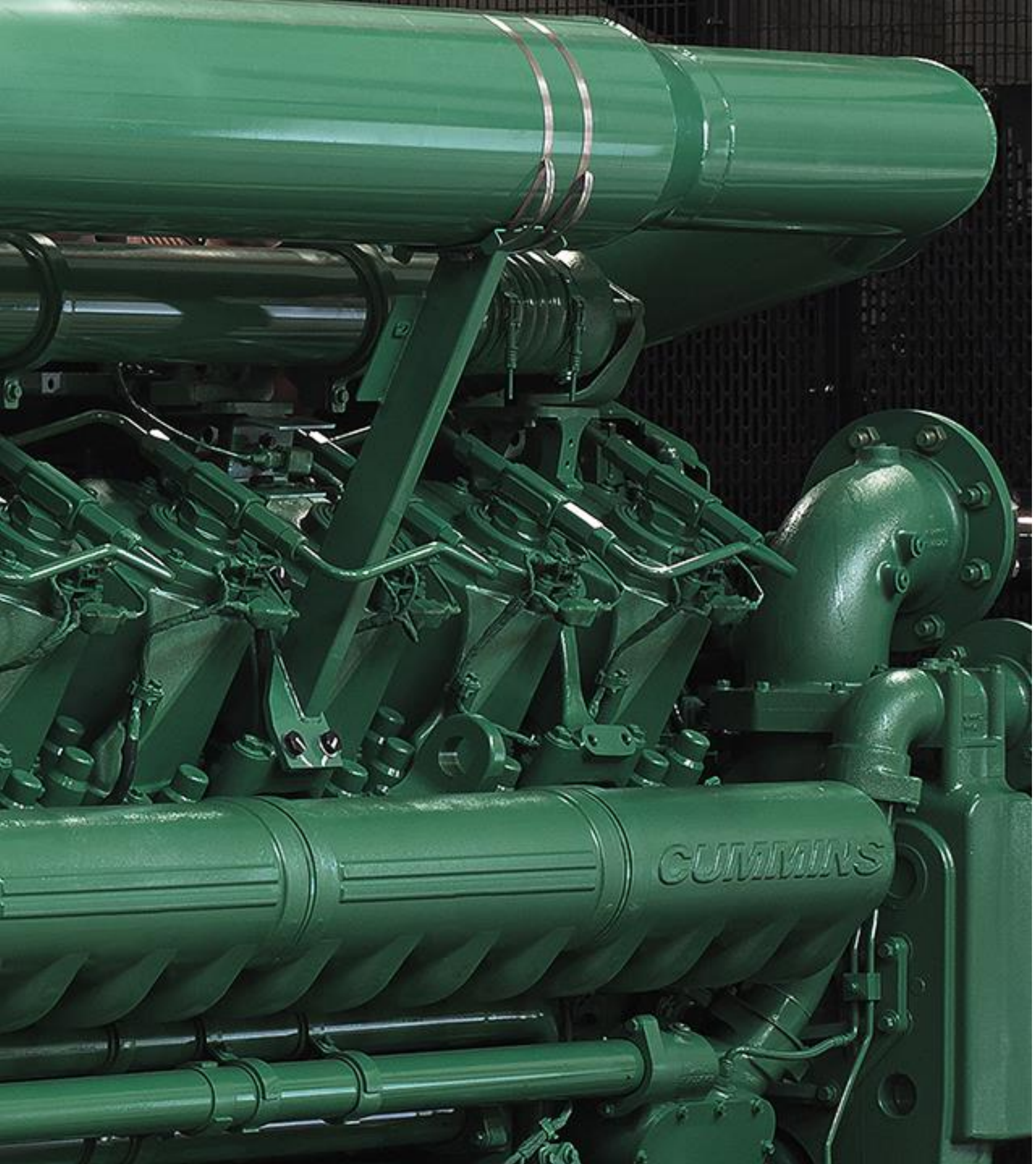

Cummins®

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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- Interact with Cummins experts and gain access to ongoing technical support
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- Attendees are in “listen only” mode throughout the event.
- Use the Zoom Q&A Panel to submit questions, comments, and feedback throughout the event. Time is allotted at the end of the PowerHour to address Q&A.
- 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

Cummins instructor:

Rich Scroggins
Technical Advisor - Data Center Markets
Cummins Inc.

Cummins facilitator:

Michael Sanford
Product Strategy and Sales Enablement Leader
Cummins Inc.

Your local Cummins contacts:

- AZ, ID, NM, NV: Carl Knapp (carl.knapp@cummins.com)
- CO, MT, ND, UT, WY: Christopher Scott (christopher.l.scott@cummins.com)
- CA, WA, OR, AK, HI: Brian Pumphrey (brian.pumphrey@cummins.com)
- MA, ME, NH, RI, VT: Jim Howard (james.howard@cummins.com)
- CT, MD, NJ, NY : Charles Attisani (charles.attisani@cummins.com)
- Northern IL, MI : John Kilinskis (john.a.kilinskis@cummins.com)
- NE, SD, KS: Earnest Glaser (earnest.a.glaser@cummins.com)
- IL, IN, KY, MO: Jeff Yates (jeffrey.yates@cummins.com)
- IA, MO: Kirby Holden (kirby.holden@cummins.com)
- DE, MD, MN, ND, OH, PA, WI, WV: Michael Munson (michael.s.munson@cummins.com)
- TX: Scott Thomas (m.scott.thomas@cummins.com)
- OK, AR: Wes Ruebman (wes.ruebman@cummins.com)
- LA, MS, AL: Trina Casbon (trina.casbon@cummins.com)
- TN, GA: Mariano Rojas (mariano.rojas@cummins.com)
- FL: Bob Kelly (robert.kelly@cummins.com)
- NC, SC, VA: Bill Morris (william.morris@cummins.com)
- Canada: Ian Lindquist (ian.lindquist@cummins.com)

Disclaimer

The views and opinions expressed in this course shall not be considered the official position of any regulatory organization and shall not be considered to be, nor be relied upon as, a Formal Interpretation.

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

Course Objectives

Data Center Design Challenges: Specifying Standby Generator Set Requirements

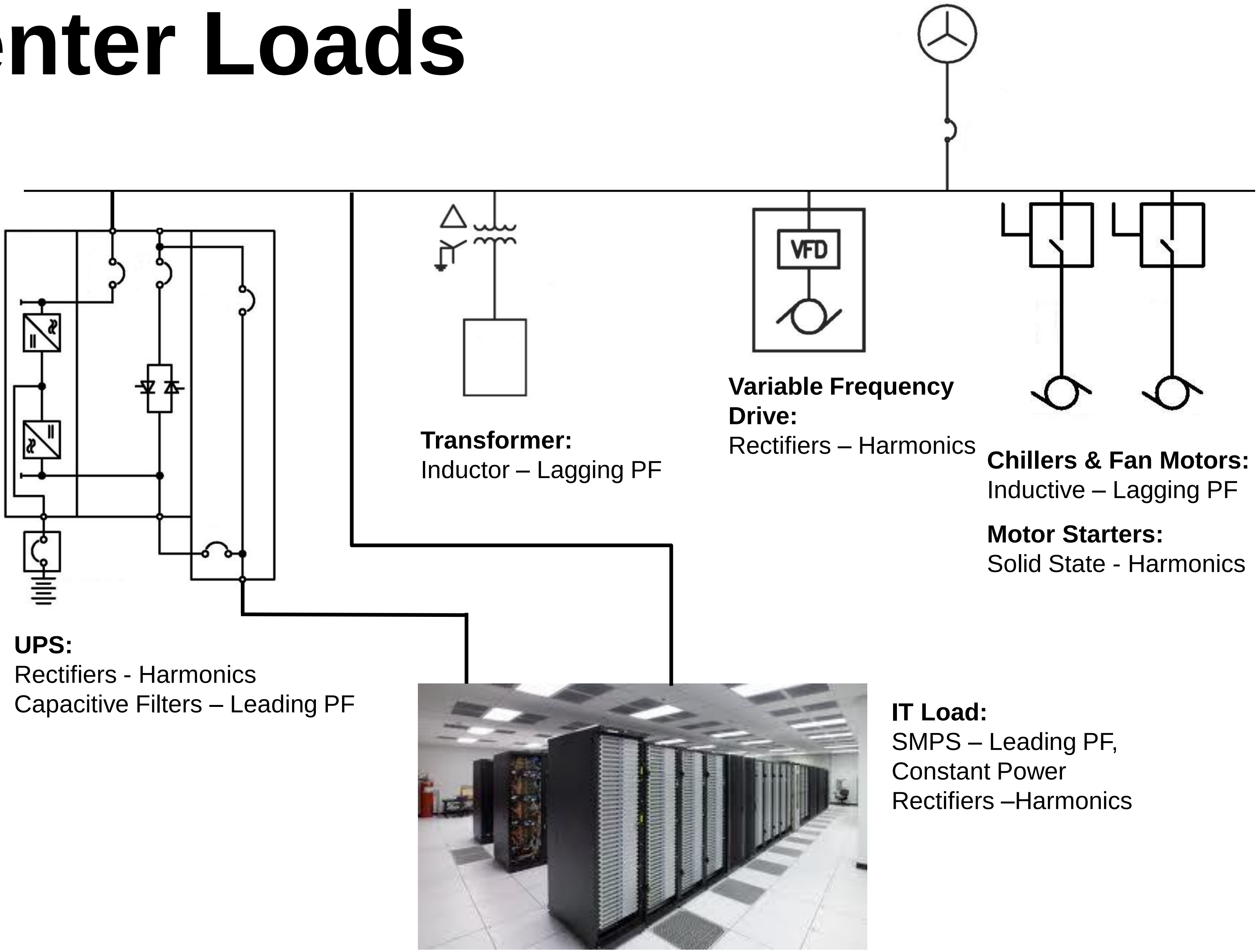
Data centers around the world have developed unique power system designs ensuring top tier reliability and cost effectiveness. In addition to their unique design, load profiles in data center applications often differ significantly from their industrial or traditional standby counterparts. In many cases, 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:

