BUSWAY APPLICATIONS WITH HARMONICS

SUMMARY

Nonlinear power supplies for single phase computers and other nonlinear loads like electric discharge lighting cause odd triplen harmonics that do not cancel in the neutral. As a result, there can be current in the neutral even when the three phases are balanced. This will cause sandwich style busways or four wires in a conduit or other raceway to have a higher temperature rise than with the same phase current without the harmonic neutral currents. This is true because there is more heat generated with the added neutral harmonic current and the enclosure can only dissipate the same amount of heat.

If the neutral harmonic current ratio to phase current is the expected maximum of 200%, then sandwich style busways would only carry 65.5% current with 100% neutral and 77.5% current with 200% neutral to run at the same temperature rise as busways with balanced three phase current and no neutral current.

PROBLEM

The computer problem only exists on 208Y/120V 3∅ 4W systems and 480Y/277V 3∅ 4W systems with a Y/Y transformer since the load neutral is carried back to the service entrance by the busway. On the more typical 480Y/277V 3∅ 4W systems with a Δ/Y transformer between the busway and the load, the harmonic neutral current is only present from the transformer downstream and does not affect the busway.

In the paper *A SURVEY OF NEUTRAL CURRENTS IN THREE-PHASE COMPUTER POWER SYSTEMS* by Thomas M. Gruss, Member IEEE, a study was made of 146 sites with single phase computer loads. With line to neutral power supplies for the computers in these facilities, the typical neutral current as a ratio to the phase current is shown below:

Harmonic	$I_N / I_\varnothing$
3	0.52
9	0.13
$3\sqrt{I_3^2 + I_9^2}$	1.61

As can be seen, the neutral current was 1.61 times the phase current. The "3" multiplier is due to the fact that these harmonic currents do not cancel in the neutral so the harmonic current from each phase is additive in the neutral. The paper states "Under worst-case conditions with rectifier conduction angles of 60° the neutral current could be 1.73 times the phase current."

THEORY

The heat generated by the current in the bars must equal the heat dissipated by the housing. For a 3∅ busway without harmonic current in the neutral the equation is shown below:

$$3I_{\varnothing}^2 R_{\varnothing} = h\Delta T$$

where:

$I_{\varnothing}$ = Current in each phase
$R_{\varnothing}$ = Resistance line to neutral of each phase bar
h = Heat transfer coefficient
ΔT = Temperature rise

With harmonic current in the neutral, the equation is shown below:

$$3I_{\varnothing H}^2 R_{\varnothing} + I_N^2 R_N = h\Delta T$$

where

$I_{\varnothing H}$ = Current in each phase with harmonic currents
$R_{\varnothing}$ = Resistance line to neutral of each phase bar
I_N = Harmonic current in the neutral
R_N = Resistance of the neutral

With the heat transfer coefficient and temperature rise constant, the heat generated with and without harmonic currents would have to be equal.

Thus:

$$3I_{\varnothing}^2 R_{\varnothing} = 3I_{\varnothing H}^2 R_{\varnothing} + I_N^2 R_N$$

If the neutral bar is the same size as the phase bars (100%), then $R_N = R_{\varnothing}$. Using $(I_N/I_{\varnothing H})$ ratio of neutral current to phase current for I_N and substituting in the last equation on the first page gives:

$$3I_{\varnothing}^2 R_{\varnothing} = 3I_{\varnothing H}^2 R_{\varnothing} + \left[\left(I_N/I_{\varnothing H}\right)I_{\varnothing H}\right]^2 R_{\varnothing}$$

The $R_{\varnothing}$ cancels from the equation. Solving for $I_{\varnothing H}/I_{\varnothing}$ gives:

$$\frac{I_{\varnothing H(100\%\ N)}}{I_{\varnothing}} = \sqrt{\frac{3}{3 + \left(I_N/I_{\varnothing H}\right)^2}}$$

If the neutral bar is twice the size of the phase bars (200%), then $R_N = 0.5\ R_{\varnothing}$. Substituting and solving the above for $I_{\varnothing H}/I_{\varnothing}$ gives:

$$\frac{I_{-H(200\%\ N)}}{I_{-}} = \sqrt{\frac{3}{3 + 0.5\left(I_N/I_{-H}\right)^2}}$$

Using the above formulas, following is a table showing $I_{\varnothing H}/I_{\varnothing}$ with varying amounts of harmonic neutral current:

	$I_{\varnothing H}/I_{\varnothing}$	
$I_N/I_{\varnothing H}$	100% N	200% N
0	1.000	1.000
0.25	0.990	0.995
0.50	0.961	0.980
0.75	0.918	0.956
1.00	0.866	0.926
1.25	0.811	0.891
1.50	0.756	0.853
1.75	0.703	0.814
2.00	0.655	0.775

The busway with neutral bar the same size as the phase bars (100%) and 200% harmonic current in the neutral will only carry 65.5% of rated current to run at the same temperature rise.

