Unbalanced Loads on Generators

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INTRODUCTION

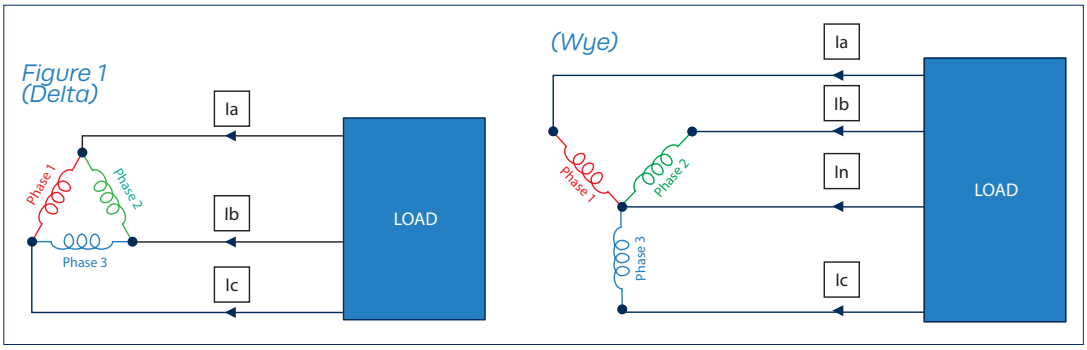
Power systems, including generators, often use voltage configurations that support the use of both three-phase and single-phase loads. Ideally, electrical loads are evenly distributed across all the phases. However, in most real-world applications, power systems rarely maintain perfect phase balance due to equipment characteristics and varying load demands.

Attention to balanced and unbalanced loads is critical for normal and safe generator operation. This white paper provides guidance on selecting and applying generators that supply power to unbalanced loads.

BALANCED VERSUS UNBALANCED LOADS

A balanced load is when power demand is equal across all three phases of the system. This means that phase currents and voltages are nearly identical, allowing the generator to operate evenly and efficiently.

Figure 1 shows 3 phase systems, Delta, and Wye, supplying power to a collection of loads. A balanced load occurs when currents Ia = Ib = Ic.

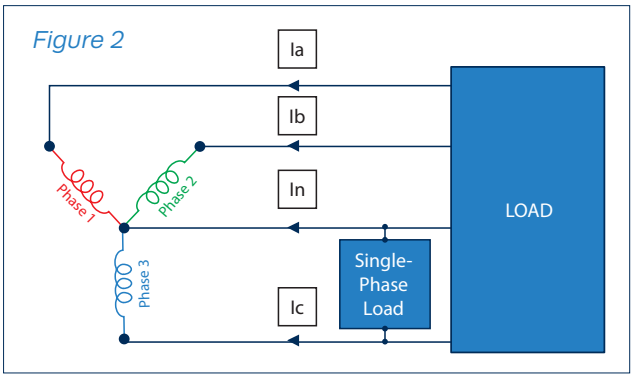


More commonly, load currents are unbalanced due to equipment characteristics and demand schedules. An unbalanced load profile is when the phase currents and voltages differ significantly from each other; Ia, Ib, and Ic are not equal. Unbalanced loads introduce electrical and mechanical stresses that can shorten a generator's life span.

WHAT CAUSES UNBALANCED LOADS

There are numerous causes for generator system load imbalance. Some sources of imbalance are:

- **Uneven single-phase load distribution:** Single-phase loads are unevenly distributed across the three phases, causing windings to carry more current than others. *Figure 2* shows the power system with an additional single-phase load connected between Phase 3 and neutral. This then draws power only on that phase and makes the system unbalanced.
- **Power factor variations:** Loads with different power factors connected to separate phases can also create imbalance, regardless of similar power magnitude.
- **Harmonic loads**: Non-linear loads generating harmonics can affect phases differently, magnifying imbalance if already present. Non-linear loads also introduce neutral currents that affect generator performance.



EFFECTS OF UNBALANCED LOADS ON GENERATORS

THERMAL EFFECTS:

Unbalanced currents cause asymmetrical heating in the generator windings, potentially exceeding insulation temperature ratings and leading to hot spots or fires in extreme cases. The increased heating in hot spots can cause the cooling systems of the generator to become less effective and propagate further hot spot generation.

MECHANICAL EFFECTS:

Currents forced through the neutral line and "Negative Sequence Voltage" can cause opposing magnetic fields in the alternator, resulting in fluctuations in torque, a decrease in efficiency, an increase in vibration, and bearing stress.