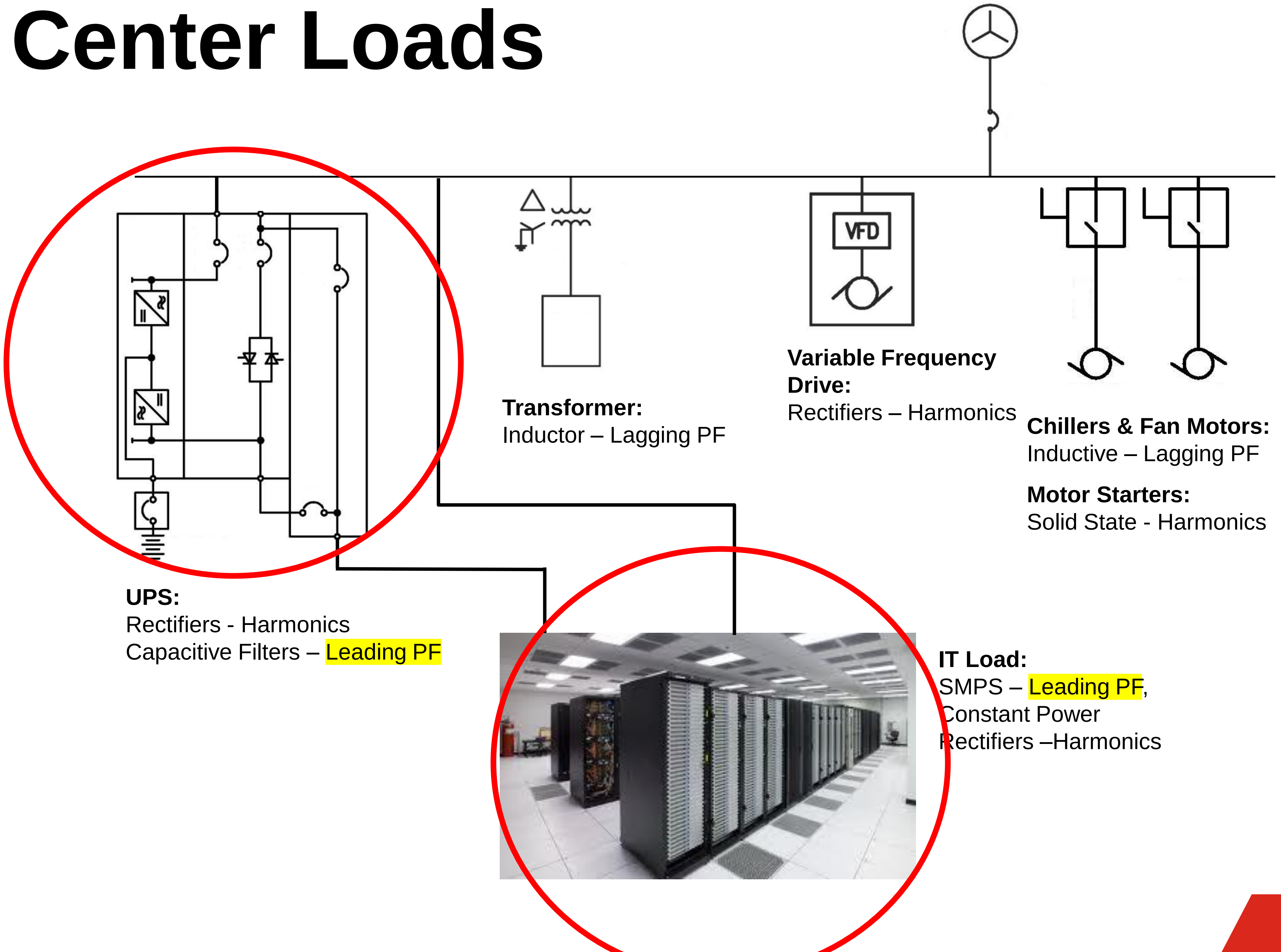
- Identify safe alternator operating zones on an alternator reactive capability chart to ensure proper operating conditions on the generator
- Recognize the differences in generator load acceptance of active power, unity power factor and conventional lagging power factor loads and define specification 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?

