CNCE™ AND NCE™ INSTALLATION AT BROADCASTING STUDIO

Concerned about video noise detected on some of its studio equipment, E! Entertainment Television (ETV), commissioned a study to determine if this noise was power quality related. The primary purpose of this survey was to determine whether any power quality related problems, particularly with respect to harmonic distortion, were the cause of video noise detected on some of the studio's equipment. Also, there was concern that the main 225 kVA technical power transformer was running excessively hot due to the harmonic content in the current drawn by the audio-video equipment.

Concerns uncovered by the survey included:

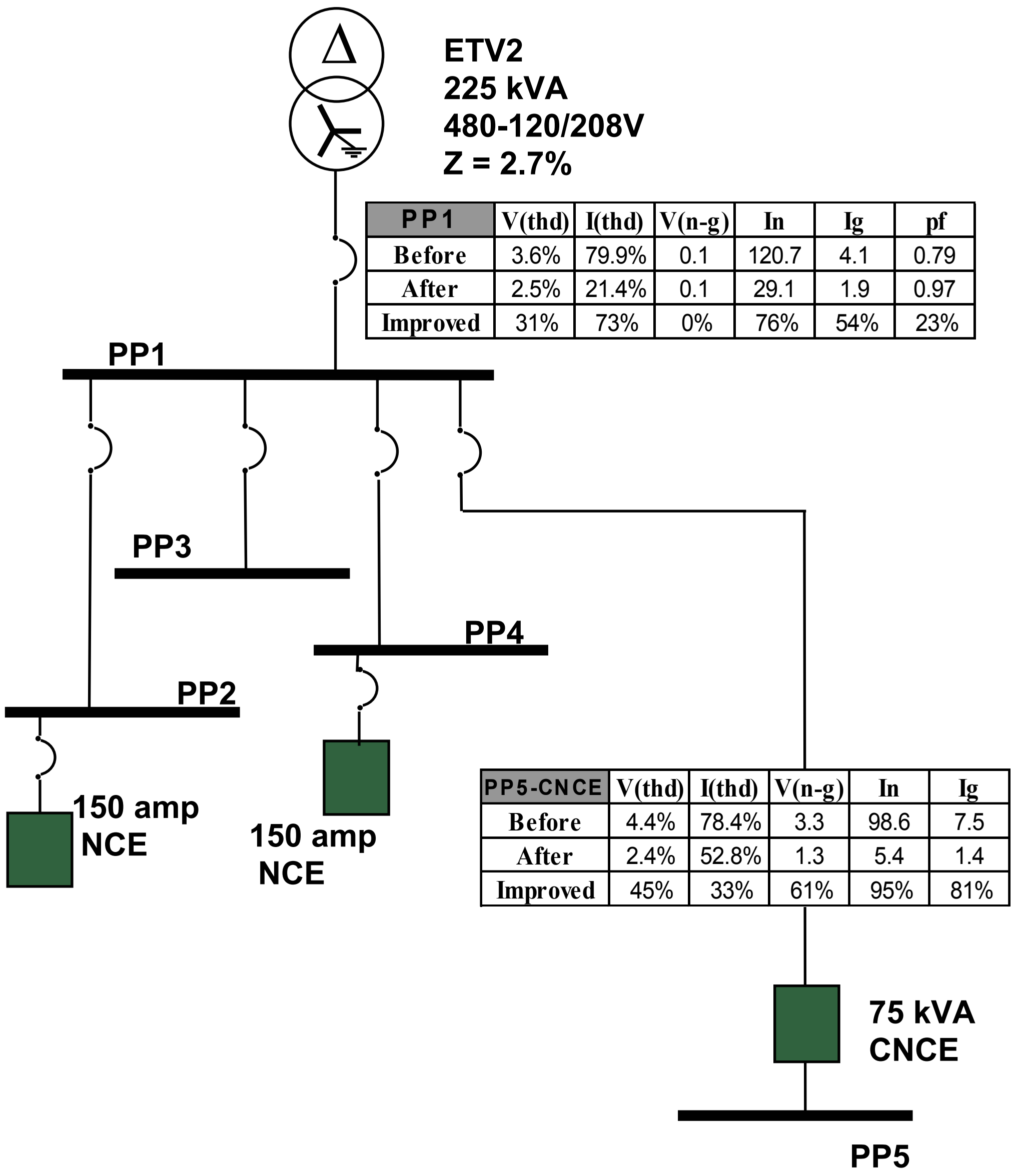
1. Total harmonic voltage distortion exceeded recommended maximum limits in some locations. Both panels downstream of the 125 kVA UPS exceeded the IEEE 519 recommended maximum of 5% total harmonic voltage distortion. Also, 5th harmonic voltage distortion levels throughout the facility were higher than the 3% limit for an individual harmonic.

