

Optimising Generator Sizing for Variable Speed Drive Pumping Systems Including Low Harmonic Drive Applications in Water and Wastewater Infrastructure

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Abstract

The increasing use of Variable Speed Drives (VSDs) in water and wastewater pumping infrastructure has significantly improved operational efficiency, process control and hydraulic optimisation. However, conventional 6-pulse Variable Speed Drives generate harmonic distortion and non-linear loading characteristics that create major challenges when operating from standby generator supplies.

Traditional generator sizing methods based purely on connected motor load are frequently inadequate for VSD-driven pumping systems. Harmonic currents generated by standard VSD rectifiers can result in excessive generator heating, voltage waveform distortion, unstable drive operation and nuisance tripping if generators are not correctly sized.

This paper examines the interaction between VSDs and standby generators in municipal water and wastewater applications. The paper further discusses the impact of low harmonic drives, harmonic mitigation techniques and practical generator sizing methodologies for both standard and low harmonic drive systems.

1. Introduction

The widespread adoption of Variable Speed Drives in municipal pumping systems has fundamentally changed the electrical characteristics of modern water and wastewater infrastructure.

VSD technology provides numerous operational advantages including:

- Improved energy efficiency,
- Reduced hydraulic shock,
- Better process control,
- Reduced mechanical stress,
- Optimised wet well operation,
- And improved pressure management.

At the same time, municipalities increasingly rely on standby generators due to grid instability and the critical operational requirements of water and sewer infrastructure.

While VSDs provide major operational benefits, they also introduce harmonic distortion and non-linear loading conditions that significantly affect generator performance. Incorrect generator sizing can result in unstable operation, excessive voltage distortion, overheating and unreliable operation of critical pumping systems.

2. Fundamentals of Variable Speed Drives

A Variable Speed Drive controls motor speed by converting incoming AC power into DC through a rectifier section before converting it back into a variable frequency AC waveform through an inverter section.

Most conventional drives utilise a 6-pulse rectifier arrangement. This creates harmonic currents that distort the incoming supply waveform.

Typical harmonics generated by 6-pulse drives include:

- 5th harmonic,
- 7th harmonic,
- 11th harmonic,
- 13th harmonic.

These harmonics result in non-linear current demand which differs significantly from conventional sinusoidal motor loading.

Unlike Direct-On-Line motors, VSDs draw current in pulses rather than smooth sinusoidal waveforms. This imposes additional stress on generator alternators and voltage regulation systems.

3. Harmonics and Generator Interaction

Harmonic distortion is one of the primary challenges associated with VSD-driven pumping systems operating from standby generators.

Total Harmonic Distortion (THD) may be expressed as:

$$\text{THD} = \sqrt{(V_2^2 + V_3^2 + V_4^2 + \dots + V_n^2)} / V_1 \times 100\%$$

Where:

- V_1 = Fundamental voltage component,
- V_2 to V_n = Harmonic voltage components.

High harmonic distortion may result in:

- Excessive generator heating,
- Voltage waveform distortion,
- Reduced generator efficiency,
- Alternator instability,
- Increased neutral currents,
- Premature equipment failure,
- And nuisance tripping.

Utility networks typically possess low source impedance and are therefore less sensitive to harmonic distortion. Standby generators, however, possess significantly higher impedance which amplifies harmonic effects.

This interaction between generator impedance and harmonic currents often results in severe voltage distortion at generator terminals.

4. Generator Behaviour Under VSD Loading

Generators supplying VSD-driven pumping systems experience significantly different loading characteristics compared to conventional motor loads.

The non-linear current demand imposed by VSD rectifiers introduces:

- Harmonic current distortion,
- Rapid transient loading,
- Poor waveform quality,
- Increased rotor heating,
- And instability of Automatic Voltage Regulators (AVRs).

One of the most critical issues is the interaction between generator sub-transient reactance and VSD front-end rectifiers. High generator impedance can lead to unstable DC bus voltages within the VSD resulting in:

- Under-voltage trips,
- Over-voltage trips,
- Drive instability,
- And pump shutdowns.

Generators that may appear adequately sized based on motor kW alone can therefore fail under harmonic loading conditions.

5. Conventional 6-Pulse Drives versus Low Harmonic Drives

Conventional 6-pulse drives are the most commonly used VSDs in pumping applications due to their simplicity and lower capital cost. However, these drives typically generate Total Harmonic Current Distortion (THDi) levels ranging between 35% and 45%.

Low Harmonic Drives (LHDs), Active Front-End Drives (AFE) and multi-pulse drive systems are specifically designed to reduce harmonic distortion. These systems typically achieve THDi levels below 5% under normal operating conditions.

Low harmonic drives achieve improved performance through:

- Active rectification,
- Harmonic cancellation,
- Advanced switching techniques,
- And improved input current shaping.

The reduction in harmonic distortion significantly improves compatibility with standby generators.

