Data Center Design Challenges: Specifying Standby Generator Set Requirements

PowerHour webinar series for consulting engineers
Experts you trust. Excellence you count on.

July 30, 2:00pm Eastern Time / 11:00am Pacific Time
(1 PDH issued by Cummins Inc.)
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- If the audio connection is lost, disconnected or experiences intermittent connectivity issues, please check your audio connection through the "Join Audio" or "Audio Connectivity" button at the bottom left of the Zoom application.
- Report technical issues using the Zoom Q&A Panel.
Meet your panelists

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Technical Advisor - Data Center Markets
Cummins Inc.

Cummins facilitator:

Michael Sanford
Product Strategy and Sales Enablement Leader
Cummins Inc.

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Participants are encouraged to refer to the entire text of all referenced documents. In addition, when in doubt, reach out to the Authority Having Jurisdiction.
Course Objectives

Data Center Design Challenges: Specifying Standby Generator Set Requirements

Data centers around the world have developed unique power system designs ensuring top tier reliability and cost effectiveness. In addition to their unique design, load profiles in data center applications often differ significantly from their industrial or traditional standby counterparts. In many cases, data center power systems tend to operate much closer to 1.0 power factor, even operating with a leading power factor in some instances, varying from the industry standard of specifying equipment at 0.8 lagging power factor. Additionally, data center power systems may include active power loads making load acceptance challenging for most standby generator sets as conventional methods for starting large motor loads may not be effective. Making power system design even more challenging, many loads in data centers are non-linear leading to harmonic voltage distortion. This PowerHour will explore some of the typical load characteristics that are unique to data centers and will recommend generator set specifications that may help in mitigating some of these challenges.

After completing this course, participants will be able to:

• Identify safe alternator operating zones on an alternator reactive capability chart to ensure proper operating conditions on the generator

• Recognize the differences in generator load acceptance of active power, unity power factor and conventional lagging power factor loads and define specification requirements and operating sequences for each type

• Describe the impact of non-linear loads on harmonics

• Recognize the tradeoffs in properly specifying an alternator for data center applications
What are some examples of data center power system design challenges you have encountered?
Data Center Loads

- **UPS:**
  - Rectifiers - Harmonics
  - Capacitive Filters – Leading PF

- **Transformer:**
  - Inductor – Lagging PF

- **Variable Frequency Drive:**
  - Rectifiers – Harmonics

- **Chillers & Fan Motors:**
  - Inductive – Lagging PF
  - Motor Starters:
    - Solid State - Harmonics

- **IT Load:**
  - SMPS – Leading PF, Constant Power
  - Rectifiers – Harmonics
Data Center Loads

**UPS:**
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Capacitive Filters – Leading PF

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**IT Load:**
- SMPS – **Leading PF**
- Constant Power
- Rectifiers –Harmonics
Alternator Operating Chart

Real Power (kW)

Leading VAR

Lagging VAR
Alternator Operating Chart

Leading PF

Lagging PF

Real Power (kW)

Leading VAR

Lagging VAR
Alternator Operating Chart

FIGURE 2 – Green area is normal operating range of a typical synchronous machine, yellow is abnormal but not damaging, and operating in

Semi-circle defines maximum alternator kVA
Alternator Operating Chart

Semi-circle defines maximum alternator kVA

Max excitation - limited by rotor heating

FIGURE 2 – Green area is normal operating range of a typical synchronous machine, yellow is abnormal but not damaging, and operating in
Alternator Operating Chart

Semi-circle defines maximum alternator kVA

Stability Limit

Max excitation - limited by rotor heating

FIGURE 2 – Green area is normal operating range of a typical synchronous machine, yellow is abnormal but not damaging, and operating in...
Alternator Operating Chart

- **Max excitation** limited by rotor heating
- **Semi-circle** defines maximum alternator kVA
- **Stability Limit**
- **Loss of voltage control**
Leading VAR Capability

Leading VAR capability ~ 0.3 pu
Leading VAR Capability

Leading VAR capability ~ 0.3 pu

Alternator rating is 4142 kVA

0.3*4142 = 1242 kVAR
Leading VAR Capability

Leading VAR capability ~ 0.3 pu

Alternator rating is 4142 kVA
0.3*4142 = 1242 kVAR

3 MW genset rating @ 0.8 PF =>3750 kVA

1242/3750 = .33

Leading VAR capability = .33 pu based on genset rating
Alternator Operating Chart

