Application Note #39

Understanding Delta Conversion Online™ "The Difference" - Part 1

Introduction

This application note is the first in a series of notes on delta conversion theory of operation, features & benefits. 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. What is different about Delta Conversion power control theory?

What is the difference? The difference is one of innovation in engineering. That innovation is being able to think outside the box and see totally new concepts and finally making those concepts reality. The fact that delta conversion is patented reaffirms that the ideas and concepts are valid and they are innovative. Of the five known static UPS topologies today, APC makes all of five and has patented two of those. One of those patented topologies is the Delta Conversion Online™ UPS. The fact that APC is innovative seems to escape its competitors. They want to label Delta Conversion Online™ UPS as a "line interactive UPS". While line interactive is not bad in itself, after all APC SmartUPS has been a huge success for APC. Lastly we certainly understand how to make double conversion technologies and how to apply innovative solutions to customer needs, like the APC Symmetra Power Array.

So how is this technology, i.e., Delta Conversion Online™ different than double conversion? What are its benefits versus competitor double conversion technology? First, let's look at some simple diagrams for comparison.

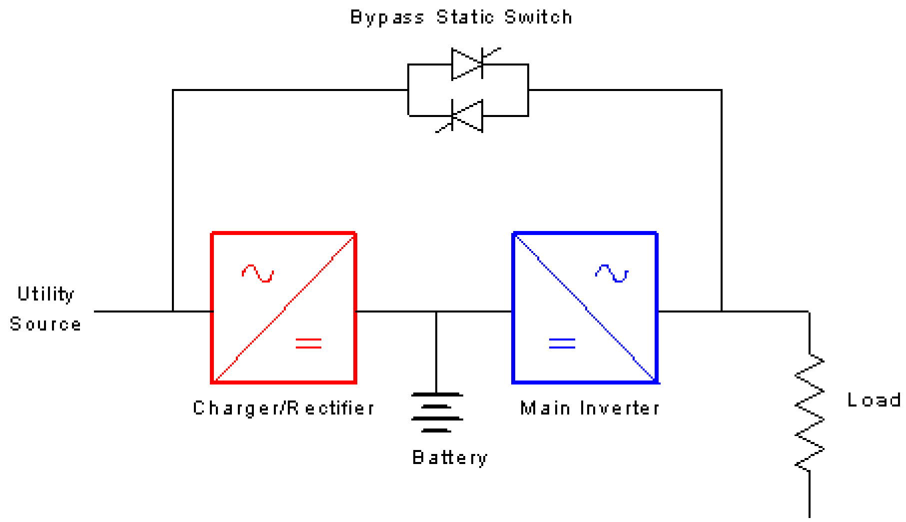

Figure 1 - *Double Conversion (a.k.a. Rectifier/charger UPS)*

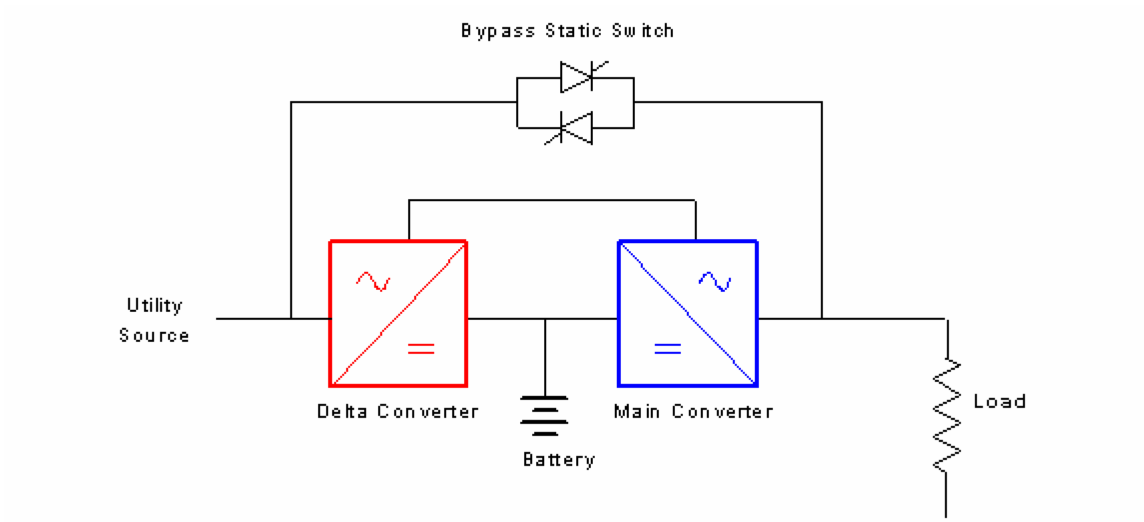

Figure 2 - *Delta Conversion Online™*

The difference really is in the second connection between the two converters, i.e., AC-to-AC shown in figure 2. This is what we call the "Pure Power Path". This pure power path allows us to use our inverters as bi-directional power converters.