2. Neutral-ground voltage in many areas was above the commonly accepted maximum limit of 2 volts.

3. Relatively high ground currents were measured at several power panels.

These power quality concerns had appeared even though the electrical system was quite lightly loaded. In order to prevent problems from developing as the non-linear load grew, it was recommended that proactive steps be taken to mitigate the harmonics. Two MIRUS CNCE's and 2 NCE's were installed for this purpose. After their installation, followup measurements were taken to determine the effectiveness of this solution in addressing the problems at ETV.

Figure 1 shows the single-line of the ETV electrical distribution with the harmonic mitigating transformers installed. Measurements taken before and after the MIRUS products were installed are shown in the accompanying tables. Several critical power quality parameters are shown - total harmonic current and voltage distortion (I_{thd} and V_{thd}), neutral-ground voltage (V_{n-g}), neutral current (I_n), ground current (I_g) and power factor (PF).



PP1	V(thd)	I(thd)	V(n-g)	In	Ig	pf
Before	3.6%	79.9%	0.1	120.7	4.1	0.79
After	2.5%	21.4%	0.1	29.1	1.9	0.97
Improved	31%	73%	0%	76%	54%	23%

PP5-CNCE	V(thd)	I(thd)	V(n-g)	In	Ig
Before	4.4%	78.4%	3.3	98.6	7.5
After	2.4%	52.8%	1.3	5.4	1.4
Improved	45%	33%	61%	95%	81%

Figure 1: Harmonic mitigation at E! Entertainment Television studio using Mirus NCE's and CNCE's

The tables in Figure 1 highlight the power quality improvements achieved through the use of the harmonic mitigating transformers and include:

1. A reduction in I_{thd} of 73% at transformer ETV2.
2. V_{thd} reduction throughout the distribution system. (Near 50% at PP5.)
3. A reduction in neutral current (I_n) upstream of the harmonic mitigation equipment. By 76% at the secondary of transformer ETV2.
4. Neutral-ground voltage (V_{n-g}) reduction at all power panels (3.3V to 1.3V at PP5).

5. Ground current (I_g) reduction throughout the distribution system (from 7.5 to 1.3 at PP5).

Operational benefits that can be attributed to these power quality improvements include a reduction in the video noise by approximately 75%, cooler running neutral conductors, transformer and UPS and near unity power factor which has freed up capacity for future load growth.

INTRODUCTION

The survey at ETV involved 2 separate distribution systems - a 225 kVA transformer feeding a main distribution panel with 4 downstream power panels and a 125 kVA Liebert UPS System feeding 2 downstream power panels. A Fluke 41 power harmonics analyzer was used to record harmonics, load and voltage measurements.

Prior to beginning the original survey, a report on an earlier survey performed by PRK Associates was reviewed. Some of the concerns highlighted in that report were as follows:

1. An observed video 'hum' was believed to be the product of 180 Hz, 3rd harmonic noise on the system. The diagnosis was that the 'hum' was caused by numerous ground loops produced by a high common mode noise - 8 volts peak to peak.

2. Fairly high ground current readings were measured, particularly at PP5 and the star connection (neutral point) of transformer ETV2.

3. High levels of harmonics generated by the nonlinear equipment required that a derating factor be applied to the 225 kVA transformer. This meant that the transformer could not be loaded to its full load rating.

The Oct. 3rd survey uncovered several power quality concerns.

1. The core temperature of Transformer ETV2 was quite high because of the high harmonic content in the phase and neutral current. This despite the fact that the transformer was quite lightly loaded. There was little risk of failure at the time of the survey due to the light load, but the risk would increase dramatically as the load increased.

2. Neutral-ground voltage at most of the downstream power panels approached levels that could potentially cause operational problems for some sensitive equipment. At over 3 V_{rms} , the highest values were measured at panel PP5.

3. Voltage distortion downstream of the UPS unit were above the IEEE 519 recommended maximum of 5%. At the power panels downstream of Transformer ETV2 voltage distortion was around 4%.

A report prepared after the original harmonic survey was completed recommended the following harmonic mitigation steps be taken:

1. Installation of 2 Neutral Current Eliminators™ (NCE™'s) and 2 Combined Neutral Current Eliminators™ (CNCE™'s) to filter out the triplen harmonics near the power panels and induce cancellation of the 5th & 7th harmonics through phase shifting. This mitigation approach was predicted to achieve the following improvements:

   a) An approximate 70 - 80% reduction in neutral current returning from the subpanels which would off-load the neutral conductors and prevent the transformer and UPS from overheating due to triplen harmonics.
   b) A reduction in V_{n-g} to about 1 volt.
   c) A reduction in phase current harmonic distortion at the output of the transformer and UPS, particularly at the 3rd, 5th, 7th & 9th harmonics. This would result in lower voltage distortion at the subpanels and reduced losses in the transformer and UPS. Also, if the non-linear load were to grow, the new harmonic mitigating equipment would help prevent voltage distortion from increasing to levels that would potentially cause operational problems in the audio-video equipment.
   d) A lower current crest factor, K-factor and improved power factor which would free-up capacity in both the transformer and the UPS.