ELECTRICAL EFFECTS:

According to NEMA MG-1, generators must be derated (reduced capacity/output) by a certain percentage starting at 1% voltage imbalance on the load. Load imbalance causes irregular voltage drops across phases and can amplify generation of harmonic distortion.

PARALLELING EFFECTS:

Load imbalance often affects the 120° phase separation making it difficult or impossible to apply parallel supplies to the same load. Paralleling generators are commonly added in sequential order as the load increases, meaning that each sequential generator needs to match the same phase separation. If each generator has different phase angles, it will result in nuisance trips.

Additionally, unbalanced loads affect the entire system, resulting in cascading effects on the generator on the generator.

THREE-PHASE MOTOR PROBLEMS:

Even a small voltage imbalance applied to a connected three-phase motor can cause disproportionate current imbalances (generally 2% voltage imbalance -> 10-20% current imbalance). This causes efficiency loss, additional noise, increased vibration, and even damage or thermal events to connected motors.

SYSTEM-WIDE ISSUES:

Unbalanced loads reduce the effective power factor for whole systems as well as increasing line current losses. Additionally, the imbalance often causes voltage distortion which affects all connected equipment, especially sensitive equipment which may fail prematurely due to unbalanced loads on generators.

NEGATIVE SEQUENCE VOLTAGE:

Load imbalance commonly causes "Negative Sequence Voltage (current)" due to unequal phase-to-phase voltages that deviate from the expected 120° separation. This manifests in an alternator winding as a negative flow current that produces an opposing magnetic field.

WHAT CAN BE DONE TO PREVENT UNBALANCED LOADS

LOAD DISTRIBUTION PLANNING:

Deliberate assigning of single-phase loads across phases helps maintain balance and is the simplest solution for new designs. Load surveying and periodically recording loads on each phase helps to continue monitoring load as systems evolve.

TECHNICAL SOLUTIONS:

Common technical solutions generally include static or dynamic balancing equipment. These work by either passively or actively redirecting flow of current to align loads across phases, depending on equipment implemented. Automatic transfer switches may also act much like a dynamic balancer to monitor and balance loads on the generator.

In general, the simplest and most effective solution is to balance loads between L1-L0 and L3-L0. Balancing single-phase loads helps reduce the overall imbalance of the system. Additionally, keeping each line current at any point within generator rating and not loading generator motor above 80% capacity further assists in load distribution.

RECOMMENDATIONS

When considering a generator for a system, the first step is to make sure everything is done to have a balanced load. Qualified personnel should review load schedules to ensure that loads are connected to the power system as evenly as possible. Single phase loads should be evenly distributed between A, B and C phases as much as possible. It is important to understand the load profile the genset is intended for. This assists in the selection process and ensures the correct generator is installed in the application. Then choose a generator applicable to the needs. The Rehlko Power Solutions Center Sizing and Specification platform can help decide what generator is perfect for the application. www.pscweb.rehlko.com

When application of a generator is required for an existing unbalanced system, a larger generator needs to be considered. Choose the generator based on the unbalanced load. A more robust maintenance program should be developed to monitor the health of the generator.

SUMMARY

Generator systems rely on a load profile as balanced as possible. Unbalanced loads can shorten the life of a generator. Efforts should be made to make the load as balanced as possible before selecting the appropriate sized generator. When a generator is used on an existing unbalanced system, consider a larger generator and develop a more robust maintenance plan to monitor the health of the generator.

ABOUT THE AUTHORS

Samuel Koland is an Electrical Engineer at Rehlko. He is a graduate of University of Wisconsin–Stout who joined Rehlko in 2023 and is a part of the Sustaining Product Development engineering team, where he is responsible for providing electrical engineering support to industrial and marine generator products.

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ABOUT POWER SYSTEMS

Power Systems, Rehlko's largest division, delivers worldwide energy solutions designed to ensure resilience for mission–critical applications of all sizes. Building on more than a century of expertise and dedication, the company offers complete power systems, including industrial backup generators (HVO, diesel, gaseous), enclosures, hydrogen fuel cells systems, automatic transfer switches, switchgear, monitoring controls, genuine parts and end–to–end services. As a global company with service partners in every country, Power Systems provides reliable, cutting–edge technology to keep industries and businesses running.
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