Reference: Analysis of Single-Phase Line-to-Line Loads on 3-Phase, 4-Wire Wye Systems

INTRODUCTION

The following article will explore the effects of adding single-phase, line-to-line loads on a 3-phase, 4-wire wye system. It is important to have an accurate understanding of installing Level 2 EVSE single-phase, line-to-line loads on a common 120/208-volt, 3-phase, 4-wire wye system due to the large growth projections of electric vehicle use in the near future. Failure to understand the loading effects will lead to improper sizing of feeders and services.

To fully understand the loading characteristics, electrical system properties must be used in addition to vector analysis. Examples of balanced and unbalanced loads are shown below. To meet the needs of customers, not all loads will be balanced. Unbalanced systems, while more complex, are as critical to understand as any other installation. In all examples, a neutral is shown but connected to the loads. On unbalanced loads, the neutral will carry the unbalanced load current and is needed for the feeder and service. All feeders are 3-phase, 4-wire, wye-systems, operating at 120/208 volts.

EXAMPLE ONE

A balanced installation consisting of three Level 2 EVSEs installed on a common 3-phase, 4-wire wye system is shown. **See Figure 1**.

It is a common mistake to calculate the line current on phases A, B, and C respectively by adding the branch-circuit currents of 32 amperes from two units supplied by branch-circuit conductors connected to the same phase conductor of the feeder. In reality, each line current is 120° out of phase with each other and therefore the currents cannot be added directly as in a single-phase system.

Another approach to accurately finding the line currents is necessary. Solving based upon power usage proves the following results:

Power for one unit:

$$32\text{ A} \times 208\text{ V} = 6{,}656\text{ VA}$$

Total power for three units:

$$3 \times 6656\text{ VA} = 19{,}968\text{ VA}$$

3-phase line current:

$$\frac{19{,}969\text{ VA}}{(1.732 \times 208\text{V})} = 55.42\text{ A}$$

Differing from the direct addition of the two branch-circuit currents. **See Figure 2**. The load connection is in a delta configuration. For delta systems, multiplying 1.732 by the phase current equals the line current.

3-phase line current:

$$32\text{ A} \times 1.732 = 55.43\text{ A}$$

Yielding the same results as the power calculation.

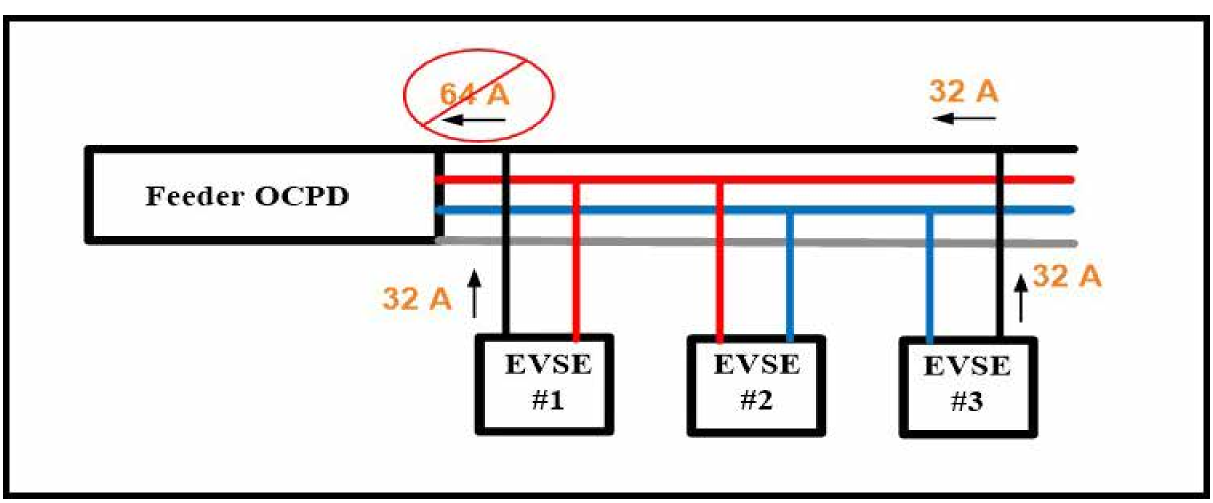

Figure 1. *This figure shows three Level 2 EVSEs on a balanced 3-phase, 4-wire system.*

Courtesy of the Electric Vehicle Infrastructure Training Program.