The double conversion (figure 1 & 3) has one power path, where the charger/rectifier and its main inverter are unidirectional power conversion devices, i.e., they change AC power (watts) to DC power (watts) and DC power (watts) to AC power (watts) respectively and feed it to the output bus. For the remainder of this discussion the word "power" will always refer to watt power (real power, a.k.a. true power). Any other form of power such as apparent power will be defined as such.

Whereas, in Delta Conversion Online™ (figure 2 & 4) both delta converter and the main converter are bi-directional devices, i.e., they have the ability to change AC power to DC power and simultaneously DC power to AC power. In other words, they can each do the same primary functions as both of the double conversion devices with some added functionality.

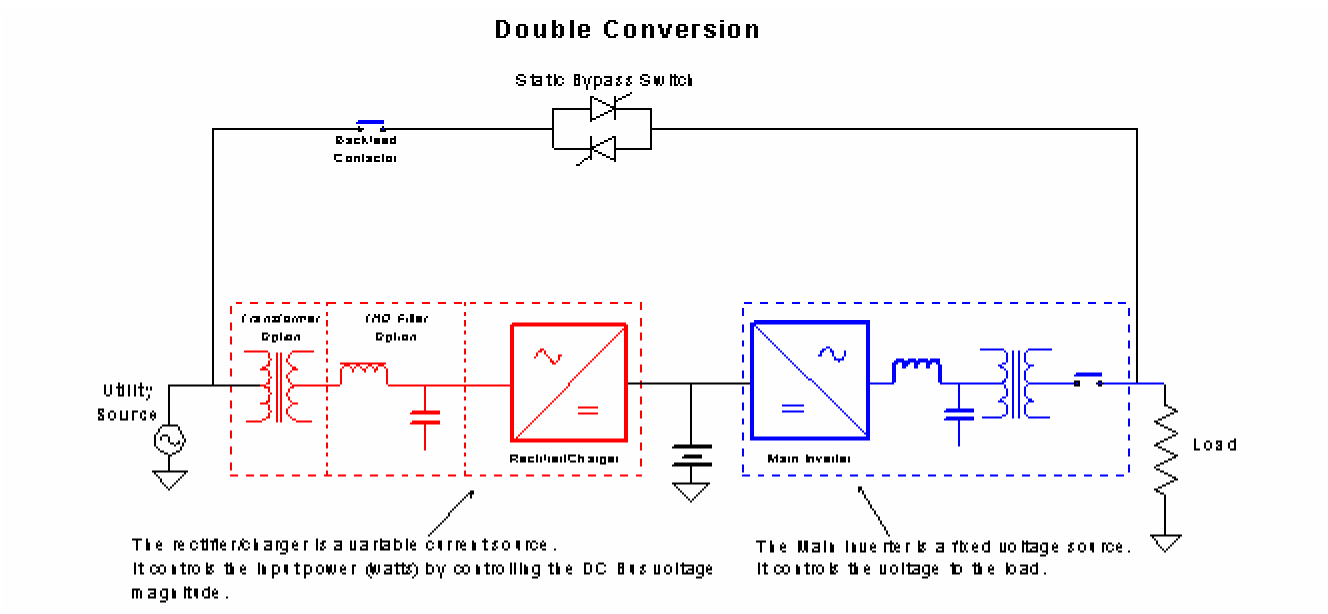

Figure 3 -- *Typical Double Conversion System w/input filter options*

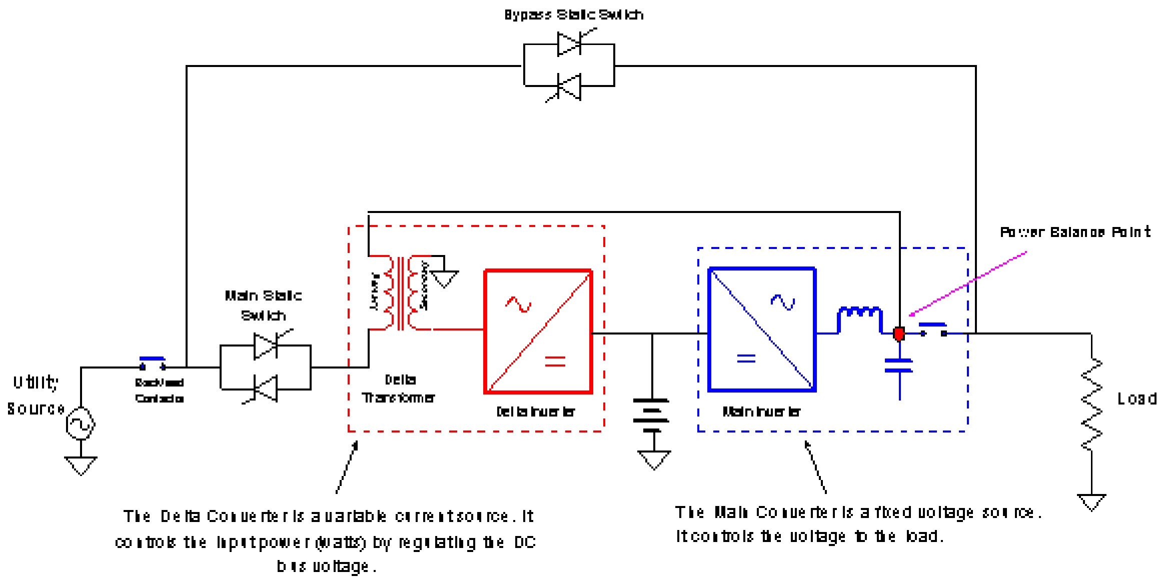

***Figure 4 --** Delta Conversion Online™*

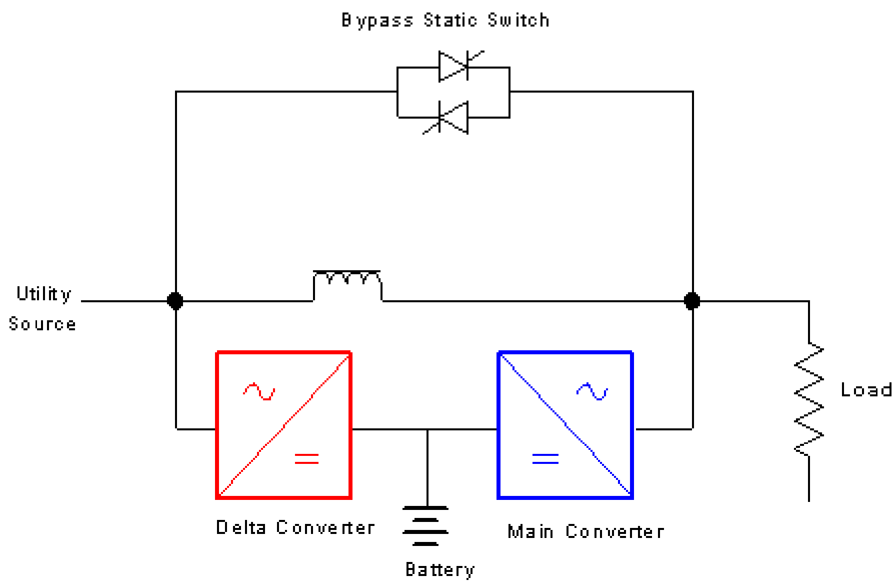

***Figure 5 --** Erroneous view of Delta Conversion Online™*

The competitors would have you believe that Delta Conversion Online™ should be drawn like figure 5. The key to understanding Delta Conversion Online™ is to first understand how the delta converter works, i.e., the delta transformer and the delta inverter working together. We will address all the issues in this series. But, for complete understanding we must proceed in a methodical manner.

The Delta Converter

The "delta transformer" in our three-phase UPS is actually three single-phase isolation transformers, one for each phase. The individual delta transformer "voltage turns ratio" is ~1:5 (primary: secondary). The current ratio is the inverse, i.e., ~5:1. This is fundamental to understanding the system power flow & power regulation. If we examine a single-phase two winding isolation transformer (figure 6), we can determine some basic rules of physics with respect to voltage & current. (Al's rules of single-phase transformer regulation)

1. Voltage - The voltage across the secondary is a function of the turn's ratio. But it is actually regulated by the primary voltage, f. ex. If we raise the primary voltage the secondary voltage will also raise. We now have the first rule, i.e., the primary voltage regulates the secondary voltage.

