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# Power Generation Fundamentals *for Water Utility*

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## INTRODUCTION

Water applications have unique power generation needs. This white paper will identify application needs specific to water and wastewater treatment, including applicable codes, standards, and installation requirements for low and medium voltage generators and paralleling switchgear.

We will discuss typical load profiles, how to size emergency power systems, and explain the key capabilities of power generation manufacturers.

# COMMON LOAD TYPES FOR WATER UTILITY

Water and wastewater treatment (WWT) applications have dynamic electrical loads that impact generator sizing. The single largest load and starting method drive the minimum electrical requirements for motor starting and corresponding alternator selection for the standby generator. Generator manufacturers typically offer multiple alternators on a single generator model to provide an oversized alternator when electrical loads have high motor starting requirements.

### COMMON TYPES OF WWT LOADS

The largest WWT loads include lift pumps, digester pumps, aeration blowers, return-activated sludge pumps, and membrane blowers. UV systems are often the second largest loads encountered, which are more environmentally friendly than chlorine treatment. UV loads are typically constant as they are not often cycled on and off.

### BIOLOGICAL ACTIVE FILTRATION (BAF) LOADS

Finally, a biological active filtration (BAF) process demands a constant plant flow. BAF does not allow treatment plants to throttle the million gallons per day (MGD) and fill during peak hours. Many end-users are now looking for non-emergency Tier 4 emission engine generators to peak shave utility demand or participate in incentivized programs.

Like utility power plants, water treatment plants work best with constant flow, requiring a lot of input, work, and coordination to modify the overall MGD output.

# SIZING GENERATOR CONSIDERATIONS

Overall minimum or maximum load requirements can impact longevity and life of the equipment and proper operation. Diesel engines running at low loads (less than 35% of the nameplate rating) for extended periods may experience performance issues when not maintained properly.

Failure to perform routine maintenance can cause excessive moisture in the oil, leading to scoring or glazing of the cylinder walls and excessive soot/un-burnt fuel in the overhead assembly and exhaust piping, also known as “wet stacking.”

Minimally loading gas generators can also be an issue, which is a regular misconception. At low loads, gas engines do not have enough cylinder pressure to maintain oil control in the cylinder, which allows oil to work past the rings into the combustion chambers, leading to ash deposits. If the unit operates below 30% for a brief period, it can be offset by exercising at high loads.

### MAXIMUM AVERAGE LOAD FACTOR

Another crucial factor to consider is the maximum average load factor. This is different from a generator power factor. The load factor is the average percentage loading viewed on a generator.  The average load factor is defined in ISO8528-1. Engine manufacturers specify a maximum average load factor for their engines for guidance in application.

This is important because exceeding the load factor impacts maintenance intervals (i.e. oil consumption) and overall durability/design life.

Sizing software like Kohler Power Solutions Center can assist with sizing the generator (https://powersystems.kohlerenergy.com/en/sizing-program).

## DIESEL VS. GAS TRANSIENT PERFORMANCE

Another factor that may impact the overall size of the equipment is the desired power quality performance of the equipment or acceptable voltage and frequency dips and time to recover. Highly inductive or capacitive loads may present a significant challenge to a generator when compared to an “infinite” utility source.

There is a difference in transient performance between diesel and gaseous fueled generators, and ISO8528-5 defines three class type standards (G1-G3) generator manufacturers use for each fuel type. Water applications often demand performance more stringent than these standards, which stems from the use of motor starting aids like VFD or soft starters and ensuring proper operation.

## STATIONARY AND MOBILE EMISSIONS

A transition is occurring in the industry where less utility scale generation is being produced due to coal plant retirements and increasing power demands on the infrastructure. Utility companies are now incentivizing end-users to install equipment that can operate at any time to counter demand or potentially even return surplus power back to the grid.

Larger water facilities with substantial megawatt (MW) installation bases are considering moving from emergency standby (Tier 2 or Tier 3) to Tier 4 certified engine generators required for operation in non-emergency applications. Any mobile (non-stationary) generators commonly seen at treatment plants and pump stations must also adhere to the EPA’s latest Tier 4 certified requirements. Incentives are offered by utilities for these peak shaving, curtailment, or demand response programs. Utility companies are even providing the equipment themselves on behalf of an end-user in instances for flexibility to control equipment operation times and reduce grid power demand for improved stability.