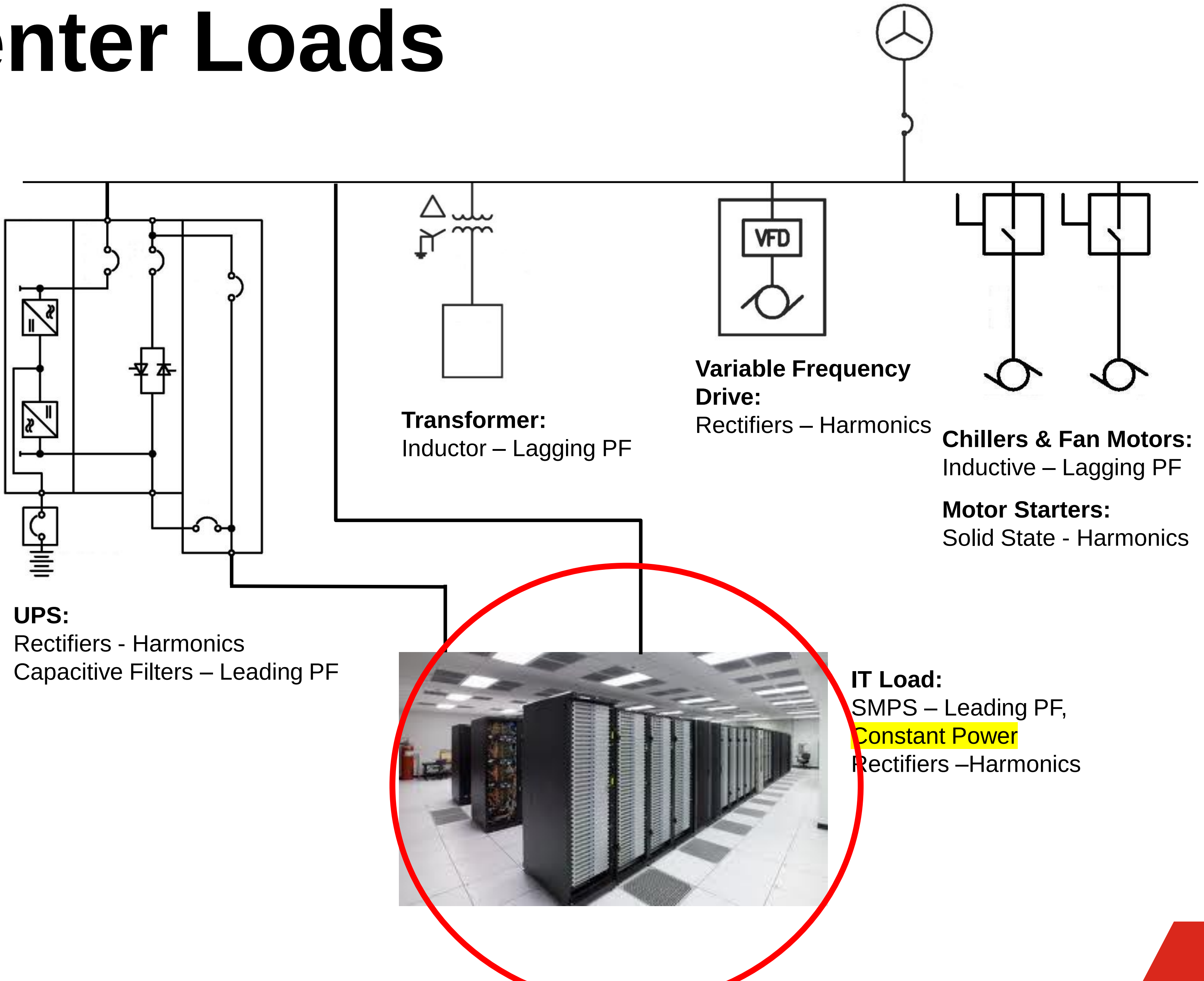
Data Center Loads



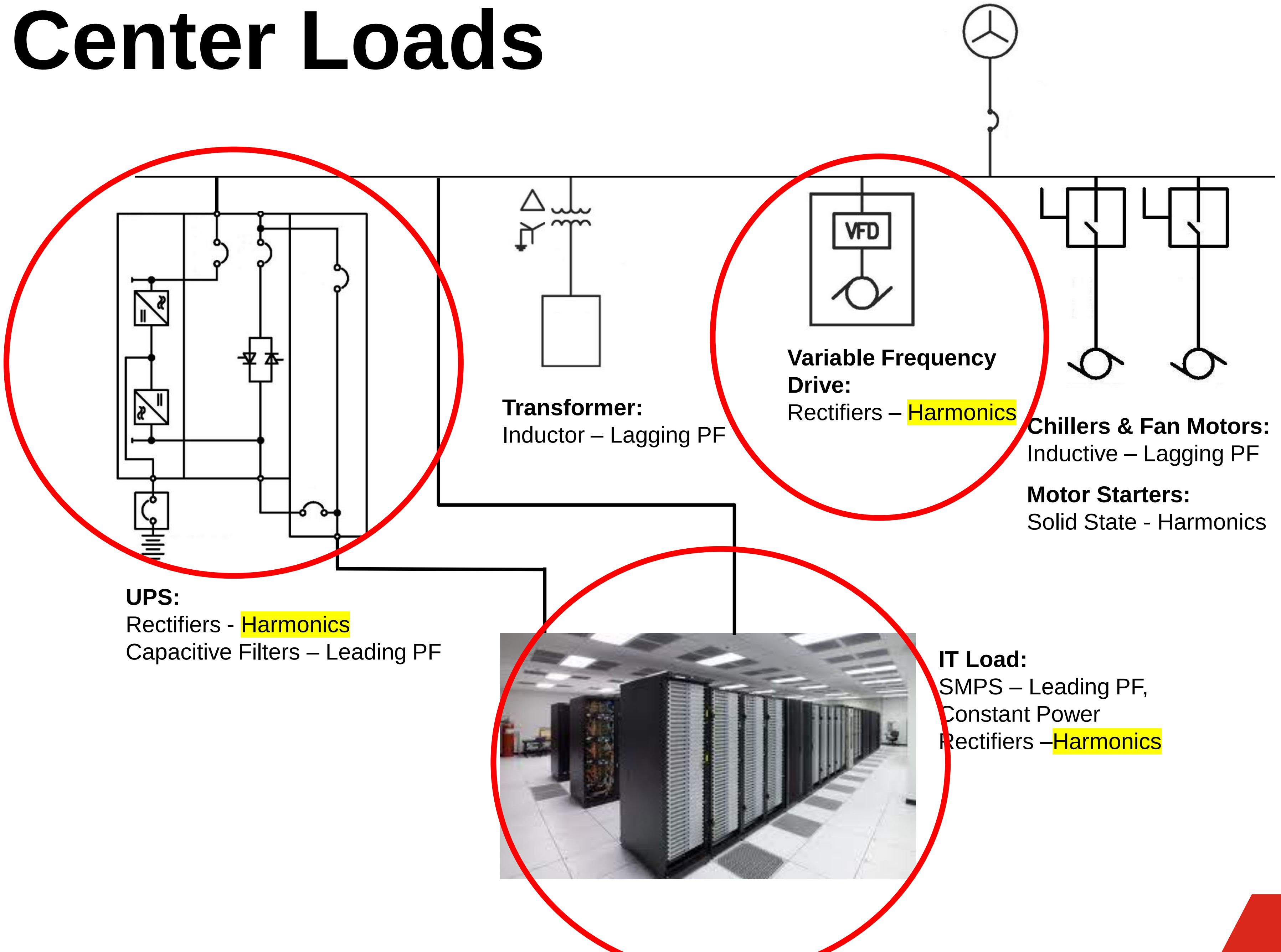
Data Center Loads



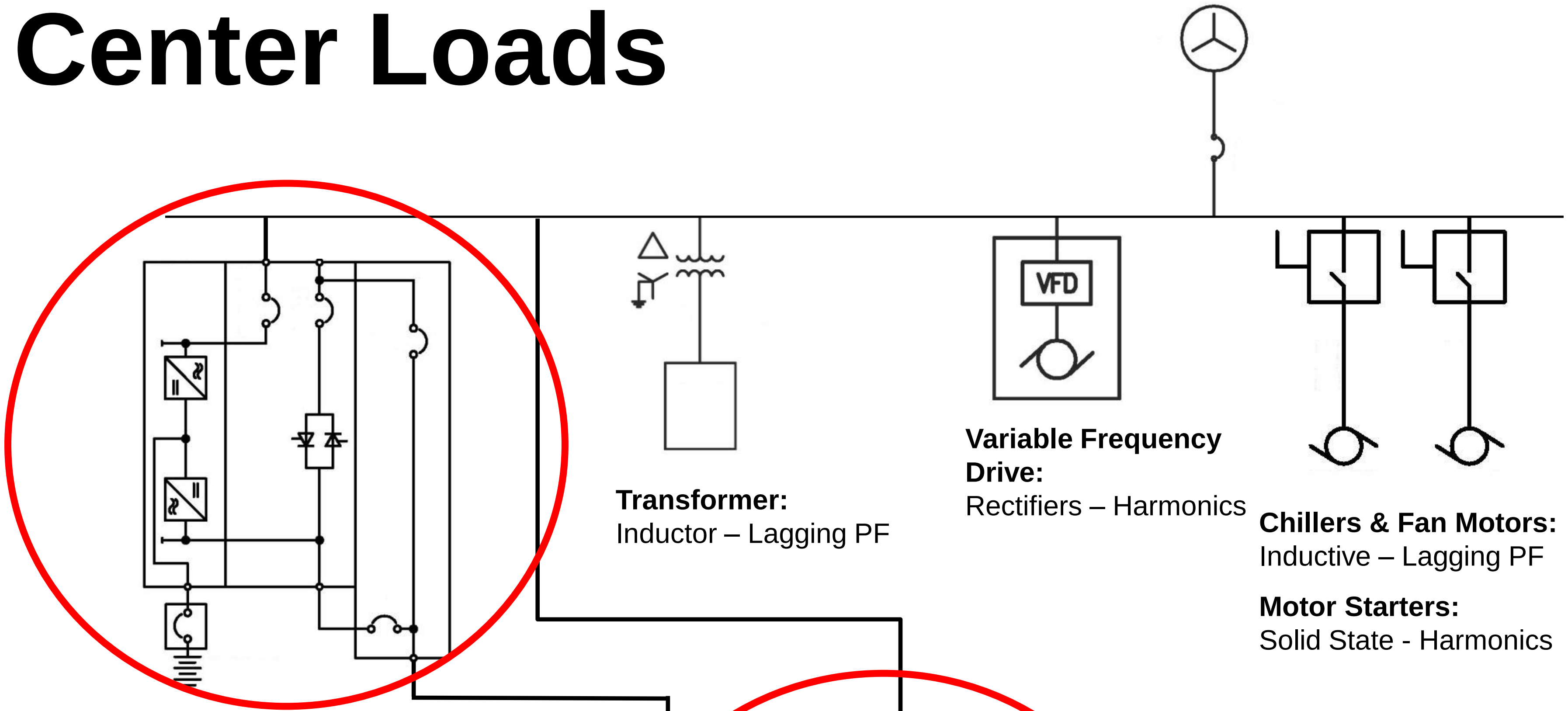
Data Center Loads



Data Center Loads



Data Center Loads



Transformer:
Inductor – Lagging PF

Variable Frequency Drive:
Rectifiers – Harmonics

Chillers & Fan Motors:
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Motor Starters:
Solid State - Harmonics

