Applying Loads to Generators in UNBALANCED THREE-PHASE DELTA SYSTEMS

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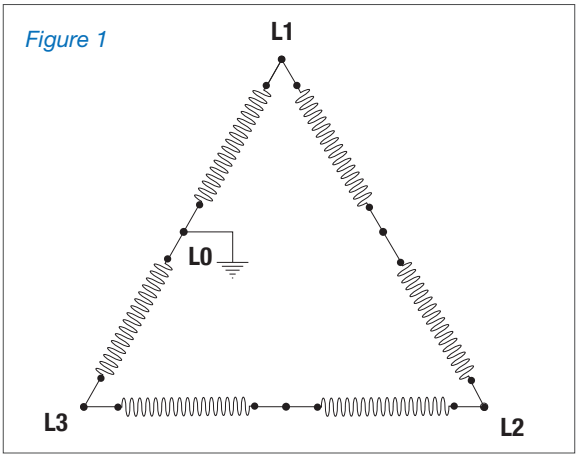
INTRODUCTION

When calculating three-phase systems, electrical engineers frequently assume that the loads to be carried will be evenly balanced across the coils detailed in Figure 1.

The problem is experience proves the opposite. Most of the systems we encounter have unbalanced loads. The most glaring example of this is the 120/240-volt three-phase delta system used for combinations of 120-volt and 240-volt single-phase loads and 240-volt three-phase loads. Unbalance is fundamental in this type of system, such as a supermarket with LED lighting and cash registers on single-phase and refrigeration and freezer motors on three-phase. In many systems today, the lighting is controlled via motion sensors, which create another factor to the balancing of the remaining loads.

3-PHASE DELTA WIRING DIAGRAM

Figure 1



3-PHASE DELTA SYSTEM VOLTAGES	
L1 TO L2	240 V
L2 TO L3	240 V
L3 TO L1	240 V
L3 TO L0	120 V
L1 TO L0	120 V
L2 TO L0	208 V

THE ISSUES TO BE ADDRESSED

SUPPLYING POWER TO EXISTING SYSTEMS

If generator manufacturers had their preference, this type of system would not be used. Unfortunately, we often find ourselves confronted with supplying standby power to an existing load of this nature.

It is relatively simple for the system designer connecting his load to a utility to select separate single-phase transformers for each of the three phases. However, the supplier of standby power for such a system has a problem. The three-phase windings of a generator are all equal in size, but we have very little control over the load. We would prefer a small single-phase load and a larger three-phase load, but that situation is rarely encountered.

PROBLEMS TO BE ADDRESSED

There are actually two problems. One, how do you avoid damage to the generator from the unbalanced load, and two, how do you avoid damaging three-phase motors connected to systems with unbalanced loads?

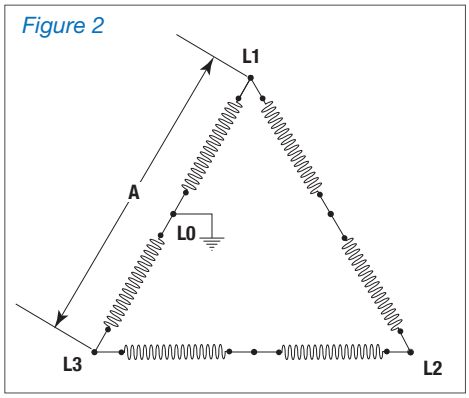
CONNECTING SINGLE-PHASE LOADS

CONNECTIONS TO A THREE-PHASE DELTA SYSTEM

Figure 1 shows a six-winding delta connected generator with three-phase terminals L1, L2 and L3 with a grounded neutral at L0. The system voltages are listed for reference. The 120/240-volt delta configuration is also unique in having a phase that has a higher voltage than the others. The L2 phase will be 208 V (phase to neutral/ground), which is also called high-leg or dogleg connection.