Understanding Tier 4 applications requires additional exhaust after-treatment components driving complexity with diesel oxidizing catalysts, selective catalytic reduction, and/or diesel particulate filters.

## LOAD STEP MANAGEMENT

The starting sequence of loads or load set management is an important consideration in balancing the starting and running loads to properly size the generator. As referenced above, the single largest load and starting method will drive required starting kilovolt-amps (sKVA) to select the correct alternator to use for a generator model.

Therefore, we must ask specific questions to understand the application and sequence of steps:

- How many loads are considered emergency or life safety loads?
- Are line input filters required to reduce line harmonics?
- How is the starting sequence initiated (e.g. SCADA System, ATS's, VFD Master Control, or other)?
- What is the rated MGD flow vs. Peak MGD flow vs. Seasonal MGD Flow considering peak ambient conditions?
- Do any loads have not-to-exceed voltage dip and frequency dip requirements to ensure proper operation?
- What is the starting method for each load? For example, is the intended method across-the-line or can a motor starting aid be used?

## MOTOR STARTING METHODS AND ALTERNATOR SELECTION

The starting method for a motor is a major factor to ensure a properly sized generator. A reduced method of start like a soft-start, VFD, wye-delta, or other may be a more cost-effective solution than up-sizing a generator to handle the large instantaneous load in an across-the-line start (ALS). In many cases with an ALS, any high horsepower motor will require such an oversized alternator that it will not work with the generator model sized for the running loads.

Figures 1 and 2 below iterate how a reduced voltage start method decreases the size of equipment. It also shows how input filtering or a higher quality VFD (18-pulse vs. 6-pulse) can mitigate overall harmonics on the alternator, reducing the size of equipment. Typically, assuring less than 10-12% total harmonic distortion (THD) ensures the VFD will stay engaged, but design engineers should reference and specify required power quality characteristics to avoid the VFD disengaging.

Figure 1

6-Pulse VFD vs Across the Line Starter

| HP | kW Genset Identified | | THD | | % Load | |
|---|---|---|---|---|---|---|
| | ALS | VFD | ALS | VFD | ALS | VFD |
| 20 | 80 | 50 | 7.72 | 8.56 | 26 | 46 |
| 50 | 150 | 80 | 0 | 12.6 | 27 | 55 |
| 60 | 200 | 100 | 0 | 11.35 | 25 | 53 |
| 70 | 200 | 100 | 0 | 13.08 | 28 | 62 |
| 80 | 200 | 125 | 0 | 11.31 | 32 | 56 |
| 90 | 200 | 125 | 0 | 12.51 | 36 | 63 |
| 100 | 200 | 125 | 0 | 13.9 | 40 | 70 |

Figure 2

18-Pulse VFD vs Across the Line Starter

| HP | kW Genset Identified | | THD | | % Load | |
|---|---|---|---|---|---|---|
| | ALS | VFD | ALS | VFD | ALS | VFD |
| 20 | 80 | 30 | 7.72 | 7.56 | 26 | 76 |
| 50 | 150 | 60 | 0 | 9.25 | 27 | 76 |
| 60 | 200 | 80 | 0 | 4.99 | 25 | 66 |
| 70 | 200 | 80 | 0 | 7.38 | 28 | 78 |
| 80 | 200 | 100 | 0 | 4.98 | 32 | 71 |
| 90 | 200 | 100 | 0 | 5.51 | 36 | 79 |
| 100 | 200 | 125 | 0 | 4.63 | 40 | 70 |

Another example of how the motor starting method affects the overall generator size is shown in Figure 3. Note that the generators can be between 100kW and 350kW, which can increase the equipment cost by up to 3 times what is required based on the starting method used.