Benefits of low harmonic drives include:

- Reduced generator derating,
- Improved voltage stability,
- Reduced alternator heating,
- Lower neutral currents,
- Improved power factor,
- And reduced harmonic filtering requirements.

Although low harmonic drives generally involve higher capital cost, they may substantially reduce overall generator sizing requirements and improve long-term system reliability.

6. Generator Sizing Methodology for Standard and Low Harmonic Drives

Traditional generator sizing methods based purely on motor kW are inadequate for modern VSD pumping systems.

Generator sizing must consider:

- Harmonic distortion,
- Voltage dip performance,
- Transient response,
- Generator impedance,
- Simultaneous loading,
- Alternator heating,

- And future expansion.

Example 1 – Conventional 6-Pulse VSD:

Consider a 110 kW sewage pump operating through a standard 6-pulse VSD.

Assume:

- Motor load = 110 kW,
- VSD efficiency = 96%,
- Power factor = 0.95,
- THDi = 40%.

The apparent power demand becomes:

$$\text{kVA} = \text{kW} / (\text{Efficiency} \times \text{PF})$$

$$\text{kVA} = 110 / (0.96 \times 0.95)$$

$$\text{kVA} \approx 121 \text{ kVA}$$

Due to harmonic distortion and transient performance requirements, a generator derating factor between 1.8 and 2.2 is commonly applied.

Therefore:

$$\text{Required generator size} \approx 121 \times 2.0$$

$$\text{Required generator} \approx 242 \text{ kVA minimum.}$$

In practical municipal applications, additional margin is normally applied resulting in a generator size of approximately 275 kVA to 300 kVA.

Example 2 – Low Harmonic Drive:

Consider the same 110 kW sewage pump operating on a low harmonic drive with THDi below 5%.

The fundamental load remains approximately 121 kVA, however harmonic distortion and transient loading are significantly reduced.

Typical generator derating factors may reduce to between 1.2 and 1.4.

Therefore:

$$\text{Required generator size} \approx 121 \times 1.3$$

$$\text{Required generator} \approx 157 \text{ kVA minimum.}$$

In practice, a generator between 180 kVA and 200 kVA may be suitable depending on operating conditions.

This demonstrates how low harmonic drives may significantly reduce generator sizing requirements and improve system stability.

7. Harmonic Mitigation Techniques

Several methods may be used to reduce harmonic distortion in VSD pumping systems.

Common mitigation techniques include:

- Line reactors,
- DC chokes,
- Passive harmonic filters,
- Active harmonic filters,
- 12-pulse drive systems,
- Isolation transformers,
- Active Front-End Drives,
- And low harmonic drives.

Line reactors and DC chokes are commonly used in municipal applications due to their simplicity and lower cost.

Active harmonic filters and low harmonic drives provide superior harmonic performance but involve higher capital expenditure.

The selection of harmonic mitigation methods should therefore form part of the overall lifecycle and reliability assessment of the pumping system.

8. Operational Considerations in Pumping Systems

Water and wastewater pumping systems present unique operational challenges for generator sizing.

These include:

- Duty and standby pump operation,
- Simultaneous VSD operation,
- Wet well level control,
- Hydraulic transients,
- Emergency bypass operation,
- And varying inflow conditions.

Rapid load fluctuations associated with pump sequencing can create significant transient loading on generators.

Generator systems must therefore be designed not only for steady-state operation, but also for dynamic operational conditions experienced during pump cycling and varying flow conditions.

9. Recommended Engineering Approach

Accurate generator sizing for VSD-driven pumping systems requires a detailed engineering assessment rather than simplified connected load calculations.

Recommended methodology includes:

- Detailed load schedules,
- Harmonic studies,
- Voltage dip analysis,
- Generator transient analysis,
- Motor acceleration studies,
- Diversity assessment,
- Harmonic mitigation evaluation,
- And future expansion considerations.

Proper coordination between:

- Electrical engineers,
- Mechanical engineers,
- Pump suppliers,
- VSD manufacturers,
- And generator suppliers

is essential to ensure reliable operation.

Failure to adequately coordinate these disciplines frequently results in undersized generators, unstable operation and increased commissioning costs.

10. Conclusion

The increasing use of Variable Speed Drives in water and wastewater infrastructure has introduced significant challenges in standby generator design and sizing.

Traditional generator sizing methods based solely on connected motor load are inadequate for modern VSD-driven pumping systems due to harmonic distortion and non-linear loading characteristics.

Conventional 6-pulse drives typically require substantial generator derating due to harmonic current distortion and transient performance limitations. Low harmonic drives, however, can significantly reduce generator sizing requirements while improving voltage stability and operational reliability.

Reliable operation requires careful consideration of:

- Harmonic generation,
- Generator impedance,
- Voltage distortion,
- Harmonic mitigation,
- And dynamic operating conditions.

In modern pumping infrastructure, generator sizing can no longer be based solely on motor kW. Proper engineering assessment of harmonic interaction between VSDs and standby generators is essential to ensure reliable operation of critical water and wastewater infrastructure.

References

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