- Lower synchronous reactance (Xd) increases leading VAR capability
- Larger alternator will have lower Xd based on generator rating
Leading VAR Capability

Leading VAR capability ~ 0.35 pu
Alternator rating is 4464 kVA
0.35*4464 = 1562 kVAR

3 MW genset rating @ 0.8 PF
=>3750 kVA genset

1562/3750 = .41

Leading VAR capability = .41 pu
based on genset rating
Leading PF Takeaways

Key parameter is leading VAR, not PF

- Set reverse VAR protection accordingly
Leading PF Takeaways

Key parameter is leading VAR, not PF
- Set reverse VAR protection accordingly

Low kW, high leading VAR is a risk
- Avoid operation in this region
- Disconnect PF correction or filter caps
- Select “Gen mode” if UPS supports
Concept Check

Which of the following statements is true:

a) A generator set’s leading VAR capability can be determined from the alternator operating chart.
b) Generator sets can operate at any power factor as long as there are power factor correction capacitors in the system.
c) Generator sets can not operate at leading PF of less than .95.
d) Generator sets can produce full rated output at any lagging power factor.
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**Motor Starters:**
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**IT Load:**
- SMPS – Leading PF, Constant Power
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**UPS:**
- Rectifiers - Harmonics
- Capacitive Filters – Leading PF
UPS with Walk-In Function

Server Switched Mode Power Supplies are active loads

- Draw constant power
- As voltage drops current is increased
- V/Hz doesn’t help
UPS with Walk-In Function

Server Switched Mode Power Supplies are active loads

- Draw constant power
- As voltage drops current is increased
- V/Hz doesn’t help

UPS with walk-in allows gen to take on 100% active power load step

- Allows batteries to take the load initially and then ramp on to the gen
100% Constant Power Load Acceptance

Voltage

Frequency

Power on genset
100% Constant Power Load Acceptance

- UPS senses voltage and frequency excursion

**Voltage**

**Frequency**

**Power on genset**
100% Constant Power Load Acceptance

- UPS senses voltage and frequency excursion
- Transfers load to battery
100% Constant Power Load Acceptance

- UPS senses voltage and frequency excursion
- Transfers load to battery
- Genset voltage and frequency recover and stabilize
100% Constant Power Load Acceptance

- UPS senses voltage and frequency excursion
- Transfers load to battery
- Genset voltage and frequency recover and stabilize
- UPS ramps load on to genset
Unity PF Transients

- Transient performance is typically documented at 0.8 PF
- Acceptance testing is typically done with resistive load banks (1.0 PF)
- Resistive loads often result in worse voltage transients than inductive loads
Unity PF Transients

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- Acceptance testing is typically done with resistive load banks (1.0 PF)
- Resistive loads often result in worse voltage transients than inductive loads

**Testing at 0.8 PF**
- Inductance creates a lag in kW load hitting the engine
- Governor response limits frequency dip
- V/Hz voltage roll off is reduced
Transient Spec Recommendation

- Consider actual operating sequence
- Under what scenario will a 100% load acceptance be required?
  - Will this only occur in the event of a failover to a reserve gen?
  - Would a UPS walk-in function be more appropriate than a 100% load acceptance requirement?
- Specify realistic acceptance test
Transient Spec Recommendation

- Consider actual operating sequence
- Under what scenario will a 100% load acceptance be required?
  - Will this only occur in the event of a failover to a reserve gen?
  - Would a UPS walk-in function be more appropriate than a 100% load acceptance requirement?
- Specify realistic acceptance test

**Spec Note** Generator set manufacturer shall provide documentation from the manufacturer’s sizing software demonstrating compliance with specified transient limits.
Data Center Loads

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Harmonics and Non-Linear Loads

A load in which the relationship between current and voltage is directly proportional.