The recommendations were adopted and this report prepared to analyze their effectiveness.

BACKGROUND

As with most of today's electronic equipment which utilize switchmode power supplies, audio-video equipment produce troublesome amounts of harmonic currents. By drawing current in a non-sinusoidal manner, these non-linear loads create harmonics which circulate through the electrical distribution system. The most common problems which result are:

- Overheating neutrals, transformers and other electrical distribution equipment
- Excessive voltage distortion and neutral-ground voltage which can cause equipment malfunctions, component damage and shortened equipment life span
- Ground currents which can cause video noise problems.

Over heating due to harmonics: The additive effect of the 3rd and other triplen harmonics in the neutral and the significantly increased losses in transformers due to harmonics have been well documented in recent years. In order to prevent transformer failures due to harmonic loading, CBEMA (Computer & Business Equipment Manufacturers Association) recommends the following derating factor (dF) be used on standard transformers:

$dF = 1.414 \times I_{rms} / I_p$

, where: dF = transformer derating factor

I_{rms} = current rms value

I_p = current peak value

When applied to transformer ETV2 before harmonic treatment:

I_{rms} = 128 A and I_p = 307A

Then,

dF = 1.414 x 128 / 307 = 0.59

Therefore, using this method, the transformer at ETV2 could not be loaded to more than 132 kVA (225 kVA x 0.59).

Rather than derate the transformer, it can be off-loaded by treating the harmonic currents near the harmonic generating loads. One proven method is through the application of zero sequence filtering to remove the triplen harmonics and phase shifting to produce cancellation of the 5th & 7th harmonics.

High voltage distortion and neutral-ground voltage: Harmonic problems which have been less well documented, but are potentially even more serious, are the heavy voltage distortion and high neutral-ground voltages (common mode noise) that are common where high densities of non-linear loads exist. Most of the distortion is the result of the interaction of the harmonic currents with the impedance of the electrical distribution system. That is, as the harmonic currents circulate through the electrical distribution, they produce voltage drops at each harmonic frequency in relation to Ohm's law - $V_h = I_h \times Z_h$. The combined effect of the voltage drops at each harmonic frequency is what creates the overall voltage distortion. This problem becomes even more serious when the distribution system is serviced by a weak source, such as an UPS system or diesel generator. Distortion levels are higher when system impedance is higher. System impedance is generally high when fairly long cable runs are serviced from a supply with high source impedance, such as an UPS. This is demonstrated by the higher 6.6% voltage distortion level downstream of the UPS system at this site.

The same Ohm's Law relationship is what creates high neutral-ground common mode noise voltages. Heavy neutral currents, resulting from the additive effect of the triplen harmonic currents, 3rd, 9th, 15th, etc., in the neutral will produce a voltage drop along the neutral conductor. This voltage drop will appear as a potential difference between neutral and ground near the harmonic generating loads (ie. at the power panels and power receptacles). Commonly referred to as common mode noise, this voltage can have a very adverse affect on the operation of equipment which is subjected to it.

An effective strategy for harmonic mitigation is to isolate the harmonic currents near the loads themselves through phase shifting and zero sequence filtering. By reducing the current harmonics, the voltage distortion, neutral-ground voltage and overheating these harmonic currents produce will be dramatically reduced.

Ground Currents*:* Most electronic equipment which utilize switch-mode power supplies are equipped with π-Filters to reduce the high frequency EMI emissions.

These filters are effective at reducing EMI but may allow some low frequency harmonic leakage currents (ie. 180 Hz) to pass through to the ground wire. This can result in troublesome ground currents circulating through the power system.

OBSERVATIONS

Measurements taken on June 4th confirmed that the harmonic mitigation equipment was very effective in addressing the power quality concerns. As predicted in the original report, neutral current was reduced by over 70%, neutral-ground voltage was reduced to nearly 1V, and current distortion was significantly reduced at the secondary of transformer ETV2 (from 79.9% to 21.4%).

With the reduction in harmonic current at ETV2, power factor was improved from .79 to .97, current crest factor dropped from 2.34 to 1.79 and the phase current K-factor was reduced to 1.6 from 6.7. Each of these parameters are indicators of how reduction in harmonic current has off-loaded the transformer allowing it to run cooler. This becomes even more evident when we apply the CBEMA transformer derating factor. With harmonic mitigation equipment installed:

I_{rms} = 108 A and I_p = 194 A

Then,

$$dF = 1.414 \times I_{rms} / I_p = 1.414 \times 108 / 194 = 0.79$$

The effective transformer capacity is now 178 kVA (225 kVA x 0.79). The net result is a freeing up of approximately 45 kVA of transformer capacity for future load growth.

In summary, the installation of harmonic mitigation transformers at ETV has dramatically improved power quality at the facitlity. This in turn has resulted in many operational benefits, which include:

1. Cooler operating neutral conductors, distribution transformer and UPS unit.
2. Near unity PF which has freed-up capacity for future load growth.
3. Video noise reduction of approximately 75%.