UPS:
Rectifiers - Harmonics
Capacitive Filters – Leading PF

IT Load:
SMPS – Leading PF,
Constant Power
Rectifiers –Harmonics

Alternator Operating Chart

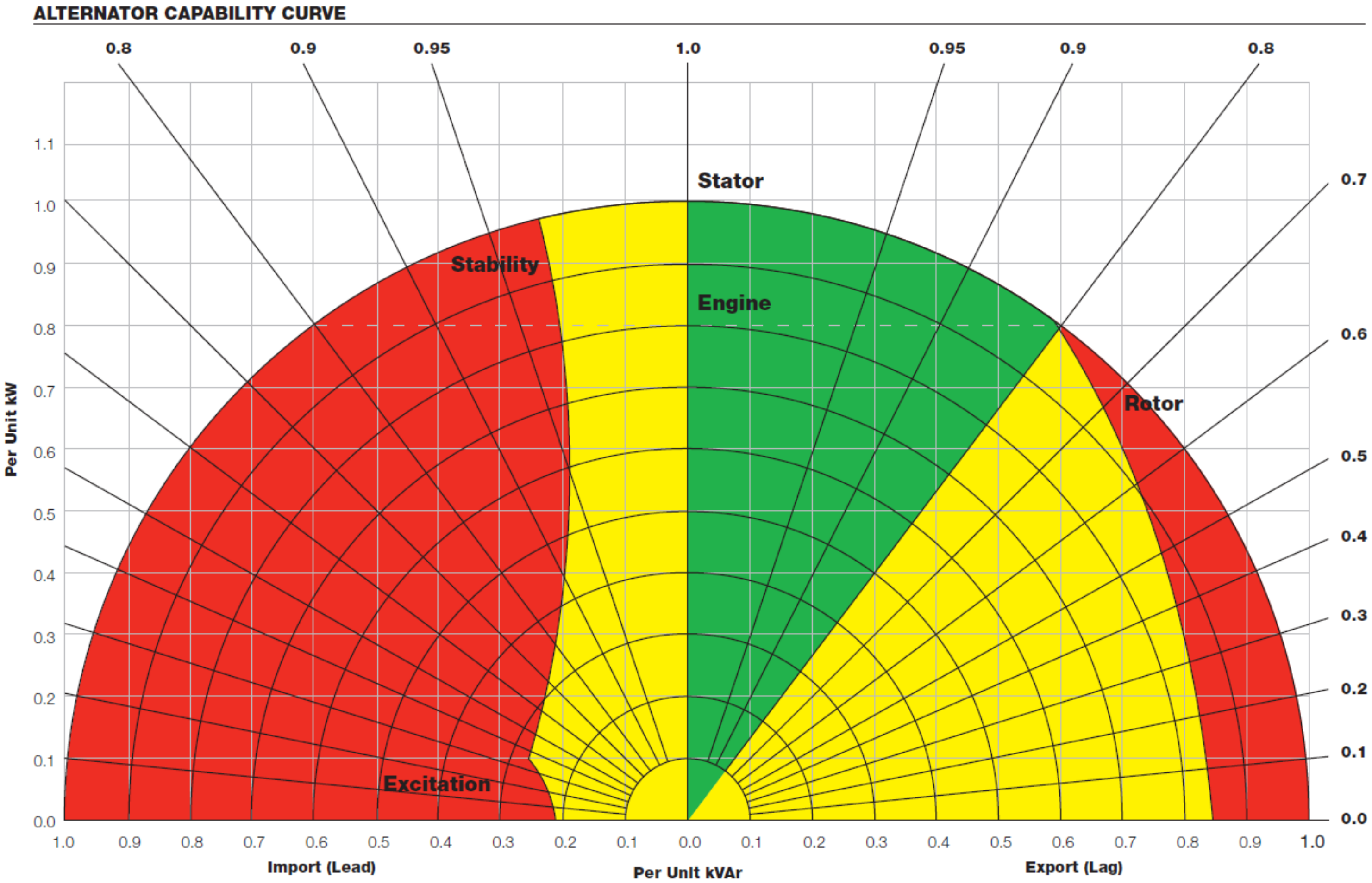


FIGURE 2 – Green area is normal operating range of a typical synchronous machine, yellow is abnormal but not damaging, and operating in