## Figure 3

Example: Generator sizing for a 3-phase 100HP motor comparing different motor starting methods

| Starting Method | Motor Starting kVA (skVA) Demand | <20% voltage dip | <15% frequency dip | Optimum Diesel Generator Size | % Loading of the Generator | Comment |
|---|---|---|---|---|---|---|
| Across-the-line | 595 skVA | 13% | 2% | 350 kW | 23% (<35% = Wet Stacking) | 300 kW >15% voltage dip |
| Soft Start with 300% current limit | 280 skVA | 20% | 2% | 200 kW | 40% | The 180 kW GenSet gave >15% voltage dip |
| Soft Start with ramp | 238 skVA | 13% | 2% | 200 kW | 40% | |
| Wye-Delta | 196 skVA | 20% | 6% | 100 kW | 80% | |
| VFD (6 pulse) with ramp | 15.33 skVA | 2% | 1% | 125 kW | 69% (Running kW = 86.3kW) | With a 6-pulse VFD the 125 kW GenSet produced 12.8% voltage harmonics (VTHD) |
| VFD (12 pulse) with ramp | 15.33 skVA | 2% | 1% | 100 kW | 86% (Running kW = 86.3kW) | With a 12-pulse VFD the 100 kW GenSet produced 13.1% voltage harmonics (VTHD) |
| VFD (18 pulse) with ramp | 15.33 skVA | 2% | 1% | 100 kW | 86% (Running kW = 86.3kW) | With an 18-pulse VFD the 100 kW GenSet produced 7.4% voltage harmonics (VTHD) |

## HARMONICS IMPACT FROM INDUCTIVE AND CAPACITIVE LOADS

Non-linear loads can drive larger alternators within the system to manage harmonic distortion of the waveform. Harmonics (i.e. current harmonics) are created by non-linear loads. An alternator, depending on its characteristics, simply enhances or mitigates the voltage distortion (i.e. voltage harmonics) at its output terminals.

There are several alternator features that can be specified to mitigate harmonics.

- An alternator with lower sub-transient reactance will produce less voltage harmonics.
- Class H insulation offers better “cushion” than Class F insulation against overheating.
- A lower alternator temperature rise reduces the chances of overheating (e.g. 80C vs. 130C).
- An alternator & AVR assembly with the following design features can continue to function effectively in the presence of harmonics:
    - A permanent magnet generator (PMG) exciter
    - A pulse width modulated (PWM) automatic voltage regulator (AVR) with true root mean square (RMS) voltage measurement
- Non-linear loads with harmonic mitigating filters (this is not an alternator feature)

Please also reference the white paper Managing Emergency Generators with Non-Linear Loads.

## FUTURE EXPANSION

For water applications, current (Day 1) sizing needs are often compared to potential future state scenarios. Increased power demands are often a direct result of projected population growth and the need for facilities to handle the increase in related MGDs. The focus is to understand optimal sized equipment for Day 1 requirements, and standardize (when possible) generator models in multiple generator scenarios to allow modular plug-and-play for future equipment to address growth. This allows for commonality of parts, identical service requirements, familiarity with the same footprints, and HMI interaction with the equipment.

There are many benefits when connecting multiple generators together to act as a larger power source. Some of the advantages include:

- Redundancy
- Efficiency
- Different kW size generators
- Diesel + Gas combination
- Value & scalability

A few of the items to be cognizant of, however, would be space constraints for the multiple generator system, more complex O&M, and depending on the load scheme, additional complexity in the overall control system.