240-V 1-PHASE CONNECTIONS IN 3-PHASE DELTA SYSTEM

Figure 2



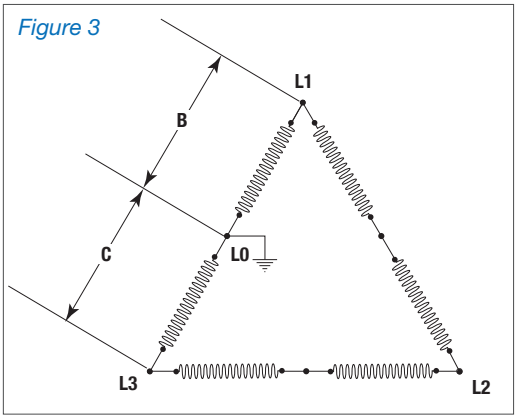
240 V 1-PHASE DELTA VOLTAGES		
A	L1- L3	240 V
	L1 - L2	240 V
	L2 - L3	240 V

LOAD "A" 240-V SINGLE-PHASE CONNECTIONS

Figure 2 shows the higher single-phase 240-V connection in a three-phase delta system. Load A is supplied not only from the windings between L1 and L0 and L0 and L3 but also those between L1 and L2 and L2 and L3. Current is higher in the L1 and L3 legs, but the system is not unlike the double-delta system which is frequently used for single-phase generator connection.

120-V 1-PHASE CONNECTIONS IN 3-PHASE DELTA SYSTEM

Figure 3



1-PHASE DELTA VOLTAGES	
B	120 V
C	120 V

LOADS "B & C" 120-V SINGLE-PHASE CONNECTIONS

A bigger problem can occur when loads are applied across B or C as shown in *Figure 3*. If load is applied at B only with nothing at C, the load has to be supplied by one of the six coils of the generator, therefore making it easy to overload one of the generator coils.

If a balancing load is connected at C, the problem is less severe. Equal loads at B and C act the same as load A. Thus, the first precaution is to make certain that loads at B and C are as nearly equal as practicable. Careful attention to these 120-V circuit load balances will avoid generator damage.

In any event, the total single-phase plus three-phase current on terminals L1, L2 or L3 should not exceed the current rating of the generator voltage unbalance.

CONNECTING THREE-PHASE LOADS

CONNECTIONS TO A THREE-PHASE DELTA SYSTEM

Up to this point, we have encountered no problems with furnishing satisfactory single-phase power to the loads. When we come to the three-phase loads in *Figure 4*, however, as at D, we do have a problem which we can do very little about.

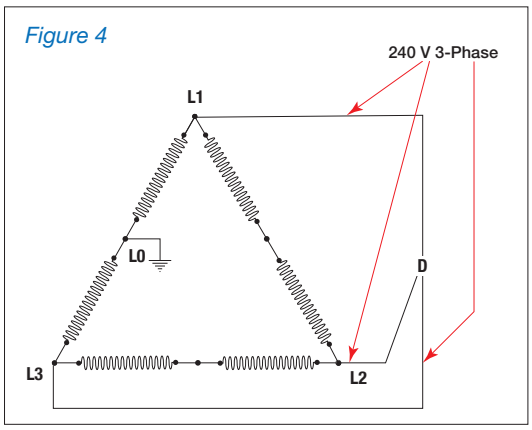
NEMA MG1, section 12.45, recommends that motor voltage unbalance should not exceed 1%. With single-phase loads equal to half the rating of the generator often encountered in these systems, the voltage unbalance in the three-phase lines is likely to be several times 1%.

NEMA prescribes a system whereby the motor must be derated if unbalanced voltages exist, so it doesn't overheat.

At 5% unbalance, the derate is 25%. The current unbalance at normal operating speed is stated to be 6 to 10 times the voltage unbalance.

3-PHASE CONNECTIONS IN 3-PHASE DELTA SYSTEM

Figure 4



3-PHASE DELTA VOLTAGES	
D	240 V

SUPPLYING AN OVERSIZED GENERATOR

SINGLE- AND THREE-PHASE MOTOR LOADS

As we become more conscious of motor efficiencies, this situation may get to be more critical as designers will tend to operate motors near their full-load rating.

The only thing that the generator supplier can do to alleviate this problem is to supply an oversized generator. (Even RMS three-phase sensing on the voltage regulation does not help balance the voltages.)

If single-phase loads are very heavy and if the three-phase motors involved are loaded up to their rating, an oversized generator is recommended.

SIZING FUNDAMENTALS FOR THREE-PHASE DELTA SYSTEMS

Key basic points of sizing are:

- Balance the loads between L1–L0 and L3–L0
- Try to keep the single-phase loads to less than 50% of the rating of the generator
- Keep the line current at any of the three terminals, particularly terminals L1 and L3, within the current rating of the generator
- Do not load connected motors beyond 80% of their full-load rating

ABOUT THE AUTHOR

Carson Bishop is a Senior Project Engineer at Kohler Co. He holds a bachelor of science in electrical engineering from Rose-Hulman Institute of Technology. Carson joined Kohler in 2018 and specializes in sustaining alternator design, large enclosure electrical design and National Electrical Code requirements.

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