Alternator Operating Chart

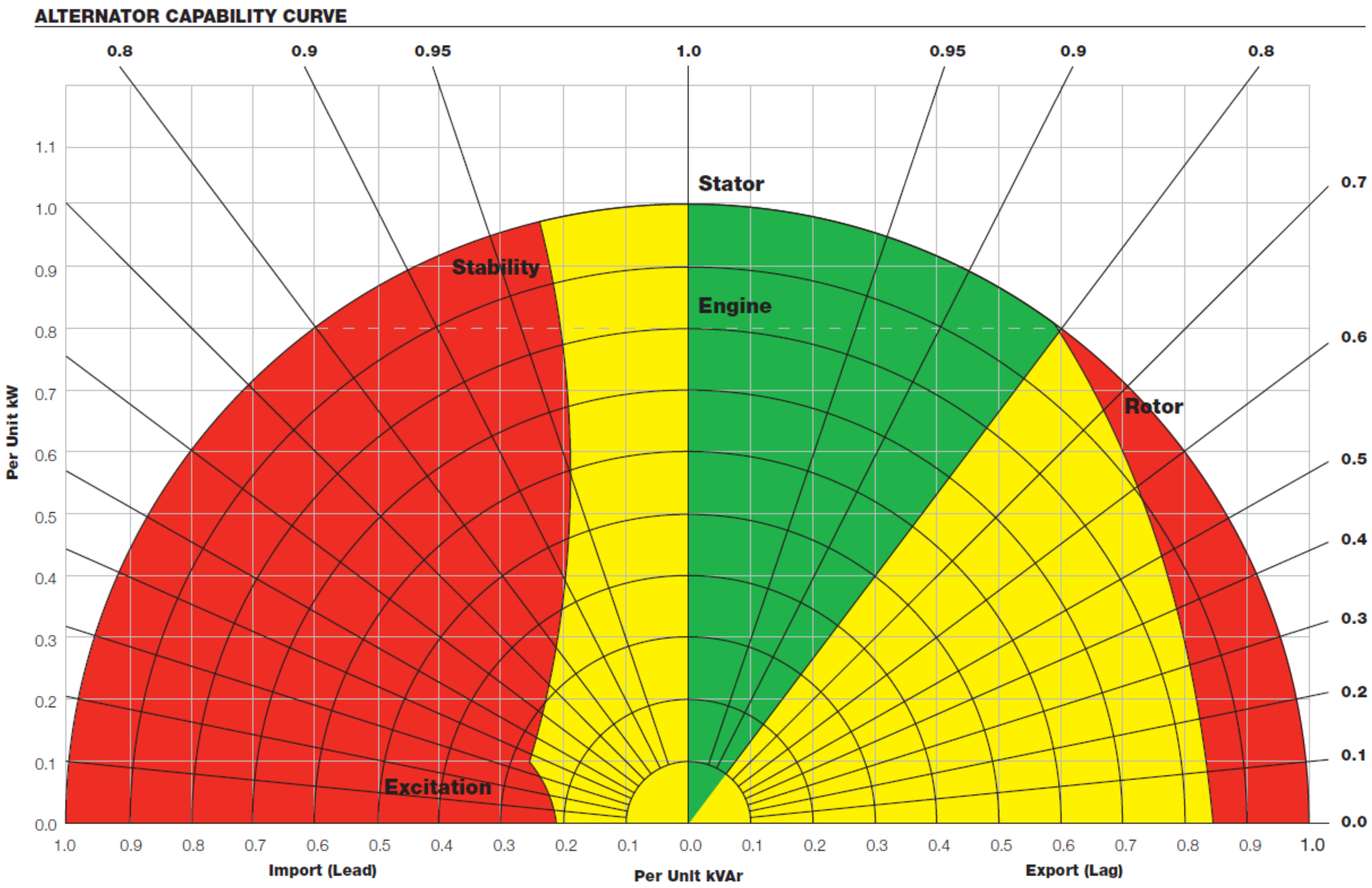


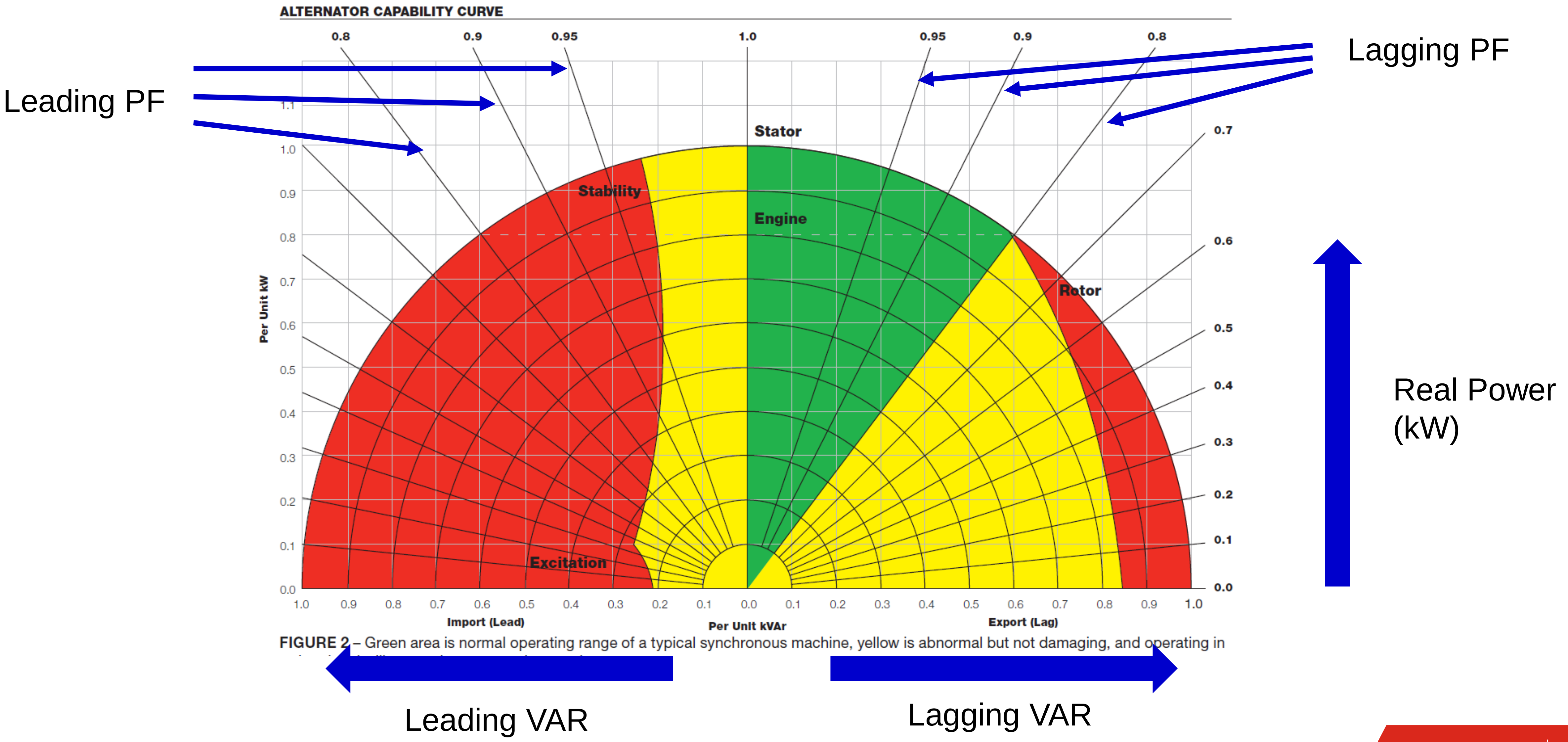
FIGURE 2 – Green area is normal operating range of a typical synchronous machine, yellow is abnormal but not damaging, and operating in

Real Power (kW)

Leading VAR

Lagging VAR

Alternator Operating Chart



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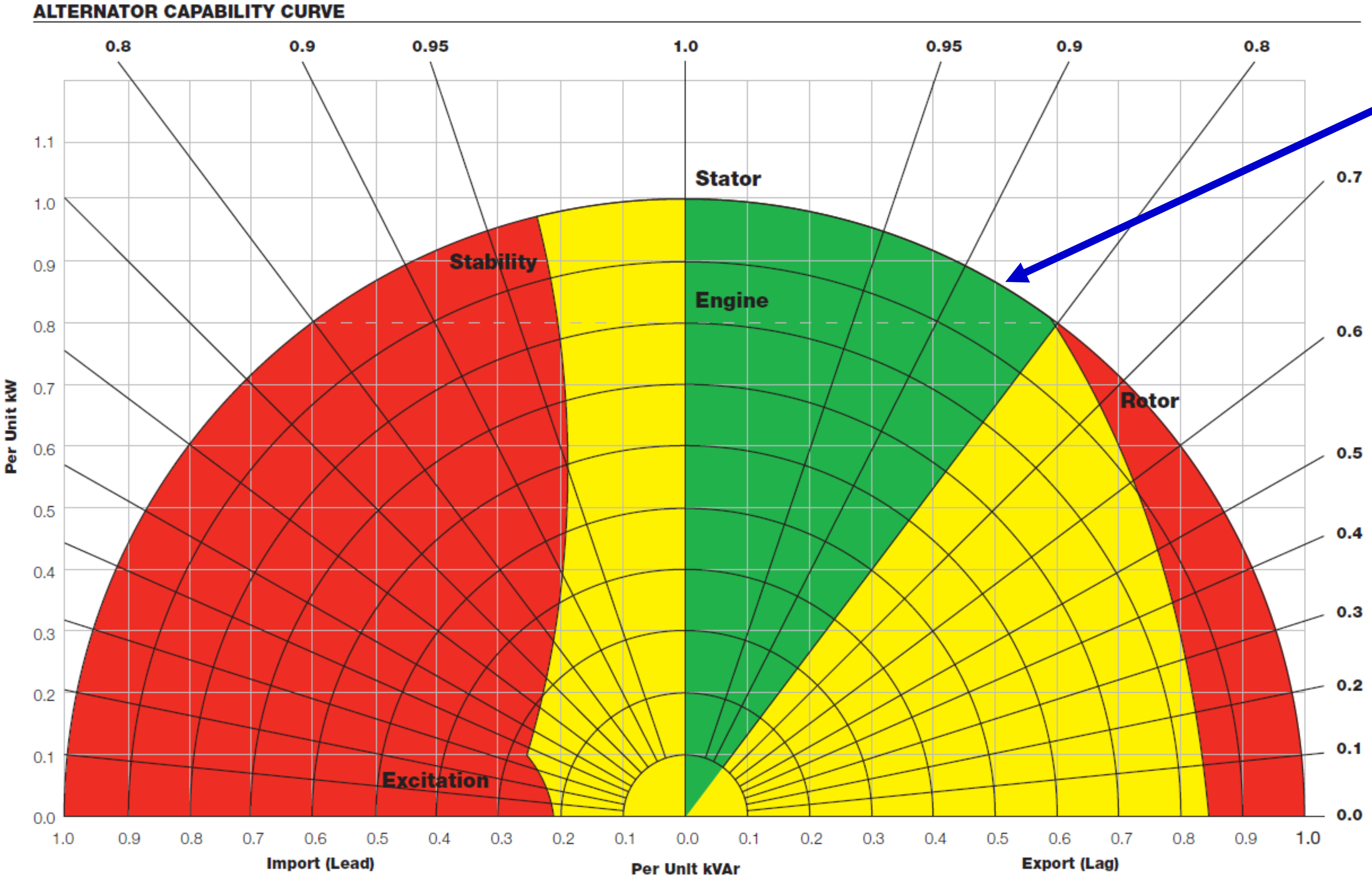