2. Current - The magnitude of current in the secondary is again a function of the turn's ratio. However the load on the secondary regulates it. If the switch is opened- there will be zero amperes in the secondary and therefore (ignoring eddy current) there is zero amperes in the primary. Close the switch with a 20A load and there will be 100A on the primary. Therefore, we have the second rule, i.e., the secondary current regulates the primary current.

3. Current waveform - The current waveform is controlled by the current characteristic of the load. If we connect a resistive load the primary current will be sinusoidal. If we connect a nonlinear load the primary current will be nonlinear. Therefore, we have the third rule, i.e., the load regulates the primary current waveform.

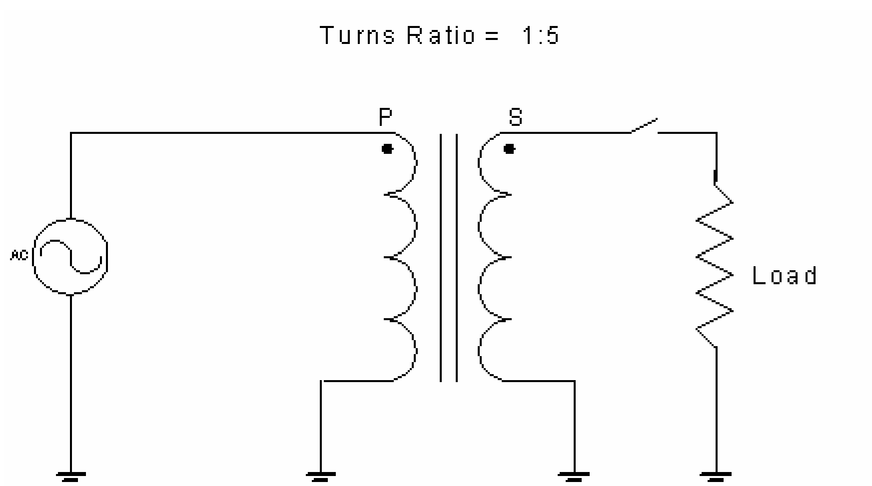

Figure 6 -- *Single Phase Isolation Transformer*

Now- if we draw the basic Delta Conversion Online™ system (one phase) with a little different layout than figure 4, see figure 7. We can apply the basic transformer regulation rules and see how the system works as a power control system. To keep the mathematics relatively simple we will use 400V as our single phase Line to-Neutral input. Obviously this is not a real world system L-N voltage for low volatge systems, i.e, those under 600VAC line to line. Typically these are 208Y/120V, 220Y/127V, 380Y/220V, 400Y/230V, 415Y/240V, 480Y/277V, 600Y346V, etc.

