AC RIPPLE CURRENTS IN UPS DC LINK

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In most Uninterruptible Power Supplies (UPSs), the DC link is the point at which the output of the rectifier, the input of the inverter, the DC filter, and the battery are all connected in parallel. The rectifier converts AC power from the utility or building generator to DC power. The DC power passes through the DC filter that usually consists of series inductance with shunt (parallel) capacitance. The filtered DC power is then used to charge the battery and supply the input of the inverter. The inverter converts the DC power back to AC power for the critical loads that are typically computers and their peripheral equipment.

Because the DC capacitors in the DC filter and the battery are connected in parallel, any AC ripple current will be shared between them. The currents will be divided by the inverse of the ratio of the two AC impedances; i.e., the lower AC impedance will conduct the higher AC current. In older UPS and battery designs, the DC capacitors always had much lower AC impedance than the battery. Changes in both designs have created a shift in this differential.

Some UPS manufacturers have lowered the amount of DC capacitors used in the DC filter when compared to older models. Fewer DC capacitors result in higher AC impedance. Using 360 Hz and the DC voltage and kVA to calculate per unit DC capacitance for 500 kVA UPSs (one C per unit, or Cpu, creates one Ω per unit at 360 Hz), older UPSs were compared to newer UPSs. The range is from Cpu = 128 on older UPSs to Cpu = 44 on some newer UPSs, or, a range of 0.78% impedance to 2.27% impedance. This is an increase of almost 300%. This means that less of the AC ripple current from the DC link will flow into the capacitors and more will be diverted to the batteries.

The battery design also changed from the thick plate “telephone cell” that was previously used for UPS batteries to thinner plates with denser packing. This lowered the internal impedances that helped the battery produce the high currents needed for UPSs. The lowered impedance also meant that the batteries would now sink, or accept, more of the AC ripple current from the DC link.

Most people point to the rectifier as the source of the AC ripple currents in the DC link. However, the inductance of the DC filter blocks most of the ripple current from the rectifier. Unless the rectifier has a malfunction such as a missing drive signal, the current from the rectifier to the DC link will be smooth with very little ripple. The majority of the AC ripple current actually comes from the inverter as it converts the DC power into AC power. Balanced linear loads (loads with sine wave currents and no harmonic currents) produce the least ripple in the DC link current.

Considering a popular design using an isolation output transformer and zigzag secondary windings, Figure 1 below shows that the DC current has 0.125 amps per unit peak AC ripple at 360 Hz with a balanced three phase linear load. (Only the fundamental frequency and its harmonics are considered and the inverter switching frequencies are not accounted for. This is true for all of the following figures.)

DC Ripple Current from Balanced Load

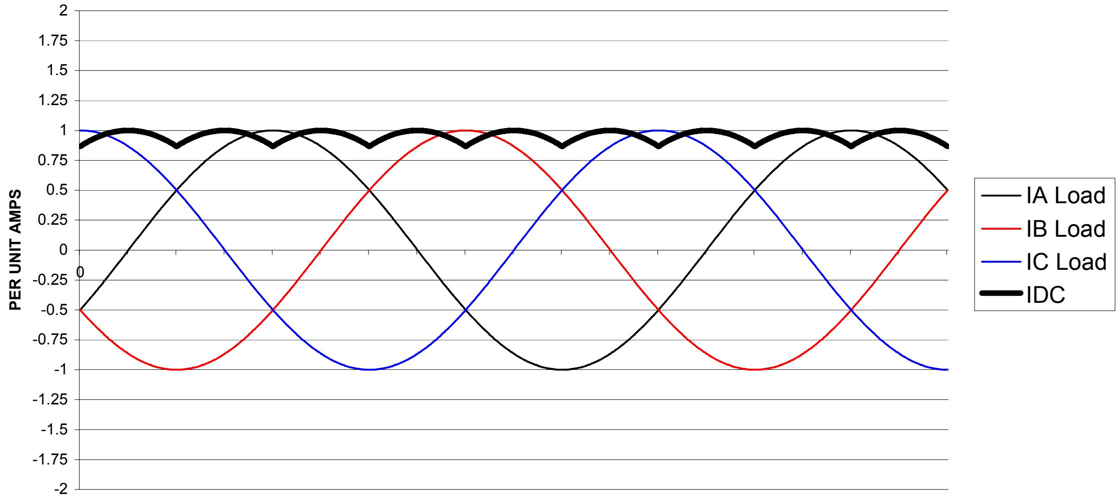

Figure 1

If the linear load is unbalanced by 20%, Figure 2 shows the ripple current increases to 0.25 amps per unit peak and now has a 120 Hz component. This means that the DC capacitor impedance will be three times higher to this lower frequency.