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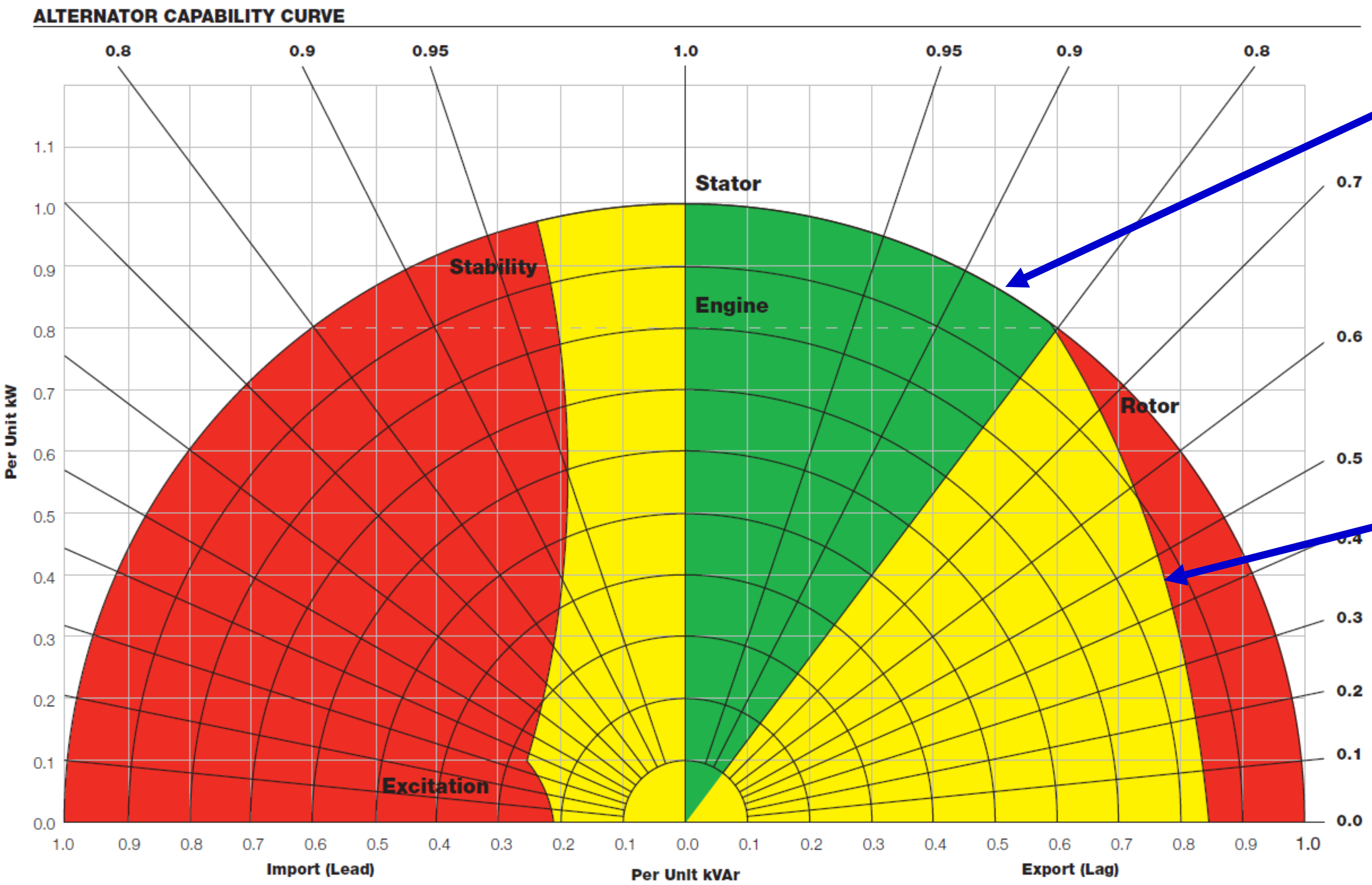
Semi-circle defines maximum alternator kVA

Alternator Operating Chart



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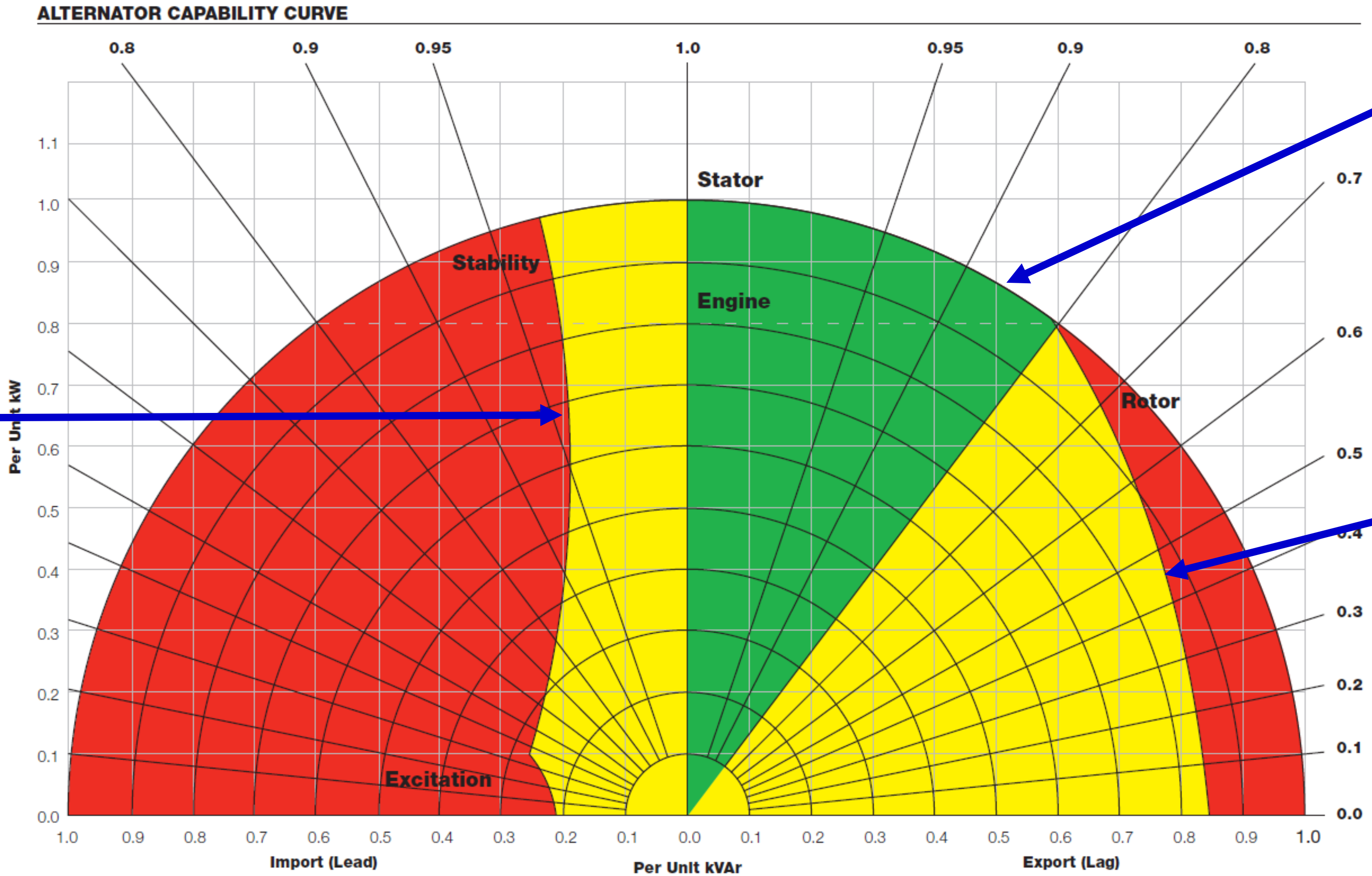
Semi-circle defines maximum alternator kVA

Max excitation - limited by rotor heating

Alternator Operating Chart



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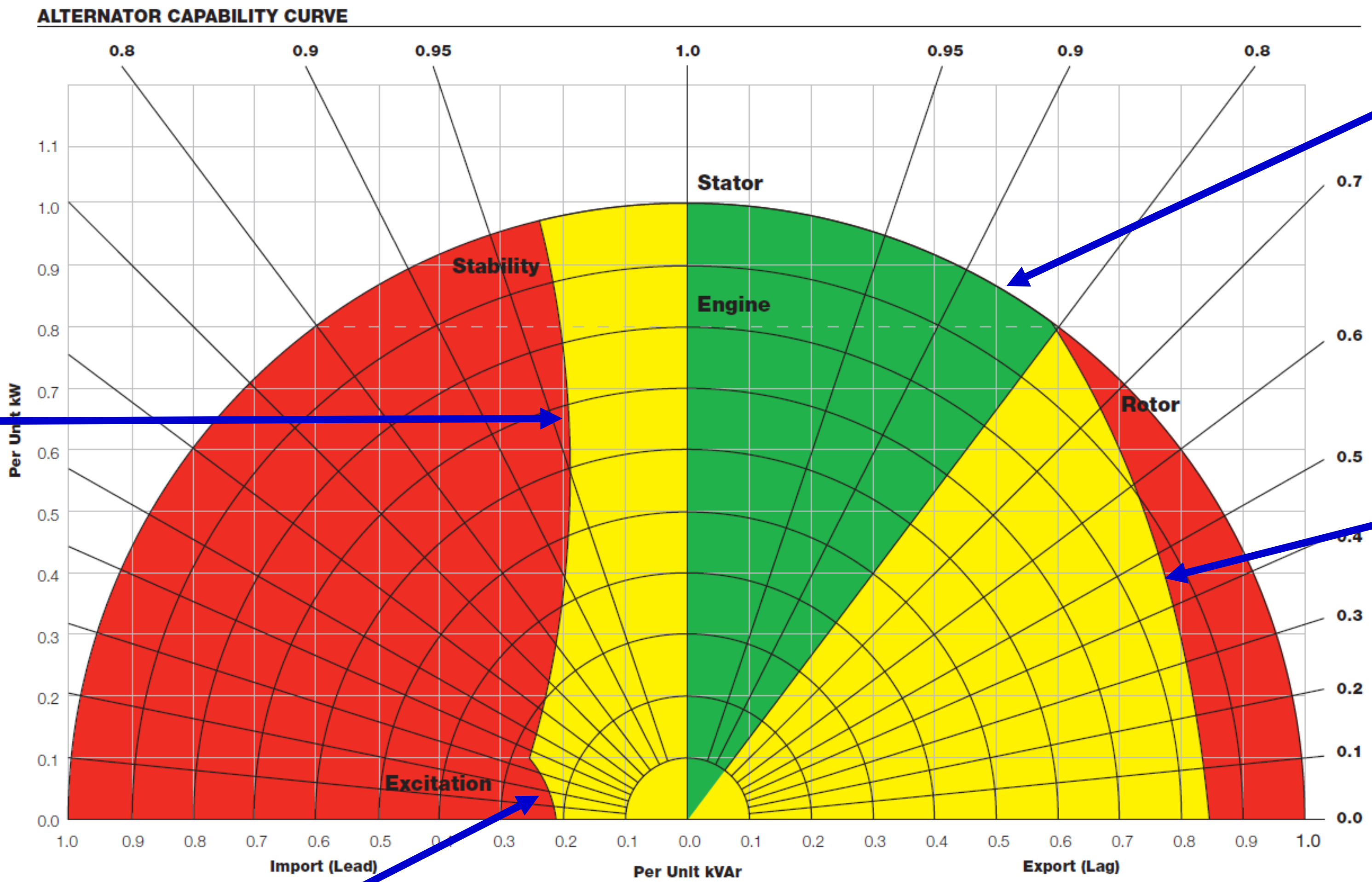