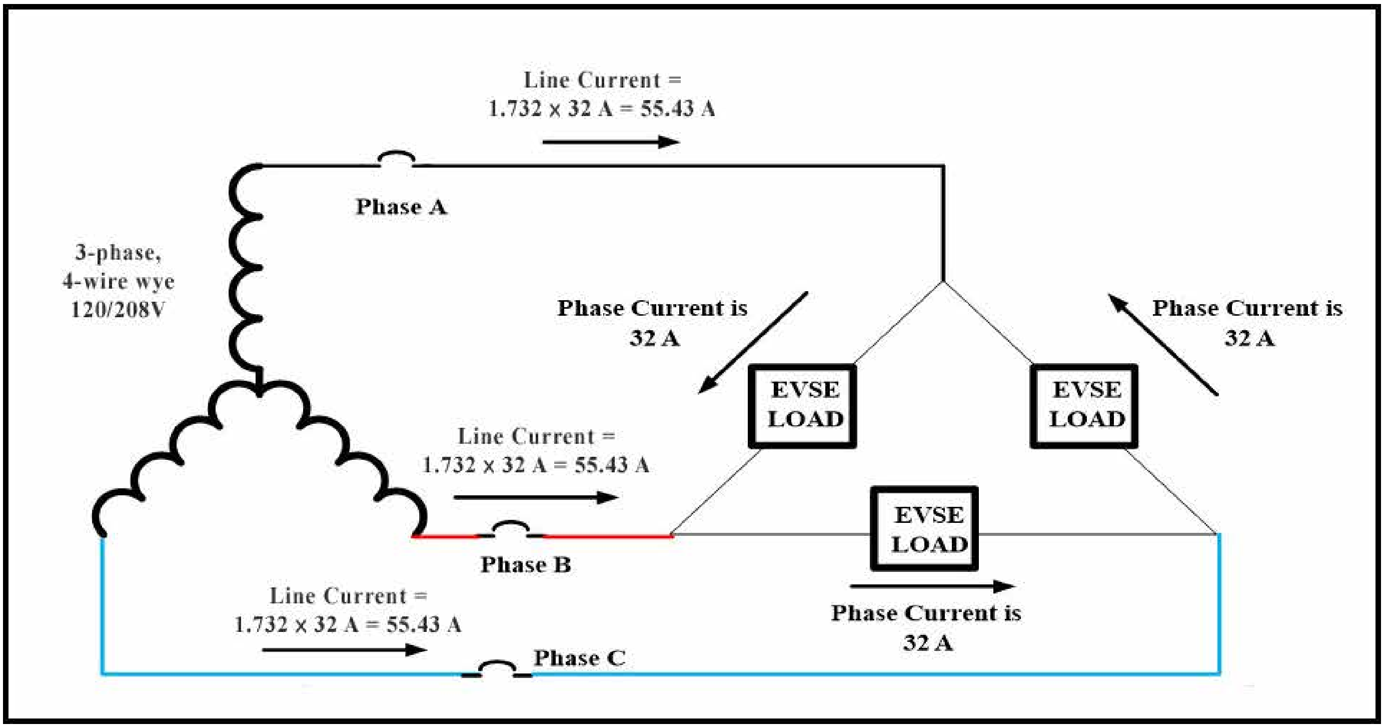

Figure 2. *Delta calculations may be used to determine the line current for loads connected in a delta configuration.*

Courtesy of the Electric Vehicle Infrastructure Training Program.

