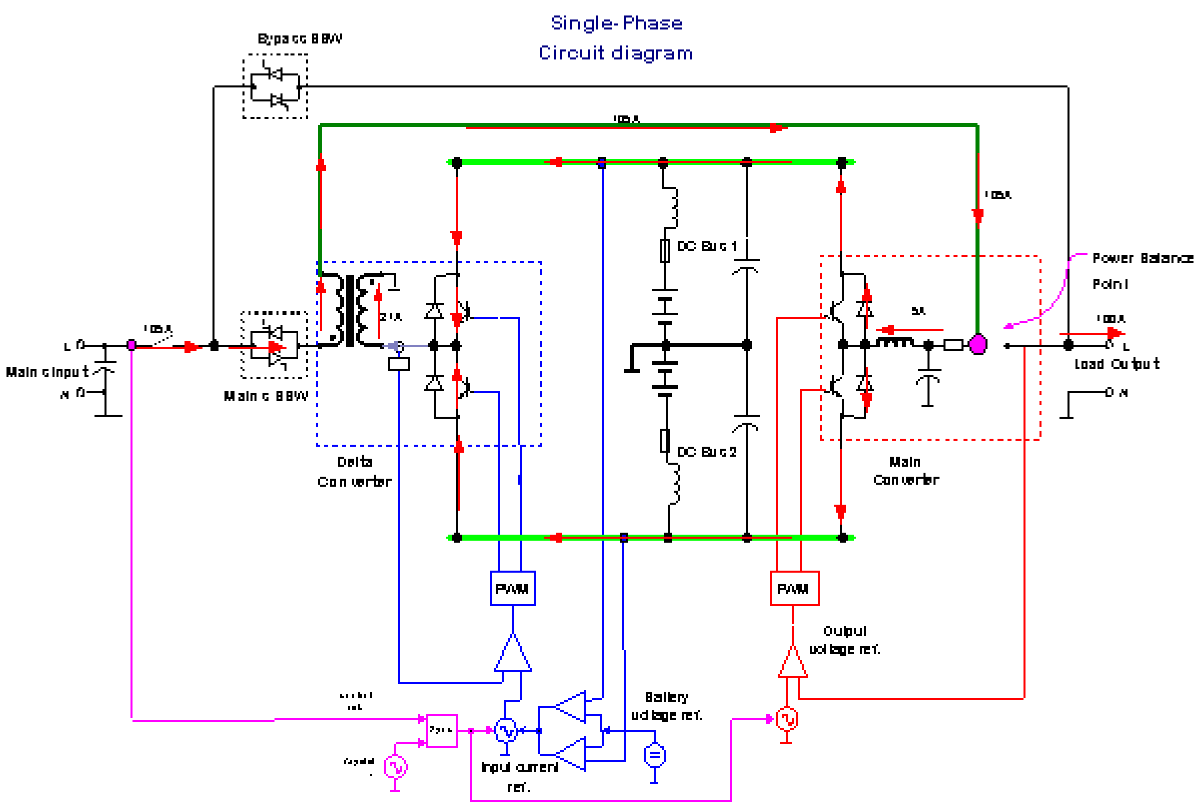

***Figure 3 -** Normal Operation: Load Power Flow + Losses*

The Power Balance Concept Control System

The control system concept used is identical to the control system in a double conversion UPS. The primary difference is that this control system is Digital Signal Processing (DSP). Using DSP gives a very high degree of accuracy. Taking a sample of the mains source the sync circuit synchronizes both inverters; a synchronization signal is fed to both inverter control circuits (purple circuit). This ensures that the input current and the output voltage are always in phase with the mains input. This also allows us to control the delta inverter too provide a sinusoidal current waveform and power factor of ~1.0 at the input.

The magnitude of the input current is controlled by PWM current control circuit (blue circuit). By monitoring the DC bus voltage just like a double conversion rectifier charger control system, we set the magnitude of input current to maintain the DC bus voltage. We do this by setting the delta inverter control to maintain the DC bus voltage at a specific level which is usually the battery float voltage. It can do this with an accuracy of .1 volt. There is also a sample taken from the delta transformer secondary to control the delta inverter current limit. The delta inverter is set to current limit at 130% of the system rating. This means that the input power through the delta transformer primary can never exceed 130%.

The magnitude of the output voltage is controlled by PWM voltage control (red circuit). The actual magnitude is set by the voltage reference, i.e., programmable to maintain +/- 1%. Again like the delta inverter control, this is settable in .1V increments. We also have a feedback control loop from a sample of the voltage at the Power Balance Point (PBP).

As we defined in Part #1 of this series the word "power" always refers to watts (a.k.a. Real power or true power) any other form of power, such as reactive power or apparent power will be identified as such. The easiest way to understand this system is through the discussion of watt power flow. With that said, we will now look at the system operation during various conditions of input voltage. We have already covered the nominal voltage condition, i.e., input = 400V. The input window for system normal operation is set at +/- 15% of nominal voltage. This means that anytime the input is within this window the system is in "normal operation" and will not be using battery power. For example if we have a 40kW system and 5% losses, we need 42KW input to maintain a 40kW load output.