DC Ripple Current from 20% Unbalanced Load

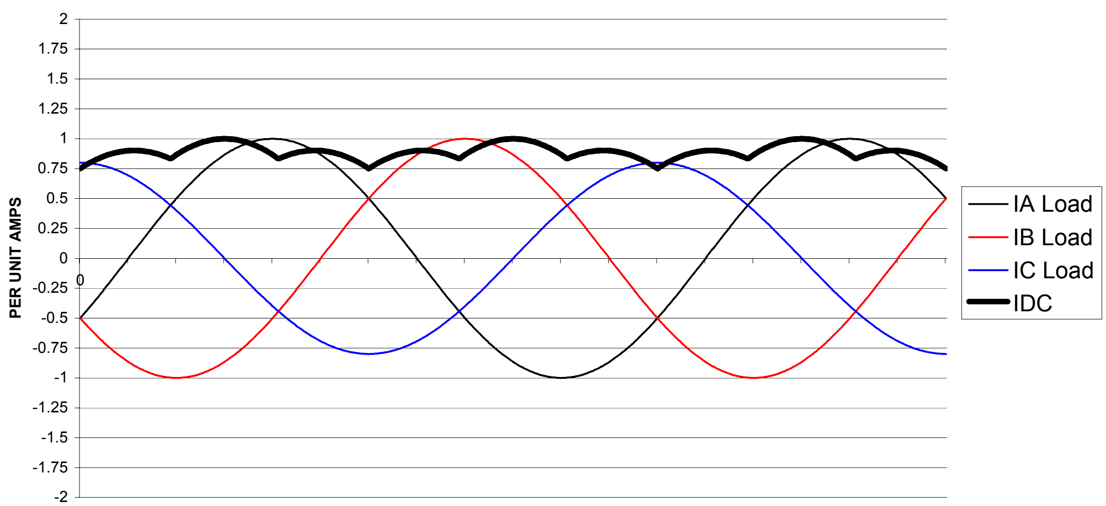

Figure 2

If the linear load is unbalanced by 50%, Figure 3 shows the ripple current increases to 0.425 amps per unit peak and the 120 Hz component becomes more pronounced.

DC Ripple Current from 50% Unbalanced Load

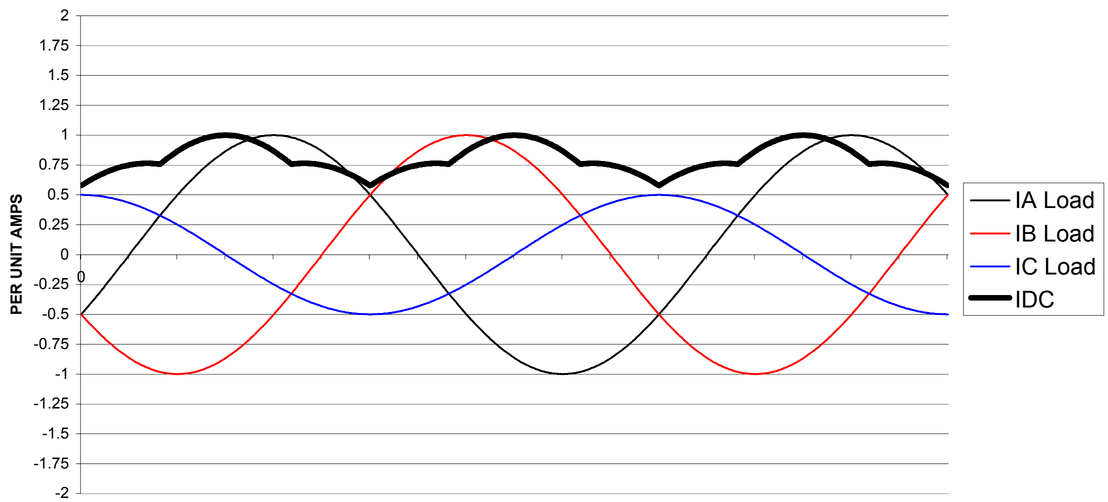

Figure 3

Older single-phase power supplies utilized a transformer-rectifier design with a series inductance or choke filter. A linear regulator circuit followed this. The input of these power supplies looked more like a square wave than a sine wave. The current waveform contained odd harmonics (third, fifth, seventh, etc.), but they were low percentages compared to the fundamental. Typically the third was 33% or less and the fifth was less than 20%. Today's power supplies utilize direct line coupled diode-capacitor voltage doublers to increase the efficiency of the high frequency switching section. The input to these supplies is a peaky current with a crest factor of up to three. (Crest factor is the ratio of peak to RMS current. A normal sine wave has a crest factor of 1.4 and a square wave has a crest factor of 1.0.) This peaky current also has odd harmonics but they are about twice the amount of those for a square wave. Also, the third, seventh, eleventh, etc. harmonics are shifted by 180 degrees.