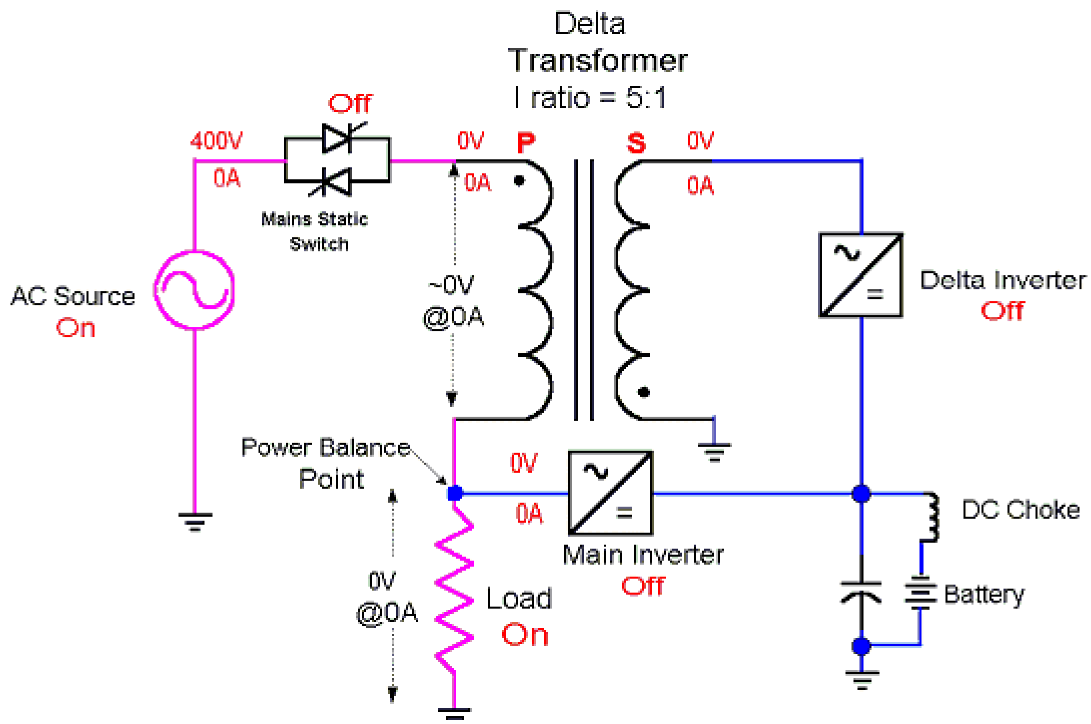

Figure 7 -- *Delta Transformer Power Flow*

Lets start from the perspective that we have a 100A load connected as shown in figure 7, both inverters are off and the AC source is on. The load appears to be directly connected to the AC source. Does the load get any power? Obviously with the mains static switch off it cannot. Anytime the mains static switch is on the main inverter also has to be on and fully operational. Therefore, we first turn on the main inverter and then the mains static switch (figure 8).

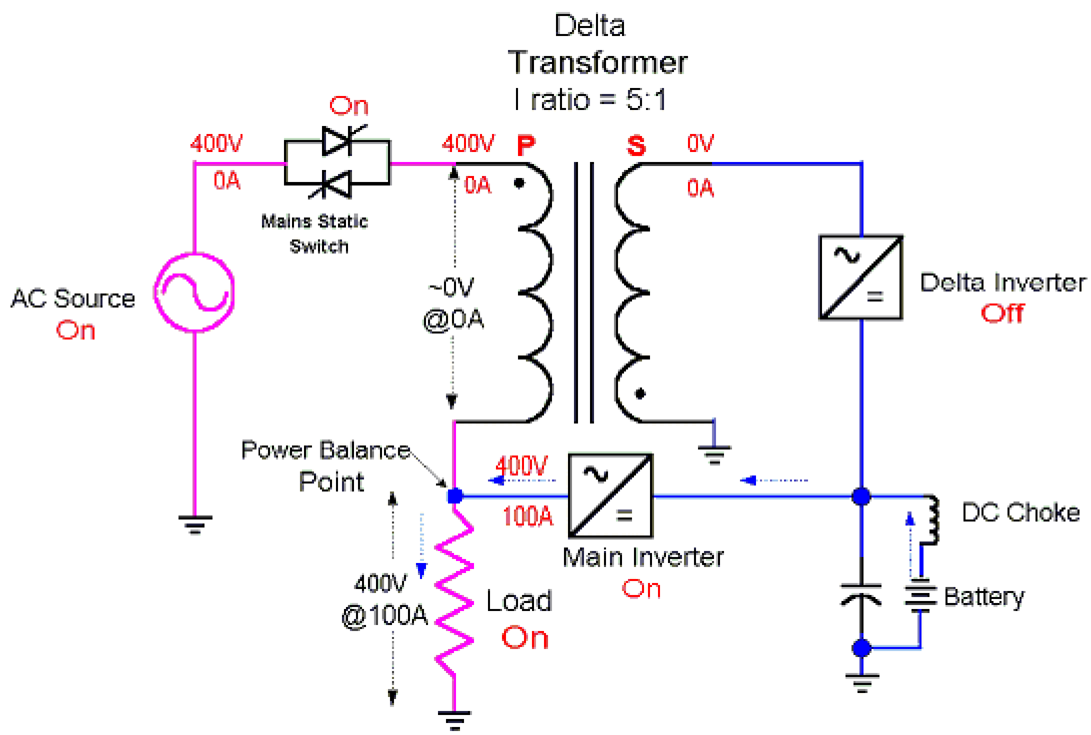

***Figure 8 --** Delta Transformer Power Flow*

Now we have power flow from the battery through the main inverter. But we also have the mains static switch on! Why doesn't power flow from the utility source to the load? Answer: Because the main inverter is producing a regulated 400V that is precisely in phase with the AC source and there is zero voltage across the primary winding of the delta transformer and because the delta inverter is off, there is zero current in the secondary winding and consequently zero current in the primary. Remember our second rule! If we have zero current in the primary, the power from the AC source has to be zero, zero volts times zero amps is zero power in the transformer primary winding. All of the power to the load is still coming from the battery bus. This satisfies all of Kirchhoff's law's of voltage & current. The only way to get power to the load from the AC source is to turn on the delta inverter (figure 9).