For a balanced system, determining the feeder line currents can be calculated correctly based on the addition of power used by each unit, or by using delta system equations. When unbalanced loads occur, calculations based on power will not yield accurate results for the feeder line currents due to the unbalance on each phase. The use of the 3-phase power formula assumes the line current is equal on all three line conductors.

$$P = 1.732 \times I \times E \times PF$$

Anytime Level 2 charging stations are installed or are operating on 3-phase wye systems, in other than multiples of three units distributed equally on the phases, unbalanced loading will occur.

For the operation of two Level 2 EVSEs, two units are installed or operating and the load is in an open delta configuration. **See Figure 3**. Phase B and Phase C line conductors will have 32 amperes respectively on each, as line and phase conductors are connected directly to each other. The line conductor for Phase A has two EVSE branch-circuit conductors connected to it, but with the currents 120° out of phase with each other, they will not add up directly to 64 amperes. Phase A line current can be found by using the delta system equation of 1.732 × 32 A = 55.43 A giving the correct line current. **See Figure 4.** The efficiency of the 3-phase system is evident with line currents of 55.43 amperes versus 64 amperes. It is an important consideration when adding Level 2 EVSE on a 3-phase system, and without it, may lead to oversizing of feeders and services.

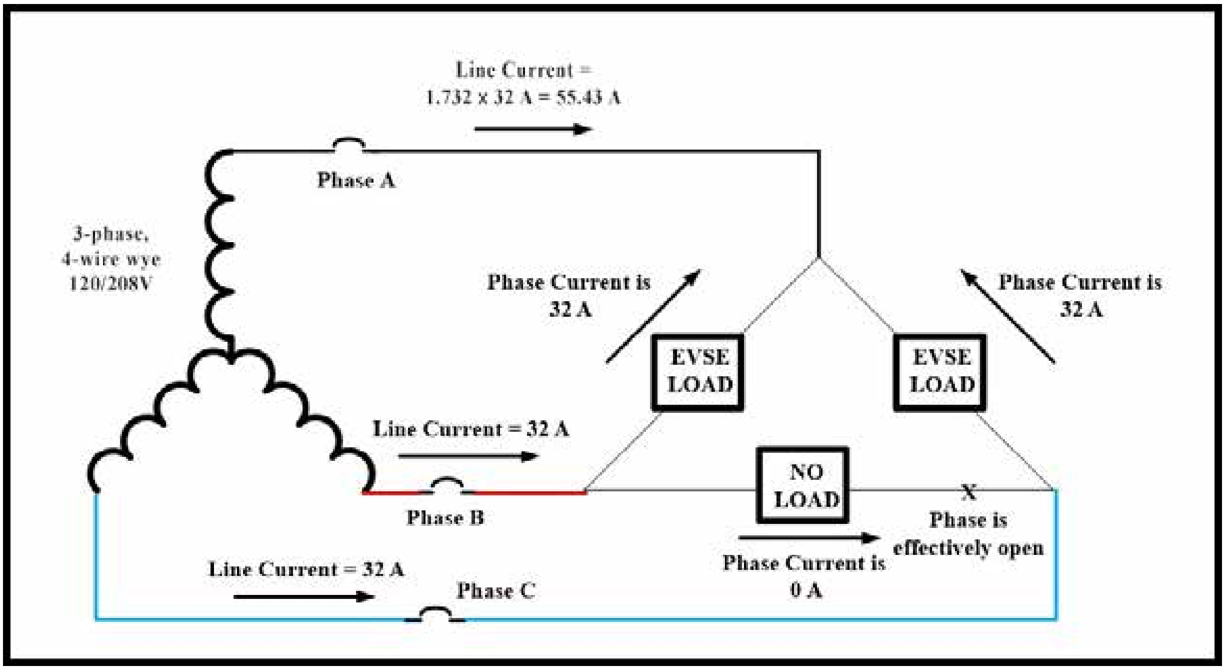

Figure 3. *Delta calculations can be used even on delta configurations where one phase is effectively open.*

Courtesy of the Electric Vehicle Infrastructure Training Program.