FIGURE 2 – Green area is norm operating range of a typical synchronous machine, yellow is abnormal but not damaging, and operating in

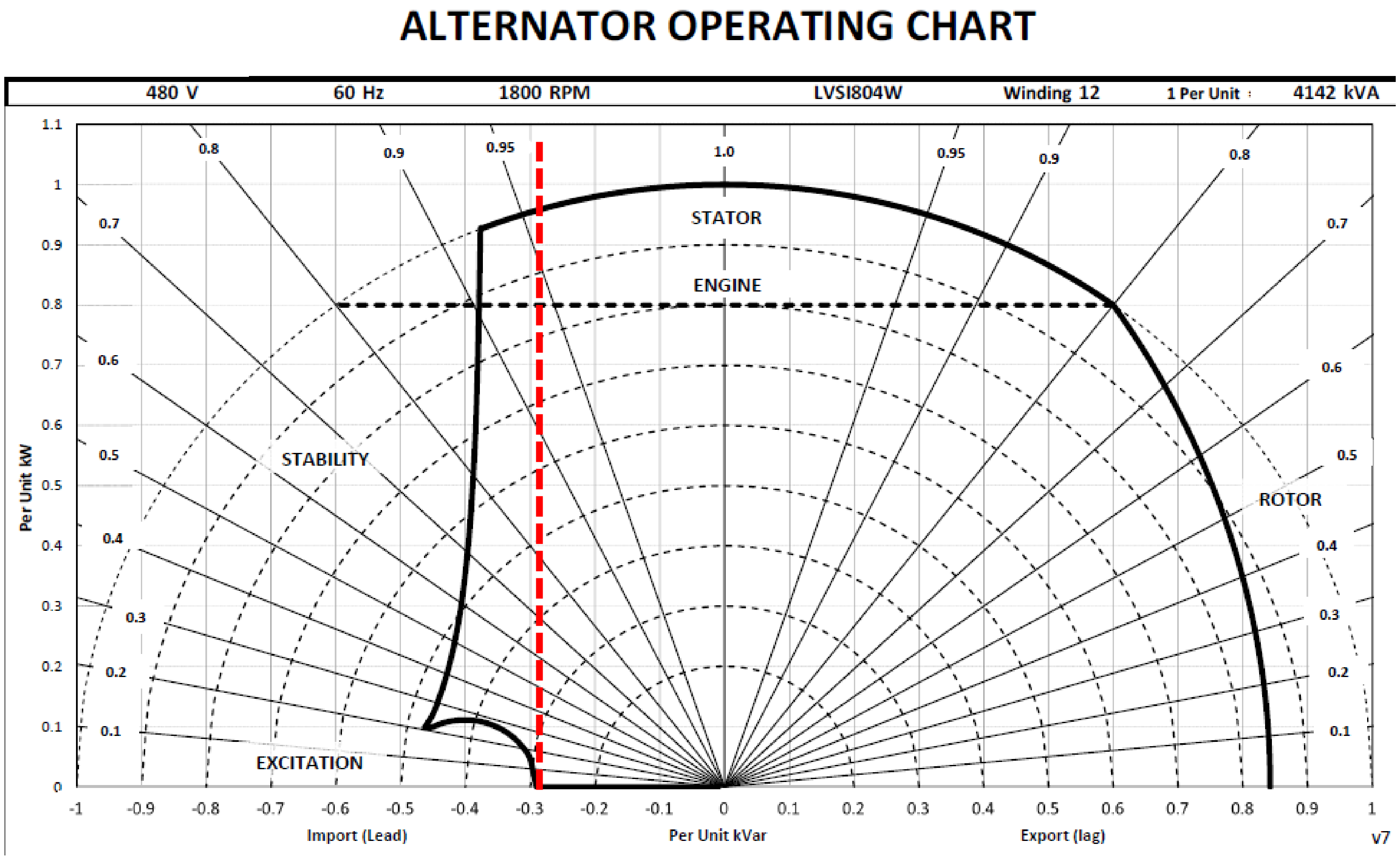
Semi-circle defines maximum alternator kVA