Load is switched on a sub-cyclic basis resulting in current that no longer conforms to the sinusoidal voltage.
Harmonic Distortion

Supply Type

6 Pulse

Current Waveform

I-THD = 29%

Switching current on a sub-cyclic basis results in a distorted current waveform
Harmonic Distortion

Supply Type

6 Pulse

Current Waveform

I-THD = 29%

Switching current on a sub-cyclic basis results in a distorted current waveform

Voltage Waveform

Transformer, SCR = 100

V-THD = 2.8%

The source (generator or utility transformer) induces current harmonic distortion on to the voltage waveform
Harmonic Distortion

Switching current on a sub-cyclic basis results in a distorted current waveform.

The source (generator or utility transformer) induces current harmonic distortion on to the voltage waveform.

Induced voltage harmonic distortion is proportional to source impedance (inversely proportional to short circuit ratio).

Supply Type

6 Pulse

Current Waveform

I-THD = 29%

Voltage Waveform

Transformer, SCR = 100

V-THD = 2.8%

Genset $X''_d = 12\%$, SCR = 8

V-THD = 34%
Harmonic Distortion

Switching circuit and the source impedance both affect voltage harmonic distortion.

Supply Type

6 Pulse

Current Waveform

- Transformer, SCR = 100
  - I-THD = 29%
  - V-THD = 2.8%
  - V-THD = 34%

18 Pulse

Current Waveform

- Genset X'' = 12%, SCR = 8
  - I-THD = 7.9%
  - V-THD = 1.4%
  - V-THD = 17%
Case Study
Harmonics at a Water Treatment Plant

- T1-3: 270 kVA isolation transformers, 460/460V, 5.3 Z at 170 C
- R1, R2: Line reactors, 3% Z at 60 hp
- VFD1-3: 250 hp 6 pulse PWM
- VFDTP1, VFDTP2: 60 HP, 6 pulse PWM
- MF1-3: Drive output (motor) filters
- HHP1-3: 250 HP vertical suction water pumps
- TP1, TP2: 60 HP pumps
Case Study

Harmonics at a Water Treatment Plant

*Reference - Generator Loading, Harmonics Monitoring and Mitigating Analysis in a Water Treatment Plant - Eddie Jones, PE; Larry Ray, PE; Tim Shuter, PE; Square D Engineering Services
Power System Harmonics

Key Takeaways

- Harmonic Voltage Distortion is a function of load generated current distortion and the source impedance
  - For a generator set source impedance is the subtransient reactance $X''d$
  - Harmonic distortion will be worse when running on a generator than on the utility

\[ V_{THD} = X \times I_{THD} \]
Power System Harmonics

Key Takeaways

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- Harmonic distortion does not impact performance of generator sets with PMG excitation

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Power System Harmonics

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  - Harmonic distortion will be worse when running on a generator than on the utility
- Harmonic distortion does not impact performance of generator sets with PMG excitation
- Use generator sizing software to select generator set that will keep harmonic distortion within acceptable limits
  - This results in an optimally sized alternator

$$V_{THD} = X \cdot I_{THD}$$

Order of Harmonic Component
Power System Harmonics

Key Takeaways

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  - For a generator set source impedance is the subtransient reactance $X''d$
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- Harmonic distortion does not impact performance of generator sets with PMG excitation
- Use generator sizing software to select generator set that will keep harmonic distortion within acceptable limits
  - This results in an optimally sized alternator

**Spec Note** Generator set manufacturer shall provide documentation from the manufacturer’s sizing software demonstrating compliance with specified harmonic distortion limits.
Concept Check

Which of the following statements is false:

a) The higher the Short Circuit Ratio, the lower the harmonics.
b) Generator Sets and Utility handle harmonics very similarly.
c) The lower the subtransient reactance (X”d), the lower the harmonics.
d) An 18 pulse rectifier induces less THDI% than a 6 pulse rectifier.
Concept Check

Which of the following statements is false:

a) The higher the Short Circuit Ratio, the lower the harmonics
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b) **Generator Sets and Utility handle harmonics very similarly**
c) The lower the subtransient reactance (X”d), the lower the harmonics
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# Temperature Rise

<table>
<thead>
<tr>
<th>Insulation system:</th>
<th>Class H throughout</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>3 Ø Ratings</strong></td>
<td>(0.8 power factor)</td>
</tr>
<tr>
<td><strong>60 Hz (wind)</strong></td>
<td></td>
</tr>
<tr>
<td>416</td>
<td>440</td>
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<tr>
<td>416 (12)</td>
<td>440 (12)</td>
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**Voltage Class**