The third order harmonics do not affect the AC ripple current on the DC link if the three output phases of the inverter are balanced and the output transformer either has a delta primary or zigzag secondary or both. This is because a zigzag secondary can be configured to cancel balanced third order harmonics and delta primary will allow them to circulate in the delta winding. The fifth and seventh harmonics will feed through the DC link unless there are AC output filters to trap them before they come through the DC link. The fifth and seventh harmonics cause an increase in the 360 Hz component of the AC ripple.

Figure 4 shows that the balanced output currents with a crest factor of about 2.5 result in similar DC link ripple current as balanced linear loads. There is an increase in the 360 Hz component to 0.67 amps per unit peak.

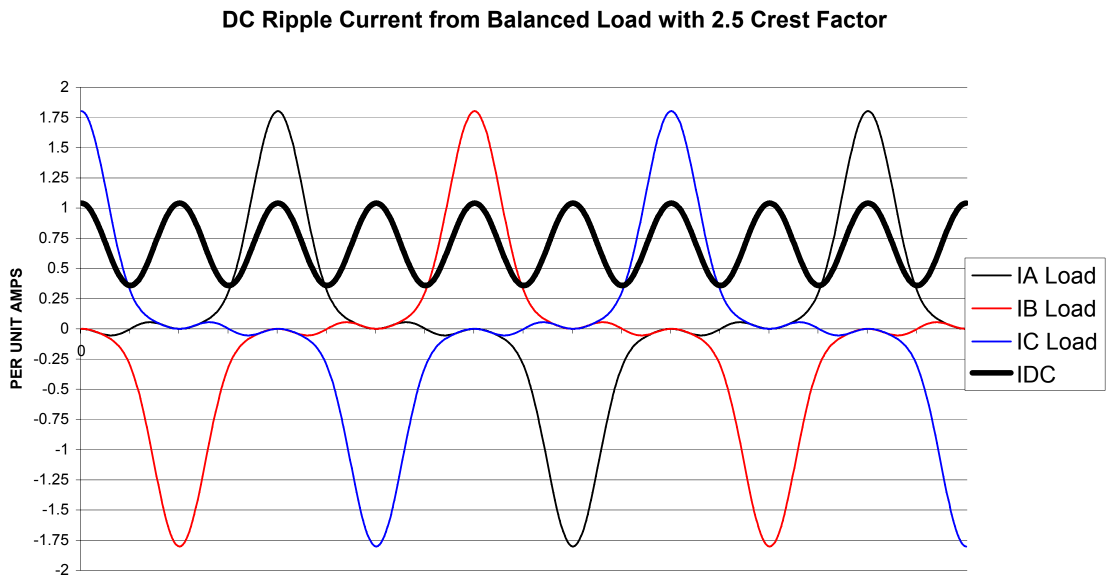

Figure 4

The same non-linear loads with 20% unbalance are shown in Figure 5. The ripple current increases to 0.77 amps per unit peak and again has a 120 Hz component.