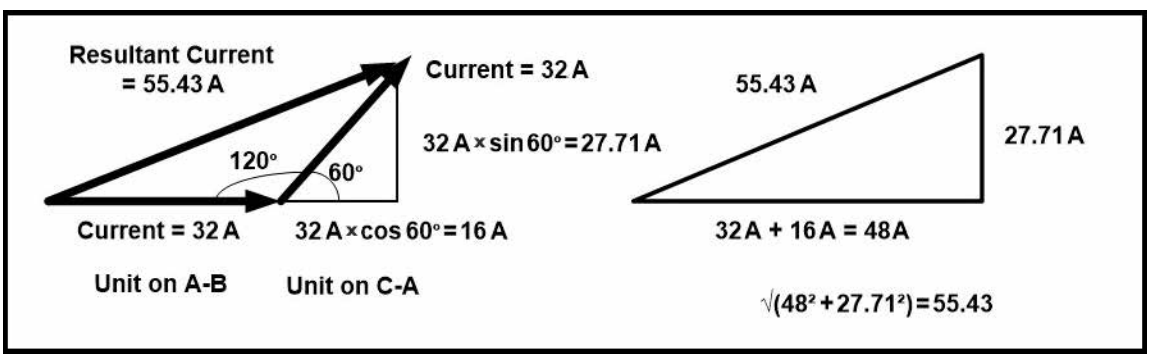

Figure 4. *A vector analysis can be useful in determining line current.*

Courtesy of the Electric Vehicle Infrastructure Training Program.

EXAMPLE TWO

Unbalanced loads, such as installing four EVSEs, may be more common than balanced loads. **See Figure 5**. Phase A to B will have two EVSEs, Phase B to C will have one EVSE, and Phase C to A will have one EVSE. For necessity of sizing feeders, services, or for the addition of EVSEs on existing loads, uneven loading needs to be considered.

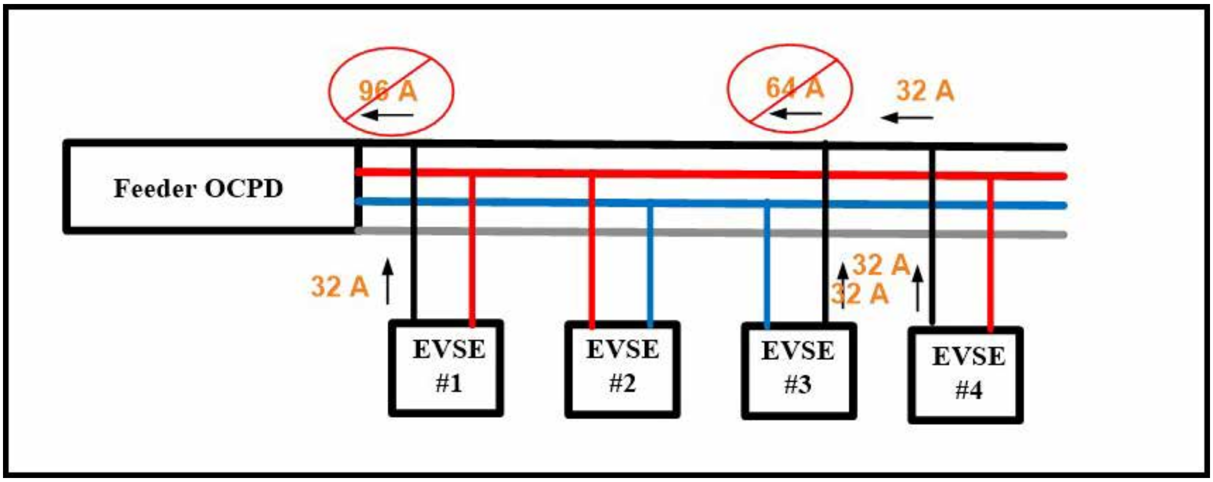

Figure 5. *Unbalanced loads, such as an installation of four EVSEs on a single 3-phase, 4-wire system, are more common than balanced loads.*

Courtesy of the Electric Vehicle Infrastructure Training Program.