The busway with neutral bar twice the size as the phase bars (200%) and 200% harmonic current in the neutral will only carry 77.5% of rated current to run at the same temperature rise.

As can be seen, busways with the neutral bar twice the size of the phase bars will carry only 0.775/0.655

= 1.18 or 18% more current than busways with a neutral bar the same size as the phase bars.

For example: A 2000A busway with a 100% neutral will carry 1310 amperes on the phase bars and 2620 harmonic amperes on the neutral. A 2000A busway with a 200% neutral will carry 1550 amperes on the phase bars and 3100 harmonic amperes on the neutral.

Larger busways must be used to have the same temperature rise as busways without harmonic neutral current.

REAL WORLD

In the paper by Thomas M. Gruss, 91% of the sites surveyed had a current of 70% of capacity or less. At 70% current, the temperature rise is about 50% that of rated current. This indicates that there is not a problem of overheating in most busway installations.

Heat tests were run with 0, 50, 100, 150 & 200% current in the neutral as well as balanced three phase current in the phase bars on a typical sandwich style busway. The current was adjusted to give the same 55°C hot spot temperature rise as required by UL. The hot spot was always in the joint. During the 0% neutral current test, the hot spot was B∅. This was only 6°C hotter than the neutral. Since the neutral is in the same sandwich package as the phase bars and the heat must go through the neutral by conduction to get to the housing, it has almost the same temperature rise as the phase bars. In fact, the housing next to the outer phase bar and the neutral is only slightly cooler. The whole assembly is like a single mass.

As the neutral current went up the difference between the phase bars and neutral bar temperature became smaller. At 150% neutral current they were the same, and at 200% neutral current the neutral was only 3°C hotter than the center phase bar and 2°C hotter than the adjacent phase bar. The extra heat being generated by the neutral is conducted quickly to the housing and the phase bars, and the temperature rise of the neutral bar does not go up appreciably compared to the phase bars.

Since the bars are within 3-6°C of each other in all cases, the insulation temperature is not affected any more with high neutral currents than with no neutral current as long as the busway is sized properly with neutral harmonic current.

This is true regardless of the type of insulation on the bars (130°C epoxy and some tape or 105°C mylar or PVC) since the heat transfer is similar on all sandwich style busways. The 130°C rated insulation will have a higher safety factor if the busway has harmonic currents, but the temperature rise of all the types of insulation will be affected the same.

The $I_{\varnothing H}/I_{\varnothing}$ obtained from these tests agree closely with the above theory.

NEC

The *NATIONAL ELECTRICAL CODE-1993* Table 310-16 **Ampacities of Insulated Conductors** Note 8(a) states:

More than Three Current-Carrying Conductors in a Raceway or Cable. Where the number of current-carrying conductors in a raceway or cable exceeds three, the allowable ampacities shall be reduced as shown in the following table:

For 4 through 6 conductors, the percent of values in the Tables is 80%.

Note 10. **Neutral Conductor** (c) states:

> On a 4-wire, 3-phase wye circuit where the major portion of the load consists of nonlinear loads such as electric-discharge lighting, electronic computer/data processing, or similar equipment, there are harmonic currents present in the neutral conductor and the neutral shall be considered to be a current-carrying conductor.

Article 100 **Definitions** defines a **Raceway** as follows:

> An enclosed channel designed expressly for holding wires, cables, or busbars, with additional functions as permitted in this code.
>
> (FPN): Raceway may be of metal or insulating material, and the term includes rigid metal conduit, rigid nonmetallic conduit, ..., surface race-ways, wire-ways, cable bus, and busways.

As can be seen, busways or wires in a conduit with high levels of neutral harmonic currents are only allowed to carry 80% of normal current. NEC probably assumes that the neutral conductor is the same size as the phase conductors, but even if it were larger, the assembly would only be allowed to carry 80% by the code.

This would be a safe multiplier for all busways considering they do not normally carry more than 70% rated current.

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