Transferring Complex Loads On STANDBY GENERATOR SYSTEMS

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INTRODUCTION

Historically, during the first decades of power generation, standby generator sets were used almost entirely for emergency lighting. As the capabilities of these standby generator sets increased, so also did the scope of the loads on standby power: in the 1970s and 1980s, the industry observed dramatic growth in motor and pump dominant applications: water treatment plants, lift stations, etc.

This placed additional requirements on coordination of power transfer from utility and back to utility; simple double-throw contactors were no longer sufficient to reliably transfer these loads with high electromechanical inertia. A more complete analysis was required to avoid system derangement when transferring from one source to another, particularly when transferring from a standby source to a utility source.

MODERN DAY CONNECTED LOADS

SCOPE OF LOADS ON STANDBY POWER

In the modern day, standby generator sets are again seeing an increase in the scope of loads on standby power. The power generation industry is seeing capacitive loads and downstream transformers become more prevalent as facilities are becoming more complex and as data service industry growth continues. Fortunately, the factors concerning leading power factor loads and downstream transformers are well known so that the specifying engineer can analyze the application and correctly coordinate equipment.

CAPACITIVE EFFECTS

DOMINANT CAPACITIVE LOAD

The increasing population of dominant capacitive loads on standby power generation systems is a modern problem; most facilities' electrical networks have historically been comprised of resistive (e.g., lighting) and inductive (e.g., motor) loads. The unique response presented by a dominant capacitive load (e.g., uninterruptible power supplies, LED lighting) on start-up is that the power factor presented to the generator set is leading.

With a typical unity (resistive) or lagging (inductive) power-factor load, the response from the generator on application of this load is a dip in voltage and a dip in engine speed. If this frequency dip from the engine is sufficiently large, the modern voltage regulator compensates by reducing voltage (to reduce load) to allow the engine to recover (sometimes called a load acceptance or V/Hz feature).

With a dominant capacitive load, the response from the generator on application of this load can be a rise in voltage and a dip in engine speed. The alternator on the generator set is shifting from an under-excited regime to an over-excited regime; meanwhile, the engine is seeing a real power load and responding accordingly.

In this case, the voltage regulator is already fighting against alternator over-excitation, and there can be a delay in engaging load acceptance behavior to permit the engine to catch up. *Figure 1* illustrates the behavior of voltage and frequency when lagging power-factor loads are introduced.

Figure 2 illustrates the behavior of voltage and frequency when leading power-factor loads are introduced in consideration of leading power-factor transient behavior, a re-evaluation of traditional requirements around load application (e.g., dip, rise, overshoot, undershoot, recovery time) may be warranted by the specifying engineer. It should be noted, as well, that any leading power-factor load condition should consider the reactive capability curve of the alternator to avoid regions of instability and/or potential alternator damage.

APPLICATION OF MIXED LOADS

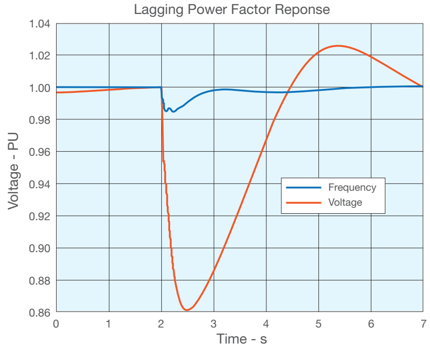
Not only do leading power-factor loads introduce a unique response under transient dynamics (e.g., load start-up or shedding), but they can and will have implications for steady-state operation.

If the capacitive element is not balanced across all three phases on a system (e.g., connected across phases A and B, or phase A to neutral), it will exacerbate any voltage imbalance the generator would present. This is a natural extension of the transient case:

a. With an inductive load applied, the voltage regulator needs to increase excitation to bring the voltage up to nominal.

b. With a capacitive load applied, the voltage regulator needs to reduce excitation to bring the voltage down to nominal.

Figure 1

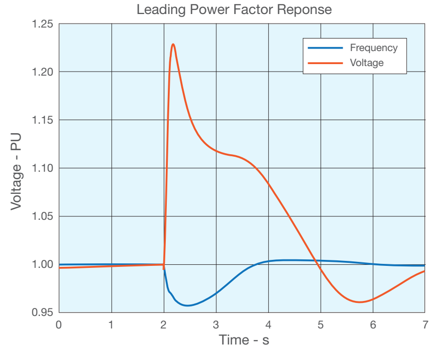


If mixed loads are applied (e.g., inductive and capacitive), the regulator must do the best it can to regulate all three L-L connections to nominal. Modern voltage regulators, such as the one built in the Kohler APM603, account for this with three-phase RMS sensing.

Invariably though, this will result in the inductive connection running a relatively lower voltage, the capacitive connection running relatively higher voltage, and the remaining connection somewhere in the middle—closer to nominal than the other two.