With the 3-phase supply system, the line currents are not the result of adding the branch-circuit currents. For Phase C, since the two phase currents connected to it are equal, the Phase C line current can be determined with the same method as for a balanced load by multiplying 1.732 × 32 A = 55.43 A for line current. With unbalanced phase currents connected to the line conductors of Phase A and B, calculating the line current can be accomplished with the use of vectors. **See Figures 6 and 7**.

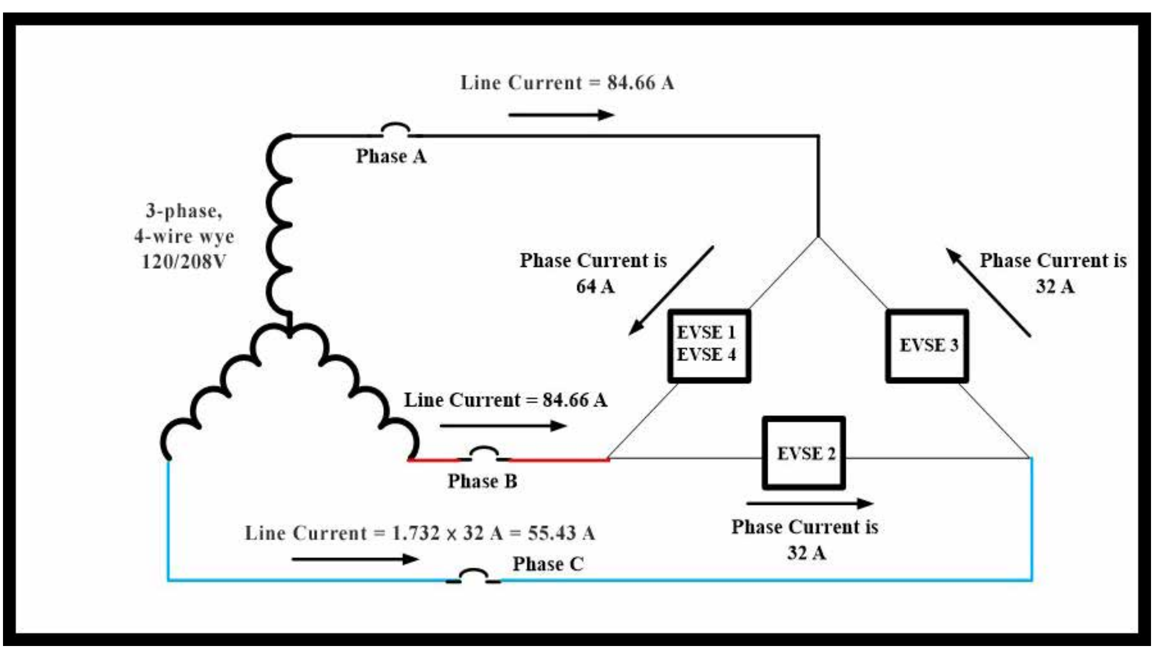

Figure 6. *The same delta calculations can be used for unbalanced and balanced loads in delta configurations.*

Courtesy of the Electric Vehicle Infrastructure Training Program.