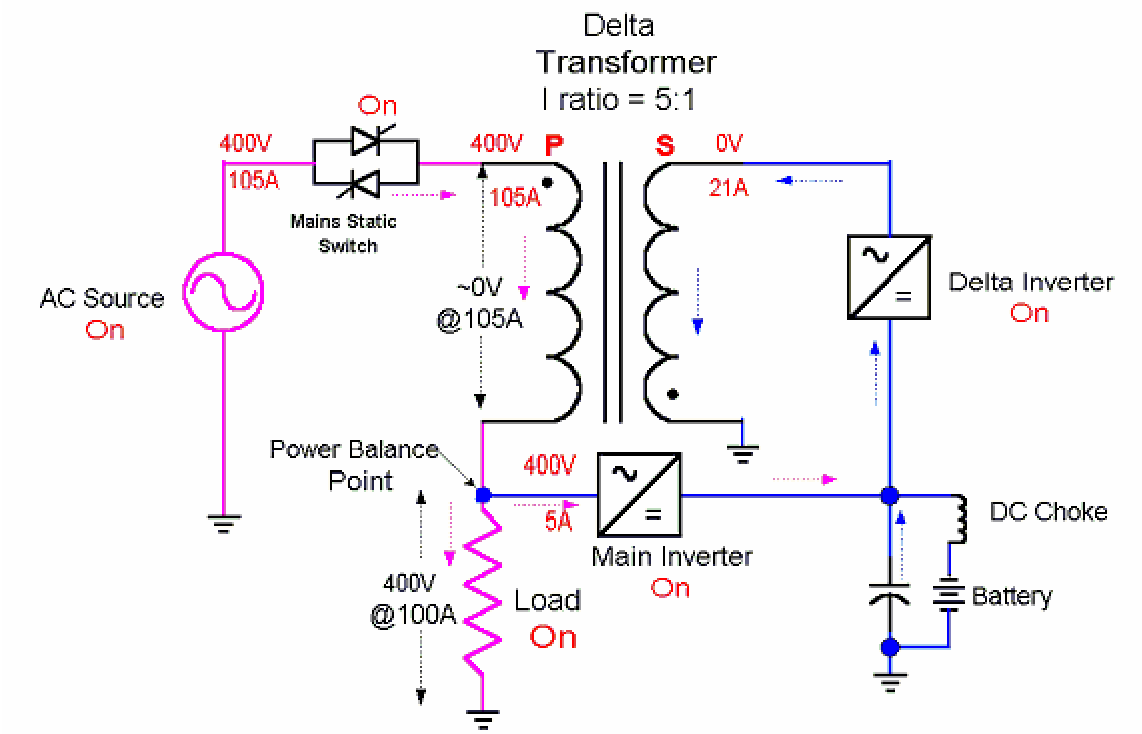

Figure 9 -- *Delta Transformer Power Flow*

The power imported is equal to the load power in kW + the system losses in kW. So if we assume 5% losses we need to import 105% power. The delta inverter would be set to 21A and we will get a corresponding 105A of current flow from the AC source. The delta inverter current is purely a control current that is precisely in phase with the AC source voltage waveform. The load consumes 100A of the imported power and the remaining 5A flows through the main inverter flyback diodes to the DC bus to make up for system losses.

Review

So in the above we have proven that from a power control circuit perspective the load is not directly connected to the source. It is connected through the impedance of the transformer primary winding, which is controlled by the delta inverter on the secondary. If the secondary circuit is infinite, i.e., open (delta inverter =off= 0A), and there has to be 0A in the primary winding. Consequently the primary winding appears as a variable impedance to power flow too our load, i.e., one which is regulated by the delta inverter. Most engineers view the system one-line shown in figure 4, and mistakenly think of the delta transformer primary winding as having similar functions as a choke. This is a huge fundamental error in thinking. It does have some choke function, but not at power frequency.

The delta inverter is a current controlled IGBT PWM inverter. It's primary function is regulating the input current and input power by acting as a variable current source in the secondary circuit of the transformer, i.e., it behaves as a load without power dissipation, except for it's switching losses. The delta inverter current waveform is controlled to be sinusoidal and in-phase with the AC source voltage. If we start the delta inverter and set the delta inverter current at 20A we will get 100A of current flow through the primary and consequently through the load impedance. Therefore, we can regulate the magnitude, wave shape and power factor of the current taken from the AC source. This concludes Part 1 of this series. Part 2 will cover "Delta Conversion Power Regulation" in detail.

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