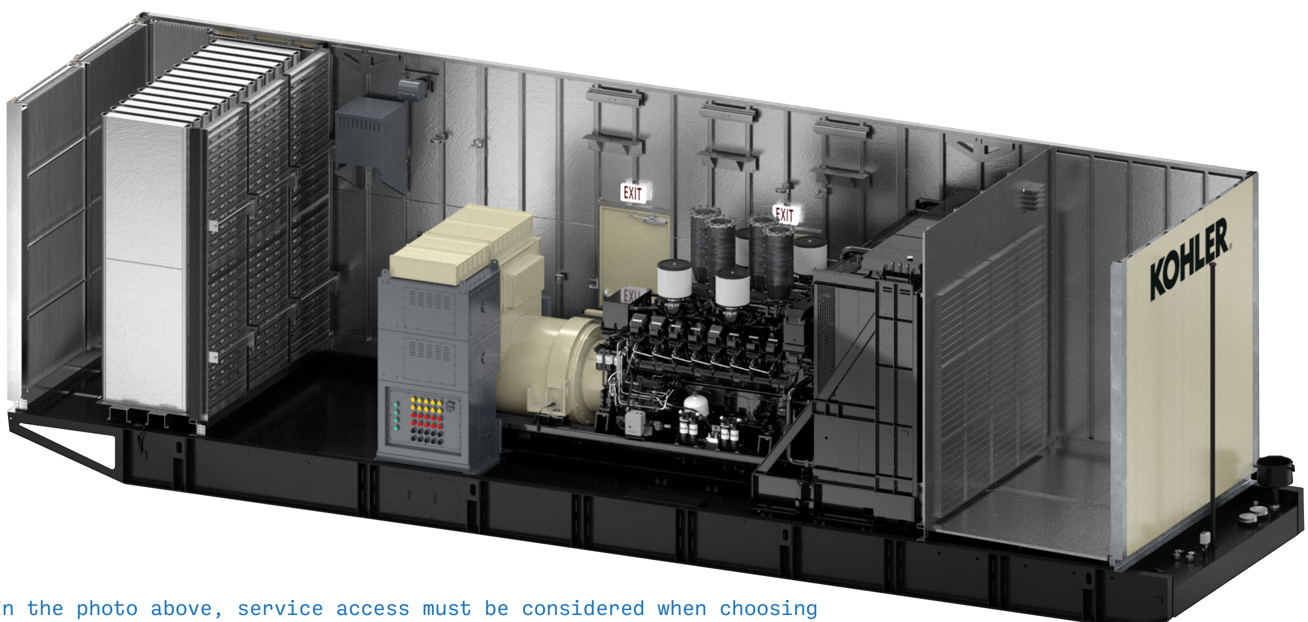
# FOOTPRINT AND PACKAGING

## FOOTPRINT CONSIDERATIONS

On larger projects, consideration must be made for low versus medium voltage generation. When generating at 5 or 15kV class it must be decided if it is preferred to have a disconnect at the generator or in a switchboard panel. This can be a fused disconnect or a medium voltage breaker; however, both are large sections of gear and drive custom packaging if desired inside the generator enclosure. See Figure 4.

Medium voltage automatic transfer switch (ATS) requirements can result in an increased packaging footprint. Manufacturer assistance early in the design phase can address variances in physical size, footprint, and power delivery voltage variances, clearly outlining LV or MV advantages and disadvantages. Medium voltage applications require a decision about where to locate and wire a fused disconnect (when desired), a potential neutral grounding resistor (NGR), as well as determining if it should be arc-resistant and understanding the required withstand ratings.

Figure 4




In the photo above, service access must be considered when choosing between low and medium voltage components which impacts the overall footprint of the power system.

Additionally, the generator controller acts as a human-machine interface (HMI), monitoring and protecting the engine and alternator. A controller with UL6200 is the latest standard for generator controls and may allow for the removal of the line circuit breaker on the generator, protecting against overcurrent conditions. It can also act as an energy reduction maintenance mode (ERMS) switching device, as now required by the latest code standards. Finally, a breaker-free generator with a UL6200 controller can facilitate short-circuit selective coordination.

## SOUND REQUIREMENTS

Sound performance is a critical aspect to consider. Some areas have local sound ordinances, which can be calculated when the generator installation location is known relative to the property line. It is normal to specify a sound rating at a distance (e.g. 75dBA at 7 meters), making it a performance-based requirement.

Using the terms “weather protective” or “sound attenuated” enclosure without the sound requirement leads to dissimilar products and proposals being compiled during the formal bid process which can cause delays. Understand that footprint impacts are increased when trying to achieve <75dBA average on larger diesel products. Intake bays with baffling and larger discharge plenums are required, which drastically grow the enclosure length. However, vertically discharging cooling air assists with mechanical fan noise and reduces the opportunity for recirculated heated air that could cause potential derates or even shutdowns.

## GENERATOR PACKAGING CONSIDERATIONS

The environment of a WWT plant may be corrosive in nature. Therefore, there are methods to reduce corrosion on the generator and accessories. Consider specifying NEMA 4X enclosures for ATS, coated radiator cores, and thixotropic vacuum pressure impregnated alternators.