The aggregate average of the three RMS voltages (A-B, B-C, and C-A) will be regulated to nominal. In consideration of mixed loads, adjustments may be warranted by the specifying engineer: expanding traditional limits on unbalanced voltages, balancing voltages with power factor as a consideration, and/or adjusting limits to be single-phase focused with an emphasis on loads that are voltage sensitive. This must be done carefully and in consideration of other loads that may be sensitive to operating under unbalanced voltage conditions.

Figure 2



TRANSFORMER INRUSH:

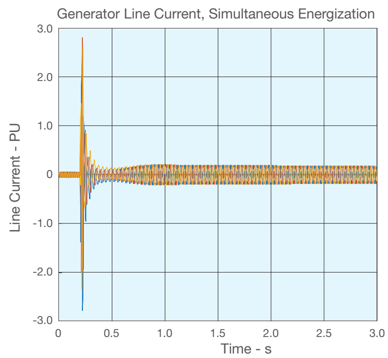
INCREASE IN COMPLEXITY OF FACILITY LOADS

An increase in facility complexity has given rise to larger and more complex arrangements of down-stream transformers than the standby power generation industry has historically seen. The rated kVA of these transformers can be as large as, if not larger than, the rating of the generator itself even though the standby loads downstream of the transformer(s) are well within the capabilities of the standby generator. In these cases, the major variable becomes transformer inrush current: can the generator energize the transformer(s)?

ANALYSIS OF FACILITY LOAD

Unfortunately, this question isn't a simple one to answer and can require some in-depth analysis, of which there are three major parts. Generator designers and manufacturers are inherently capable and equipped for the first part of the analysis: the source characteristics of the generator (e.g., sub transient reactance).

Figure 3



The second part of the analysis is associated with the characteristics of the transformer (e.g., zero sequence impedance, core hysteresis), and is unknown by the generator manufacturer.

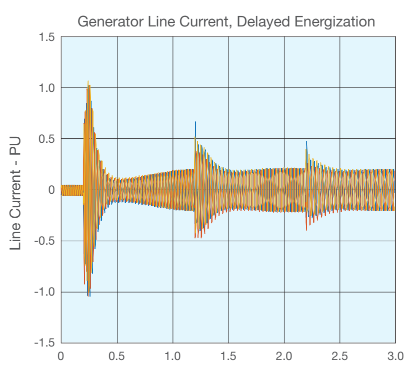
The third part of the analysis, again unknown to the generator manufacturer, is associated with the installation (e.g., load scenarios and grounding scheme, paralleled generators). With a complete picture of the subcomponents of the system, the specifying engineer is equipped to have an analysis completed to understand the power dynamics of his or her system as the transformers are energized.

MITIGATION STRATEGIES FOR SPECIFYING ENGINEERS

SEQUENTIAL STARTING OF TRANSFORMERS OR LOADS

If there are several transformers in the system whose simultaneous inrush characteristic is problematic, sequential starting can alleviate or mitigate some of the stress seen on equipment within the installation.

Figure 4



Additionally, after the first transformer is on line, it can provide additional stability to subsequent transformers. A time delay of approximately one second between starts is recommended. *Figure 3* and *4* illustrate an example for three transformers with a cumulative rating of 1.9 per unit of generator kVA. *Figure 3* shows generator line current during simultaneous energization; *Figure 4* shows generator line current with a delay of one second between energizations.

SIMULTANEOUS STARTING OF GENERATORS AND ENERGIZATION OF TRANSFORMERS

If the transformers are permitted to be energized as the generator starts, the effects of transient inrush current on the system will be mitigated. Modern voltage regulators are equipped with a load acceptance feature to ramp voltage as a function of frequency. This slope of voltage vs. frequency is normally utilized to assist with engine speed recovery on load application; however, it is beneficial in a simultaneous starting scenario as it enables a predictable ramp-up of voltage with engine speed. With this voltage ramp, energizing the transformer(s) does not cause excessive inrush current.

PARALLEL GENERATOR COORDINATION

If there are multiple generators in parallel in the installation, permitting several generators to be closed to the bus before energization of the transformers can reduce the effects of the transient event on the system. With this strategy, it should be understood that the system characteristics will change based on the number of generators sourcing in parallel; any harmonic studies should consider all permissible sourcing scenarios.

FINAL COMMENTS

The standby power generators of today are supplying a wider variety of loads than have been historically seen. Capacitive loads are defying the general assumptions of what a load application looks like and may require new or modified specifications.

Larger power networks are involving more voltages throughout the installation, requiring careful consideration of how to manage not only the loads, but also the equipment between the source and loads.

With careful planning and consideration of available strategies, capacitive loads and transformer inrush can be successfully managed to keep installations in power.

Be sure to consult your Kohler authorized representative for assistance with these designs.

ABOUT THE AUTHOR

Adam Larson is a Senior Staff Engineer at Kohler Co. He holds a bachelor of science degree (BSEE) from Milwaukee School of Engineering and master of science degree (MSECE) from Purdue University. Adam joined Kohler in 2010 and has contributed to electric machine design, power system analysis, and power electronics development during his career with Kohler. Adam is a member of IEEE and has authored papers on electric machine design and optimization.

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