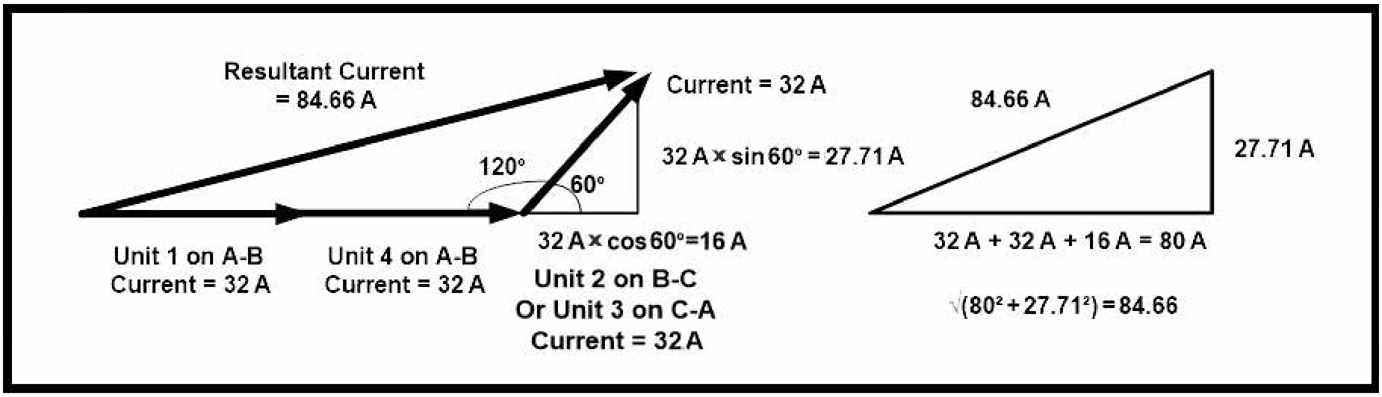

Figure 7. *Vectors can be used to calculate the line current for example two. The solution will be the same for both phases.*

Courtesy of the Electric Vehicle Infrastructure Training Program.

The resulting line current on Phases A and B, respectively, is the vector sum of two phase currents in phase with each other and one phase current 120° out of phase with the preceding two currents. Algebraically, the equation to solve for the line current on Phase A could be solved with the following equation:

$$I_{\text{lineA}} = \sqrt{\left[\left(I_{\text{phase a-b}} + (0.5 \times I_{\text{phase b-c}})\right)^2 + \left(0.5 \times \left(\sqrt{3}\right) \times I_{\text{phase b-c}}\right)^2\right]}$$

EXAMPLE THREE

The last example considers the supply of five Level 2 EVSEs on a 3-phase, 4-wire wye system. **See Figure 8**. It should be noted that line conductor Phase B now has four branch-circuit conductors supplying EVSE equipment and line conductors Phase A and C only have three branch-circuit conductors to EVSE equipment, respectively.