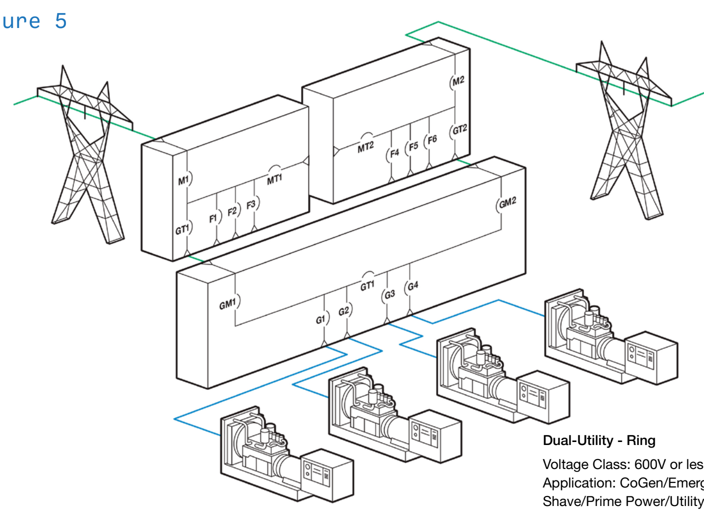
The desired run time for the equipment is used to properly size the fuel tank system which can include generator sub-base tanks, underground tanks, or a combination of both.

UL 2200 listed generator enclosure packages from the factory alleviate concerns with field inspectors on approval and avoid additional costs with 3rd party packaging which may require field certification.

## PARALLELING SWITCHGEAR AND SEQUENCE OF OPERATION

There are several common electrical designs for large water utility applications. This may be a basic ATS approach for simple systems all the way to complex dual utility ring bus designs - see Figure 5.

Figure 5




**Dual-Utility - Ring**

Voltage Class: 600V or less/Medium - 5kV / 15kV
Application: CoGen/Emergency Standby/Peak Shave/Prime Power/Utility Paralleling

Power Transfer Location: Switchgear

Consider partnering with a manufacturer who can offer seamless system integration and after-sales service support to provide:

- A sequence of operation submittal
- PLC programming instructions
- Factory tests
- Factory witness test documents
- SAT (site acceptance test)
- Final O&M manual

A Sequence of Operations Chart vs. Narrative approach has many advantages for engineers, contractors, and end users, including:

- Reduced submittal approval time
- Easier to read than a typical flowchart
- Clearly shows system response & failure modes
- Reduces mistakes in design and time in production

## FACTORY TESTING CAPABILITIES

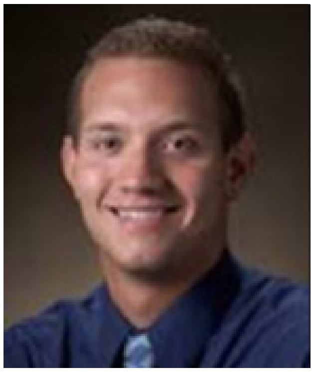
A manufacturer's test facility should allow comprehensive testing capabilities required for large complex paralleling switchgear systems including full-system resistive and 0.8 power factor tests with packaged generators and low or medium voltage paralleling switchgear and ATSs under one roof.

In the photo above, a long section of paralleling switchgear is tested at the Kohler factory with generators in the next room.

## KOHLER ADVANTAGES

Water and wastewater treatment is a unique application for power generation equipment. Kohler provides equipment and support tailored to those special needs including generator sizing and support, complete factory certified packages, and factory test capabilities for complex power systems.

Kohler has a vast distribution network to provide 24/7 service support for water utility applications. Reach out to your local KOHLER distributor to fulfill your project needs.



## ABOUT THE AUTHOR

Ross Kirschbaum, is an Engineered Solutions Sales Manager and Team Lead for the water focus segment. He has worked in Industrial Power Systems including manufacturing, application engineering, and technical design for more than 14 years. During this time, he has supported contractors, engineers, architects, and end users globally providing power system design consultations, engineering, project support, and custom solutions.

Large complex paralleling water projects were a primary focus during his 5 years within the Texas market. He speaks regularly at engineering seminars and industry events on diverse topics for mission critical applications including water, healthcare, and data centers.

## ABOUT KOHLER ENERGY

Kohler Energy, a global leader in energy resilience solutions, brings bold design and powerful impact to the energy systems that sustain people and communities everywhere around the world. The organization provides solutions across Home Energy, Industrial Power Systems, and Powertrain Technologies. Leveraging the strength of its portfolio of brands – Power Systems, Home Generators, Kohler Uninterruptible Power, Clarke Energy, Heila Technologies, Curtis Instruments, and Engines.

With more than a century of industry leadership, Kohler Energy builds resilience and goes beyond functional, individual recovery to create better lives and communities.

For more details, please visit kohler.com/energy.



PRINTED IN U.S.A. G26-57 KPS 146 06/24 