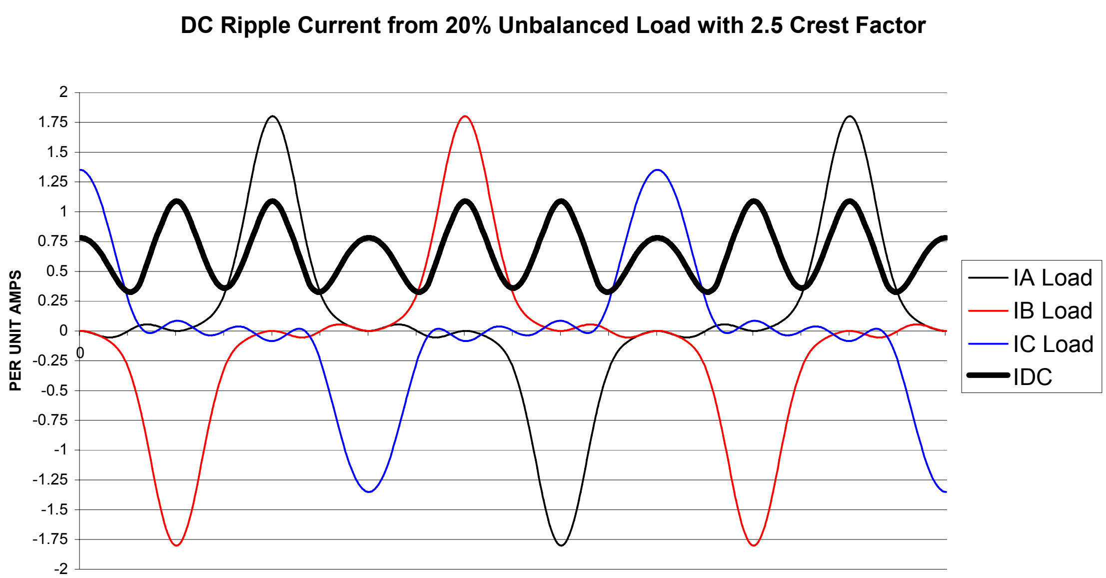

Figure 5

The condition gets even worse with 50% unbalanced currents. Figure 6 on the following page shows that the ripple current increases to 0.80 amps per unit peak.

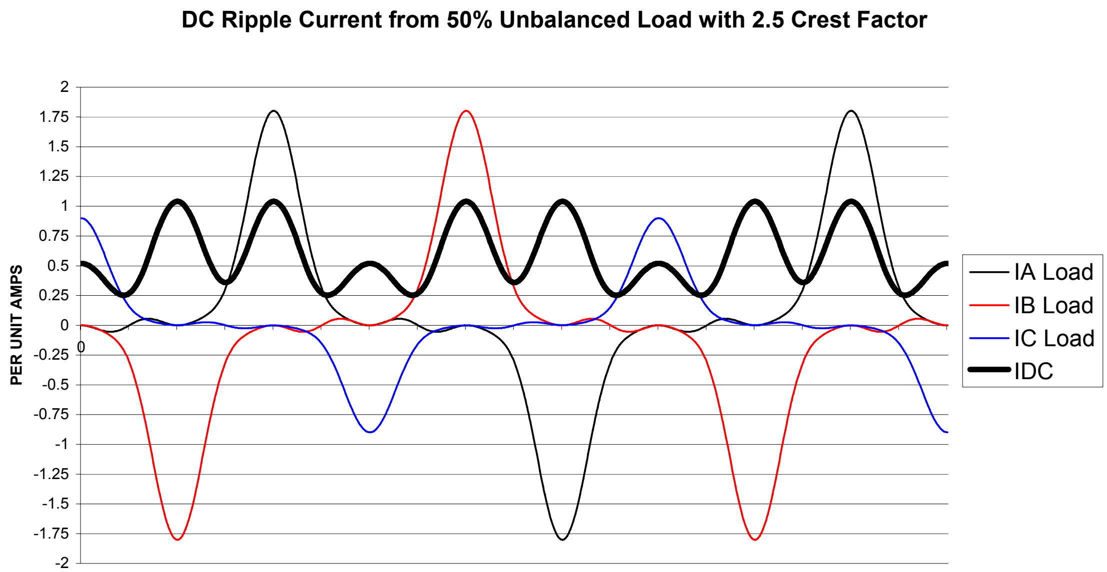

Figure 6

For a comparison, Figure 7 shows a 50% unbalance with output fifth harmonic filters. Note that the DC link ripple is about 0.47 amps per unit peak.