<table>
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<th>&lt; 10 kV</th>
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<tr>
<td>Insulation Class</td>
<td>H</td>
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<tr>
<td>Total Temperature</td>
<td>180 C</td>
<td>160 C</td>
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<tr>
<td>Nominal Temp Rise</td>
<td>125 C</td>
<td>105 C</td>
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<tr>
<td>Nominal Ambient Temp</td>
<td>40 C</td>
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<td>Hot Spot Allowance</td>
<td>15 C</td>
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4464 kVA is maximum load for 180 C insulation class

125 + 40 + 15 = 180
## Temperature Rise

**Spec Note** Specify alternator temperature rise based on insulation class and ambient conditions.

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**125°C rise ratings**

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<th>@ 40°C</th>
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<tbody>
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4464 kVA is maximum load for 180°C insulation class

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Alternator Winding Type

Random/Wire Wound

- Wire bundles
- Easier manufacturing process
- Usually better waveform quality
- Less copper and steel to reach short circuit and motor starting capabilities

Form/Bar Wound

- Individual Copper Bars
- More difficult to manufacture
- Greater mechanical strength
- Greater dielectric strength
Alternator Winding Type

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- More difficult to manufacture
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- Greater dielectric strength

Spec Note Specify generator performance criteria, not manufacturing method.
Specification Example

**Specification Requirement:**
Alternator maximum subtransient reactance shall not be greater than 12%.

- Better harmonic performance
- Greater leading VAR capability
- Lower subtransient reactance

An oversized alternator may also have:
- Higher fault current
- Slower start time
- and may be more expensive!
Specification Example

Specification Requirement:
Alternator maximum subtransient reactance shall not be greater than 12%.

Reactances at genset rating (3750 kVA)
Synchronous = 2.4 pu
Subtransient = .126 pu
Specification Example

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Should an oversized alternator be selected?
An oversized alternator may have...
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- Greater leading VAR capability
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An oversized alternator may also have…
- Higher fault current
- Slower start time
- and may be more expensive!

Reactances at genset rating (3750 kVA)
Synchronous = 2.4 pu
Subtransient = .126 pu
Course Summary

Data Center Design Challenges: Specifying Standby Generator Set Requirements

- Identify safe alternator operating zones on an alternator reactive capability chart to ensure proper operating conditions on the generator.
- Recognize the differences in generator load acceptance of active power, unity power factor and conventional lagging power factor loads and define specification requirements and operating sequences for each type.
- Describe the impact of non-linear loads on harmonics.
- Recognize the tradeoffs in properly specifying an alternator for data center applications.

Recommendations

- Define the generator’s leading VAR requirements and identify the generator’s leading VAR capabilities. Specify alternator and operating sequences accordingly.
- Consider UPS walk-in function rather than oversizing generator set for full load acceptance.
- Specify transient requirements and acceptance test requirements that are representative of actual usage.
- Use generator set sizing software to evaluate harmonic requirements.
Additional Resources

Cummins White Papers
- Data Center Continuous (DCC) Ratings: A Comparison of DCC Ratings, ISO Definitions and Uptime Requirements (Nov 2019)
- Understanding ISO 8528-1 Generator Set Ratings (Nov 2019)
- Transient Performance of Generating Sets
- Specifying and Validating Motor Starting Capability

Cummins On-Demand Webinars
- Generator Set Ratings for Data Centers and Other Applications
- Common Failure Modes of Data Center Back Up Power Systems
- Using Fuel Cells to Address Energy Growth and Sustainability Challenges in Data Centers
- Advanced Generator Set Sizing Software: Transient Performance and Motor Load
Q&A

Please type your questions, comments and feedback in the Zoom Q&A window.

After the PowerHour, a complete list of questions and answers will be published on powersuite.cummins.com.

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Closing

Watch out for a follow-up email including:

- A link to the webinar recording and copy of the presentation
- A certificate issuing one professional development hour (1 PDH)

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Please contact Michael Sanford if you have any questions related to the PowerHour webinar (michael.sanford@cummins.com)

Upcoming PowerHour Webinars:

**August** – Emission and Air Permitting for Emergency Generator Sets

**September** – Ask the Experts: Transfer Switch Fundamentals

**October** – Emergency Power System Installations in Healthcare Applications