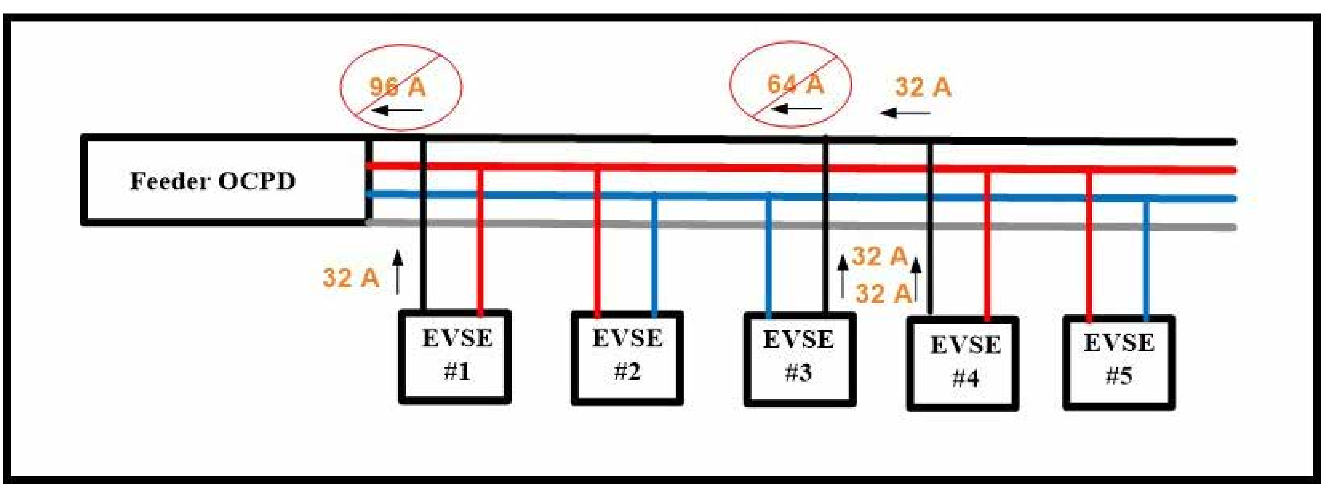

Figure 8. *Five Level 2 EVSEs on a 3-phase, 4-wire system create an unbalanced load which must be taken into account when calculating line current.*

Courtesy of the Electric Vehicle Infrastructure Training Program.

For Phase B, since the phase currents that supply it are equal at 64 amperes, Phase B line current can be calculated by multiplying 1.732 × 64 = 110.85 A, the same method used for balanced loads. **See Figure 9**. Line current for Phases A and C is more complex, but is made easy with the use of vectors. **See Figure 10**.