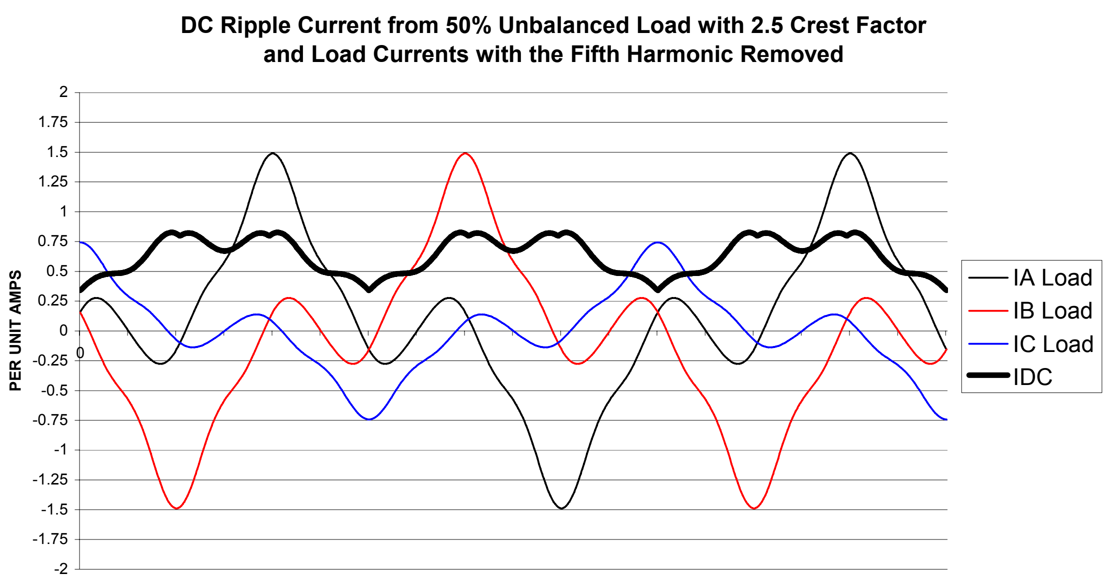

Figure 7

For another comparison, Figure 8 shows a 50% unbalance with the older style power supply. Note that the DC link ripple is about 0.25 amps per unit peak. (A square wave of 0.7 has the same RMS of a sine wave of 1.0 peak. Thus the reduced peak of the load currents.)

DC Ripple Current from 50% Unbalanced Square Wave Load

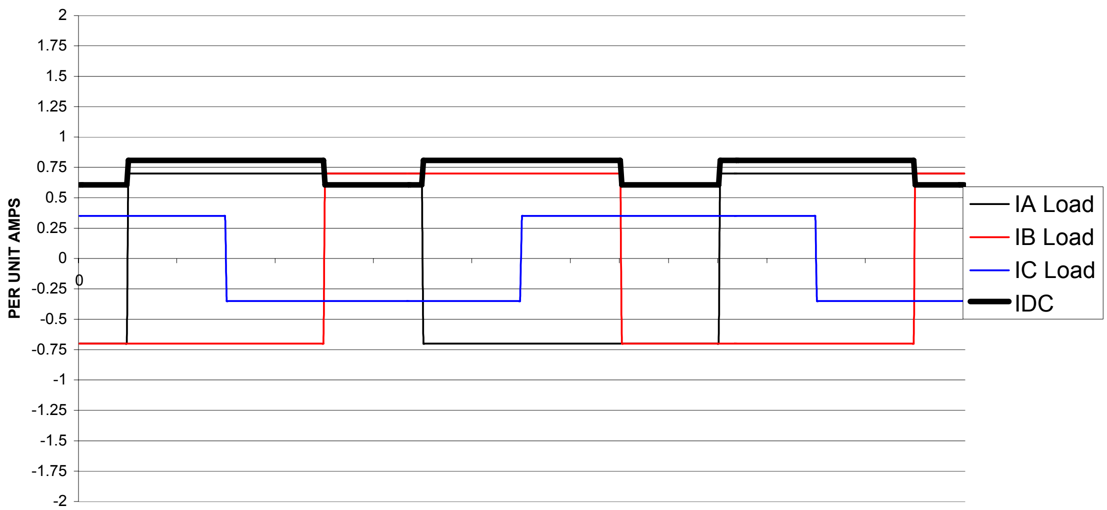

Figure 8

As can be seen by these graphs, selection of the amount of DC capacitance should be driven more by the expected loads on the inverter than by the expected ripple from the rectifier. Unbalancing the inverter loads compounds the ripple current problems. Even for linear loads, unbalanced phase loads inject a 120 Hz component into the DC link ripple currents.

When high ripple currents are encountered in the DC capacitors and batteries, both the input and output currents should be checked for balance. A normally operating three-phase rectifier draws balanced input currents. An unbalance in the input currents indicates a rectifier problem. Unbalanced output currents are the result of poor load distribution among the three phases. This can be corrected by moving loads until the output currents are more closely balanced.

Most battery manufacturers specify a maximum acceptable ripple voltage, typically 1 to 2% of the DC float voltage. AC ripple voltage will induce AC ripple current and will be directly proportional to the UPS and battery impedance. The effects of high ripple current on the batteries is typically seen in the form of excess heat. A very high or abnormal ripple current can lead to reduced battery life or thermal runaway, especially in VRLA type batteries.