POWER QUALITY INTERNATIONAL

Exclusive e-Rated® Provider

Zero-Sequence Harmonic Currents

The Zero-Sequence Harmonic Problem – In 1985, Power Quality International's engineers discovered high levels of zero-sequence harmonic current in several 2000kVA, 208/120-volt electrical subsystems at an IBM research, testing and manufacturing facility in Toronto, Canada.

When checking phase current balance at the main secondary switchboards, we were surprised to find high neutral currents, since the three phases were well balanced. In analyzing this current, we found that it was predominantly 180 Hz., with diminishing levels of 540 Hz. and 900 Hz; the first three zero-sequence 'triplen' harmonic currents. Although previously described mathematically, we were unable to find any information, including a search of IEEE papers, on the discovery of zero-sequence 'triplen' harmonics in electrical distribution systems.

On further investigation and analysis, we concluded that zero-sequence harmonic currents can only occur when nonlinear loads are connected phase-to-neutral in a three-phase, four-wire distribution system. Although positive- and negative-sequence harmonic currents have always existed in industrial power conversion systems, these nonlinear loads are always connected phase-to-phase.

In 1985, IBM was developing and testing their first personal computers. During their test cycle, we learned they had hundreds, if not thousands, of PCs supplied by these two subsystems.

In addition to the fire and safety issues created by excessively high neutral current, we also discovered very high zero-sequence voltages between the branch circuits' shared neutrals and their ground conductors at the 120-volt receptacle loads. We discovered that above 5-volts, many of the PCs' switch-mode power supplies would fail prematurely. We also found that a voltage difference of more than 5-volts, between computers and their peripherals, might cause data corruption in their communication network. This is an Ohm's Law problem. The circuits' neutrals are grounded at the source transformer, but the neutral conductors' impedances generate voltage between neutral and ground at the load-end of the circuits ($E_H = I_H \times Z_H$).

The Zero-Sequence Solution – After reporting these problems to IBM's facility engineers, we were challenged to find a solution. We'd had extensive experience designing and applying large tuned L-C filters for industrial applications. L-C filters provide an ideal harmonic current shunt, when the nonlinear loads and their harmonic profiles, are steady-state. The problem is that in an office environment, the loads and their harmonic profiles are dynamic.

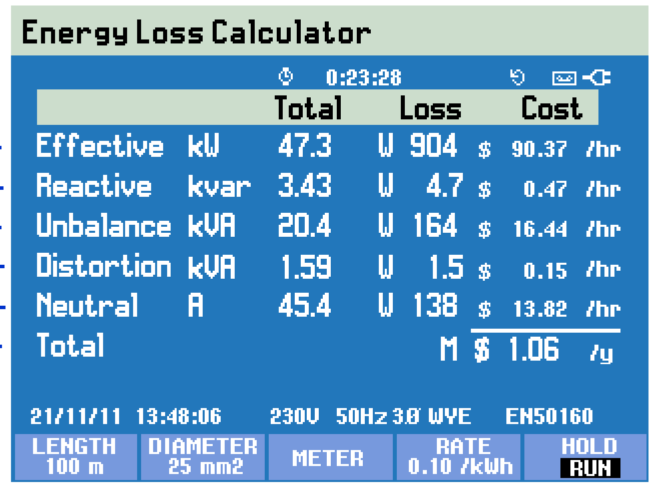
In looking for a solution, it occurred to us that a three-phase, four-wire zigzag configured autotransformer may provide a satisfactory solution, since, if properly configured, it would have an ultra-low zero-sequence impedance. If applied as-close-as-possible to the single phase nonlinear loads (i.e. at the branch-circuits' subpanel), it would shunt all zero-sequence harmonic currents, including the zero-sequence components of the fundamental and all positive- and negative-sequences that result from phase current imbalance under nonlinear loading. In addition to acting as a 'triplen' harmonic current shunt, the filter would also provide phase current balancing.

Our original filter provided zero-sequence impedance that was approximately 100 times lower than the source transformer and its feeder and branch circuit's combined source impedance. With this result, in 1986 we applied these zero-sequence shunt filters at every remote power panel supplied by the two 2000kVA subsystems. All identified power quality problems were resolved.

The Measurement of 'Penalty Losses' – Power Quality International has recently undertaken field measurements using a Fluke Model 435, Series 2 Analyzer. The instrument's Unified Power measurement system uses a combination of classical methods (IEEE 1458-2010) and the University of Valencia's mathematical calculations to express power and energy measurements that directly quantify the wasted energy or 'penalty losses' in electrical circuits. Unified Power measures harmonics and unbalance waste in terms of kilowatts, and by factoring in the cost of each kilowatt hour it's possible to calculate the cost of waste energy over a week, a month, or a year.

The screen capture below identifies *Unbalance* load and *Neutral* current losses as accounting for most of the circuit's *'penalty losses'.* The *Effective* kW power losses are due to the circuit's resistance. In a nonlinear environment, with unbalanced loading, *'penalty losses'* may exceed the circuit's resistance losses

Useful kilowatts (power) available
Reactive (unusable) power
Power made unusable by unbalance
Unusable distortion volt-amperes
Neutral current
Total cost of wasted kilowatt hours per year



The Application of Zero-Sequence Filters – Power Quality International's *I_0Filters™* – zero-sequence harmonic filters' – are highly effective, three-phase, four-wire, passive electromagnetic devices with ultra-low zero-sequence impedance. These filters have been specifically designed to provide a parallel path for all zero-sequence harmonic currents that are generated by phase-to-neutral connected nonlinear electronic loads and unbalanced systems.

I_0Filter™

The Feeder Circuit – Using the Energy Loss Calculator's screen capture for a 100 m, 208/120V feeder circuit as an example, the application of a zero-sequence harmonic filter at the load-end of the circuit will typically result in the following outcomes:

'Penalty Losses'	without *I_0Filter™*	with *I_0Filter™*
Reactive	4.7W	6.4W [1]
Unbalance	164.0W	4.8W
Distortion	1.5W	0.6W
Neutral	138.0W	3.2W
Total *'Penalty Losses'*	308.2W	15.0W

In this example, the filter has reduced the circuit's total *'penalty losses'* by 95% by shunting the 'triplen' zero-sequence harmonic currents. Because of its ultra-low zero-sequence impedance, the zero-sequence components of all positive- and negative-sequence harmonic currents (including the fundamental), which exist under unbalanced loading, will also be shunted. As a result, the filter provides phase-current balancing. Because of these characteristics, both Unbalance and Neutral losses are substantially reduced.

The Loads – With a 95% reduction in zero-sequence phase currents, the distortion of voltage at the circuit's loads will substantially reduce their internal *'penalty losses'.* With the application of zero-sequence harmonic filters, experience has taught us that the reduction of load *'penalty losses'* often exceeds circuit *'penalty losses'.*

With a reduction in neutral current of almost 98%, phase-to-neutral voltage at the loads, which may otherwise exceed the ITIC [3] 5V maximum or the IGT [4] requirement, will be brought close to zero. This outcome will eliminate corruption of data in the communication network, a common problem in computer and gaming machine networks.

The Source Transformer – A reduction in zero-sequence phase and neutral harmonic current, THD_I and K-factor will reduce the Impedance (Load) Losses in the transformer that supplies the circuit.

Notes:

[1] The application of the I_0*Filters*™ increases the circuit's inductive reactance from 4.7W to 6.4W.
[2] ITIC – Information Technology Industry Council.
[3] IGT – International Gaming Technologies
[4] It is important to understand that neither load nor source transformer losses are measured by Fluke's Energy Loss Calculator.