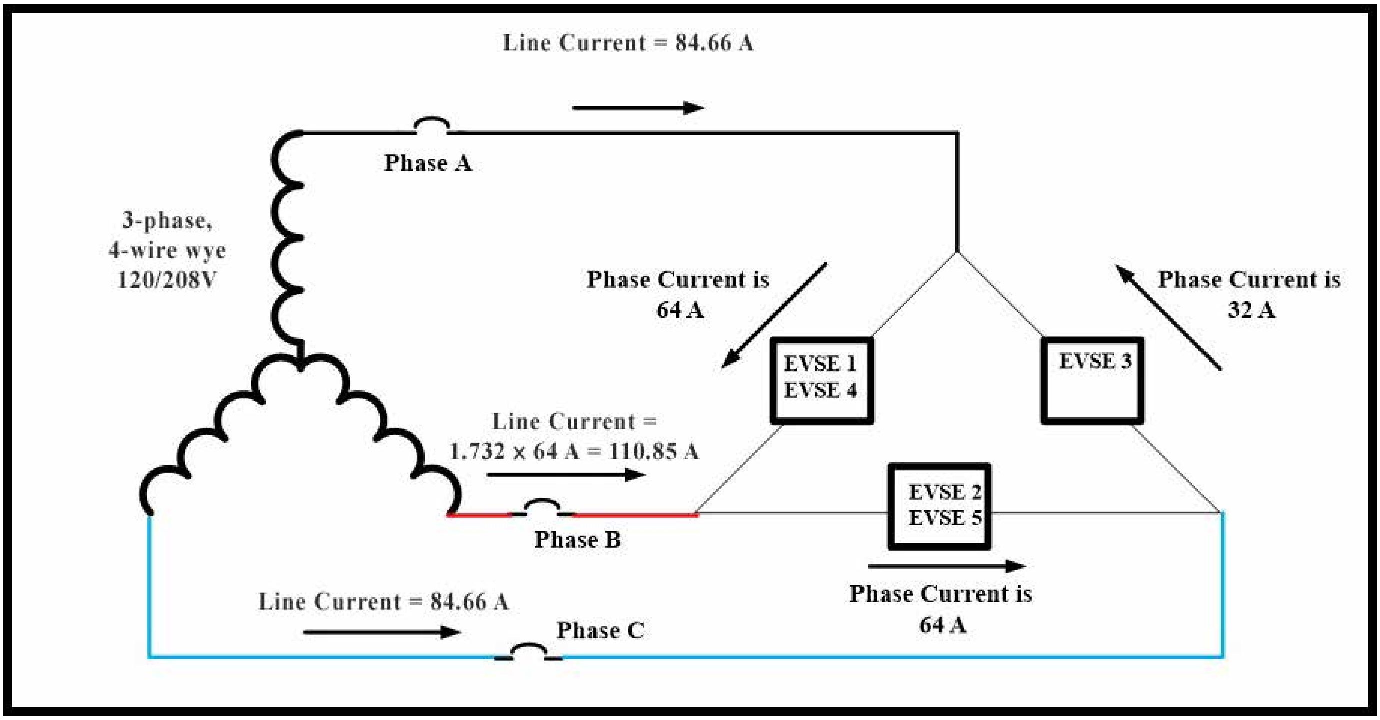

Figure 9. *The same methods used for balanced loads can be used for unbalanced loads connected in delta configurations.*

Courtesy of the Electric Vehicle Infrastructure Training Program.

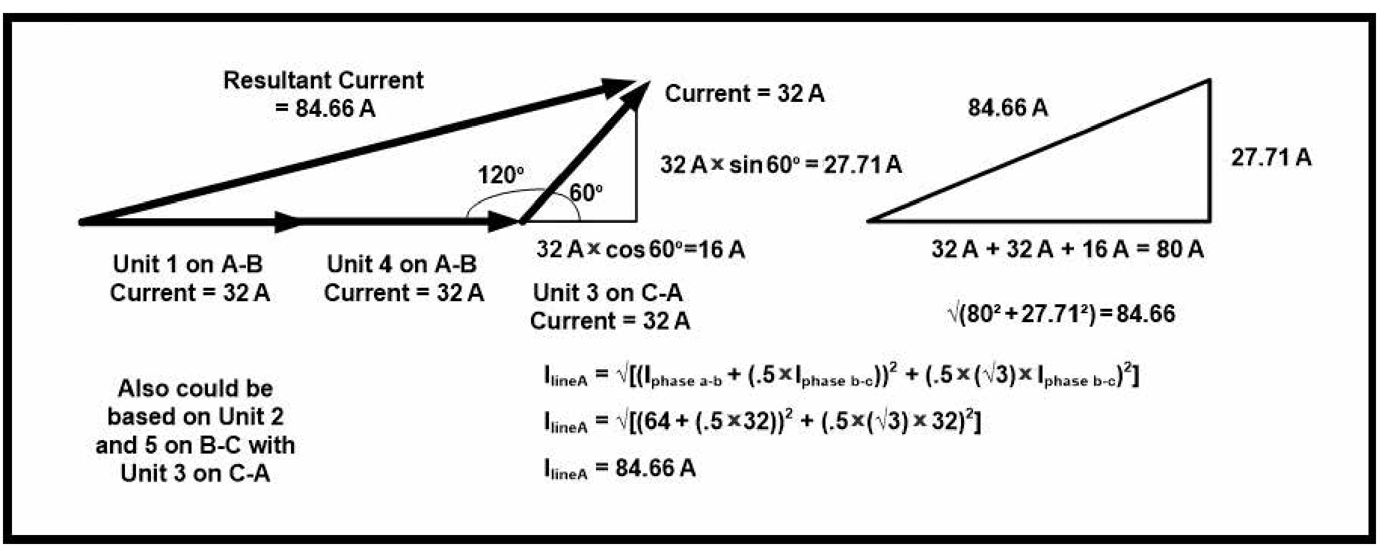

Figure 10. *Vector analysis may simplify the line current calculation process for unbalanced loads.*

Courtesy of the Electric Vehicle Infrastructure Training Program.

For unbalanced loads, vector analysis is essential for calculating line currents on 3-phase, 4-wire wye systems. Directly adding branch-circuit currents will lead to incorrect currents and improperly sized feeders and services. By correctly using vector sums to predict current levels, a qualified EVITP installer can optimize the loading of Level 2 charging stations on common 3-phase, 4-wire wye systems.