TVTechnology

1 + 1 + 1 Doesn't Always Equal Zero

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I clearly recall the moment when the mystery of the three phases was revealed to me in all of its beauty. During my mid-teens I had become aware of, and eventually familiar with, the three phase wiring found around school, college and community stages, but I was ignorant as to why heavy duty power came in groups of three rather than ones, twos or fours, and utterly baffled as to why the neutral wire was smaller than I expected.

Even when we had learned enough physics and mathematics to understand wave cancellation and interference in optics and vector calculations in mechanics and electromagnetism, the PSSC physics syllabus didn't include anything as practical as an explanation of the power distribution system that envelops our lives.

THREE-PHASE POWER SYSTEM

Several attempts at enlightenment by quizzing visiting electricians was met with mumbled and confusing explanations which led me to realize that perhaps I wasn't the only one that hadn't yet grasped the concept. Eventually I found an electrical engineering text book that covered the concepts of polyphase power.

After struggling with the more complex mathematical aspects of the topic, I finally came to appreciate the beauty and simplicity of three phase wye-connected power distribution. The notion of current cancellation in the shared neutral conductor was thrilling, and the saving of fully one-third of the cable cost in the distribution network struck me as being truly brilliant. Combined with the clever notion of stepping up the voltage to reduce the current for transmission and distribution, I came to see just how much human ingenuity was lurking in something as mundane as our power utility network.

At that time, all of the dimmers that I met were various forms of resistance device and virtually all of the lamps in use were of the perfectly ordinary incandescent filament variety. In lighting, just as everywhere else in the power grid, three fully loaded phases resulted in a cancelled neutral current of zero (1 + 1 + 1 = 0) and even the worst case scenario of a single, fully-loaded phase only produced a single phase current in the neutral conductor. For that brief period, the theoretical and real worlds appeared to be the same place.

SINE WAVES

The widespread adoption of our much loved phase control (SCR and Triac) dimmers that began in the '60s seriously disrupted the relationship between individual phase currents and the total neutral current. Because the phase control process dims by blocking off big chunks of the sine wave current that comes from the power source, the current returning via the neutral conductor is similarly mangled. Instead of three sine wave currents neatly cancelling one another out in the neutral conductor, the odd shaped remnants of the sine waves can add together rather than cancel each other out. In the worst case, with the loads on each phase dimmed to around 30 percent, the total neutral current, including the triplen (third order) harmonics of the distorted wave fragments can reach more than 170 percent of a single phase current.

Under exactly such circumstances I have experienced a main utility feeder neutral that overheated on an outdoor production during lamp check (at 30 percent), and started a small forest fire. Fortunately an alert head lighting technician shut off the power and extinguished the fire before it broke free. The utility company replaced the burned out neutral with a double-sized cable and the production went ahead that night.

HARMONIC DISTORTION

This phenomen of harmonic distortion seriously contradicts of the assumptions that we previously made for allocating conductor size in three phase wye-connected systems. The National Electrical Code in 310.15 (B)(4)(c) requires systems with high harmonic content to treat the neutral in the same way as a phase conductor and calculate its size based on actual (rather than assumed) load. The common practice is to use a neutral conductor on main power feeds with double the current rating of the phase conductors. Where dimmer systems represent a significant proportion of the load on a substation transformer, it is also considered good practice to use a transformer with a higher K factor rating (tolerance for harmonic currents) than normal.

Dimmer systems are by no means the only devices to produce large amounts of harmonic distortion in the power supply. The electronic ballasts for discharge lamps such as HMI and MSR and arc lamps such as Xenon and HTI are generous contributors, as is every computer, and most other electronic devices (including Class D, G and H audio amplifiers). What harmonic distortion does mean for us is an additional requirement to check the specifications for our studio installations, generator ratings and temporary utility feeds, to ensure that our systems are both safe and reliable.

If you're constructing a new facility or refitting an existing one, it may even prove to be more cost effective to fit the new, more expensive, sine wave dimmers with their reduced harmonic output than to allow for higher rated transformers and neutral cabling.