Power Balance at -15% Input Voltage

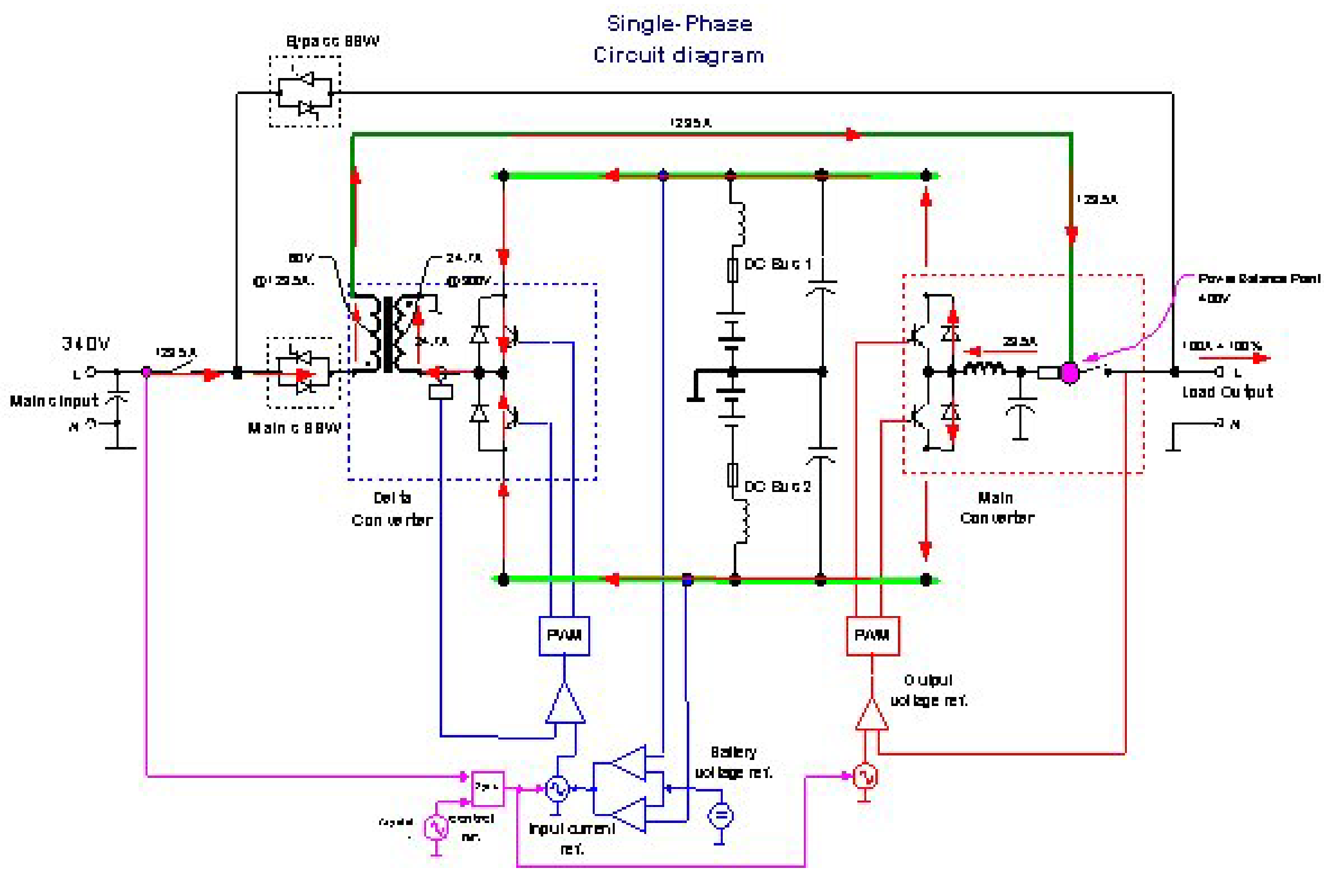

Figure 3: *Power Balance at -15% Input Voltage*

Because the input is power factor corrected, we can say that the input power is equal to the input voltage times input current, i.e., P = V*I. This means that if input voltage drops to -15% (85% of nominal) the input power will be 340V * 100A = 34kW. Clearly, this is not enough power to support the load at 100% of its power needs. The main inverter will instantaneously take 15% power from the DC bus, i.e. 85% + 15% = 100% to the load. The delta inverter control system sees this because the DC bus voltage will start to decrease. The delta inverter will then increase the input current to 123.5A to adjust the input power to 42kW (340V * 123.5A= ~42kW), i.e. 100% of the power required to support the load + 5% losses.

Now we have some very interesting things going on at this particular instant in time. To understand what's happening with the DC bus and both the inverters we need to understand a bit more about the DC bus and how it works with the two inverters (Part #3). This concludes Part #2.