Stability Limit

Max excitation - limited by rotor heating

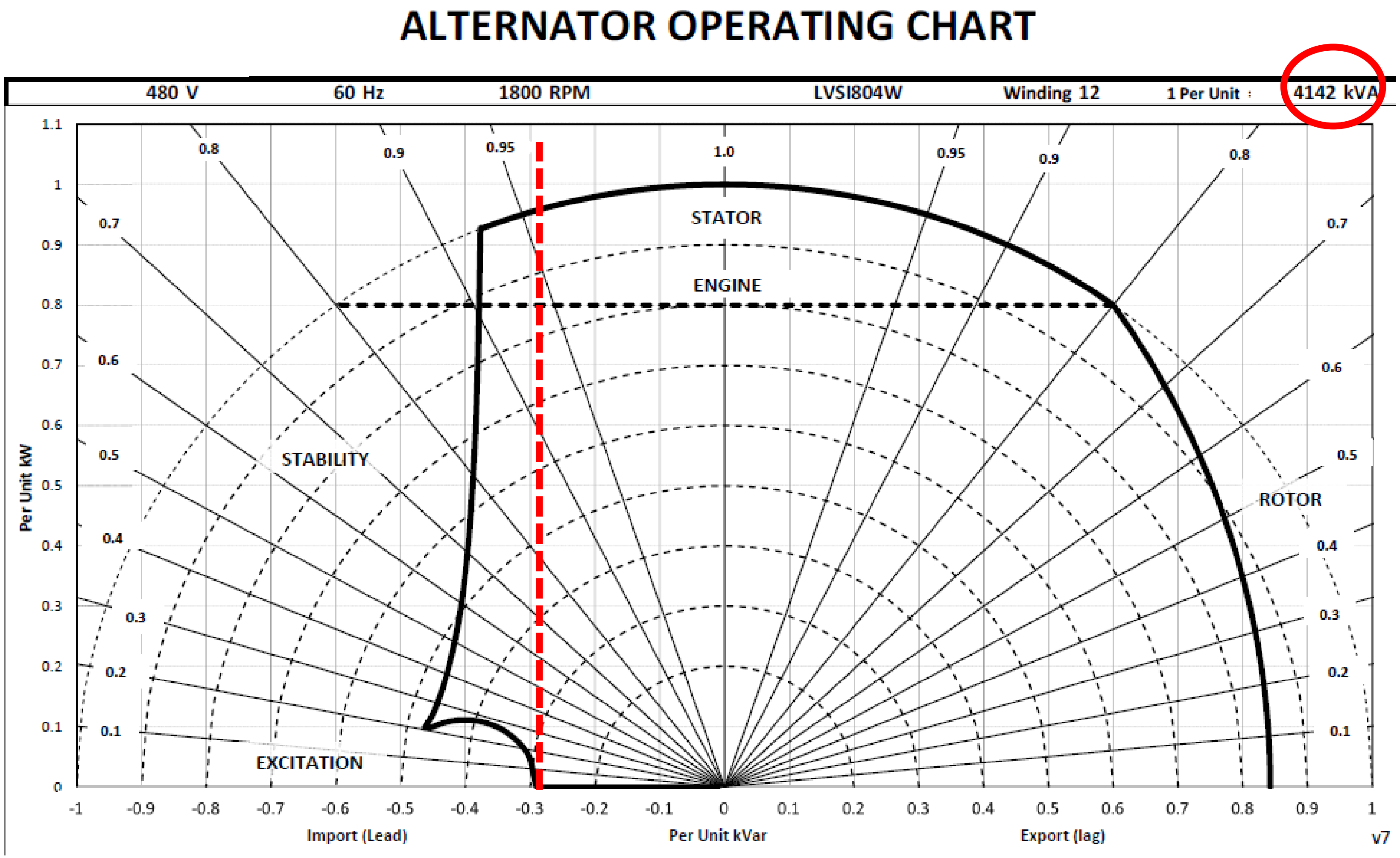
Loss of voltage control

Leading VAR Capability



Leading VAR capability ~ 0.3 pu

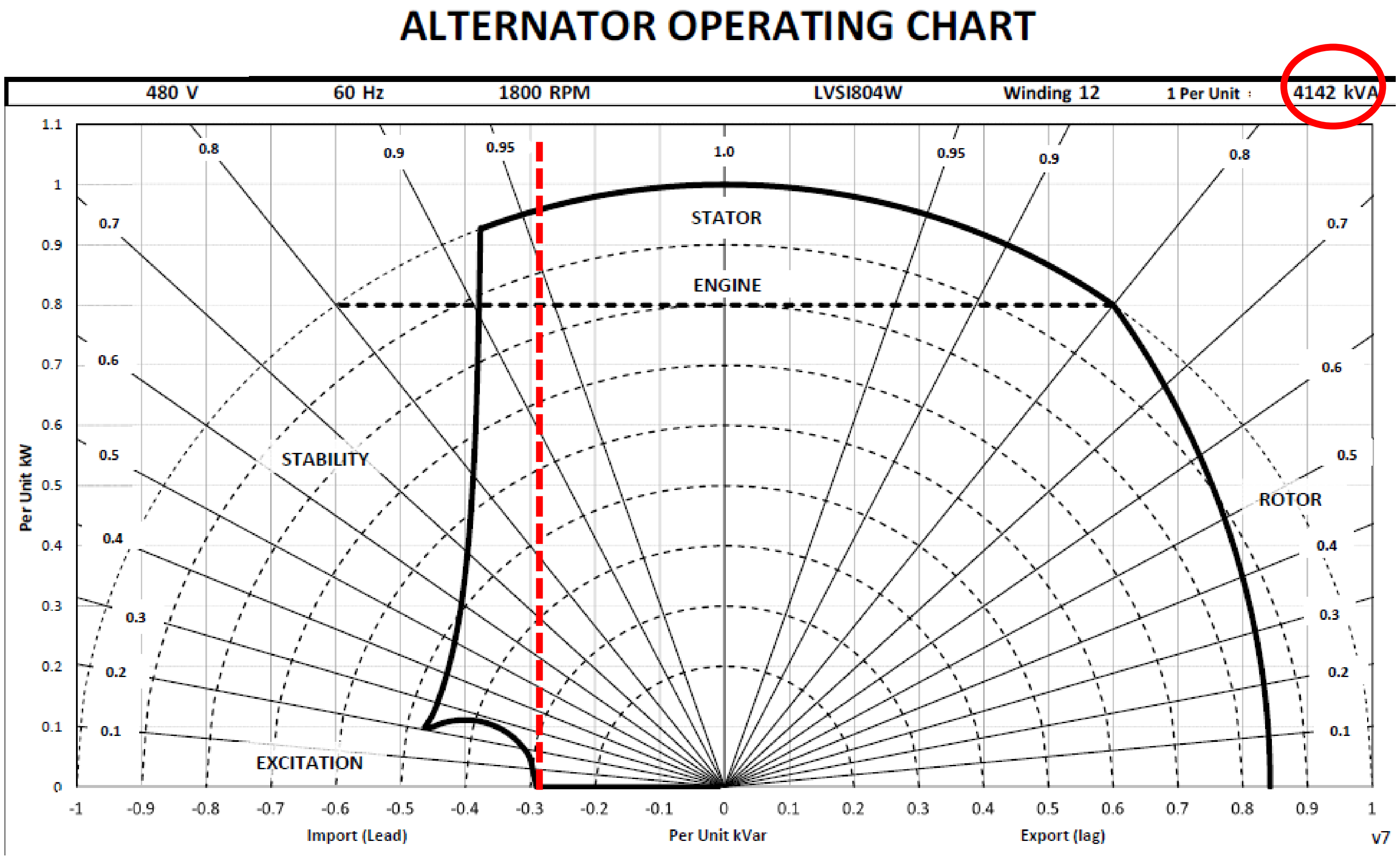
Leading VAR Capability



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

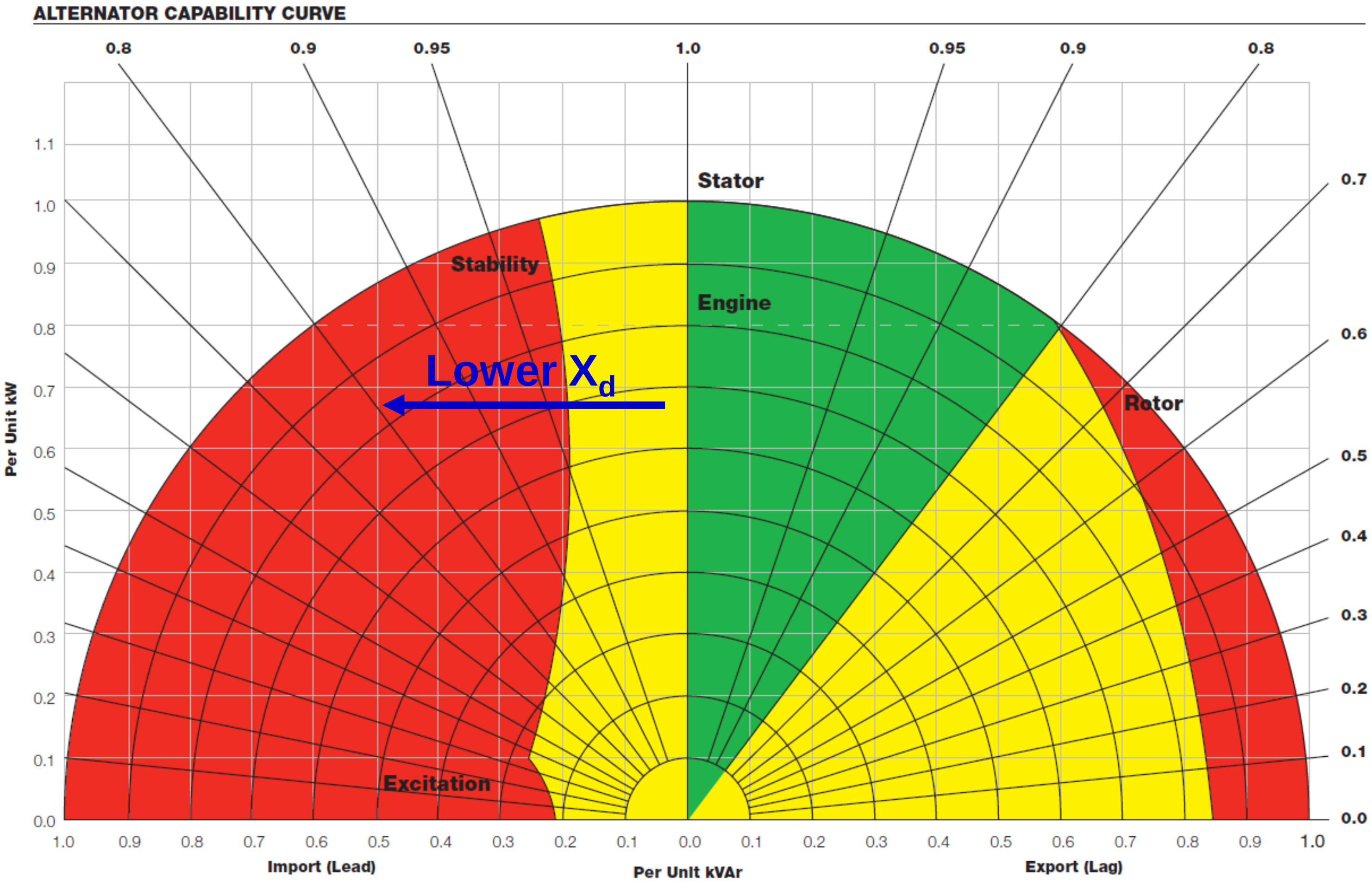
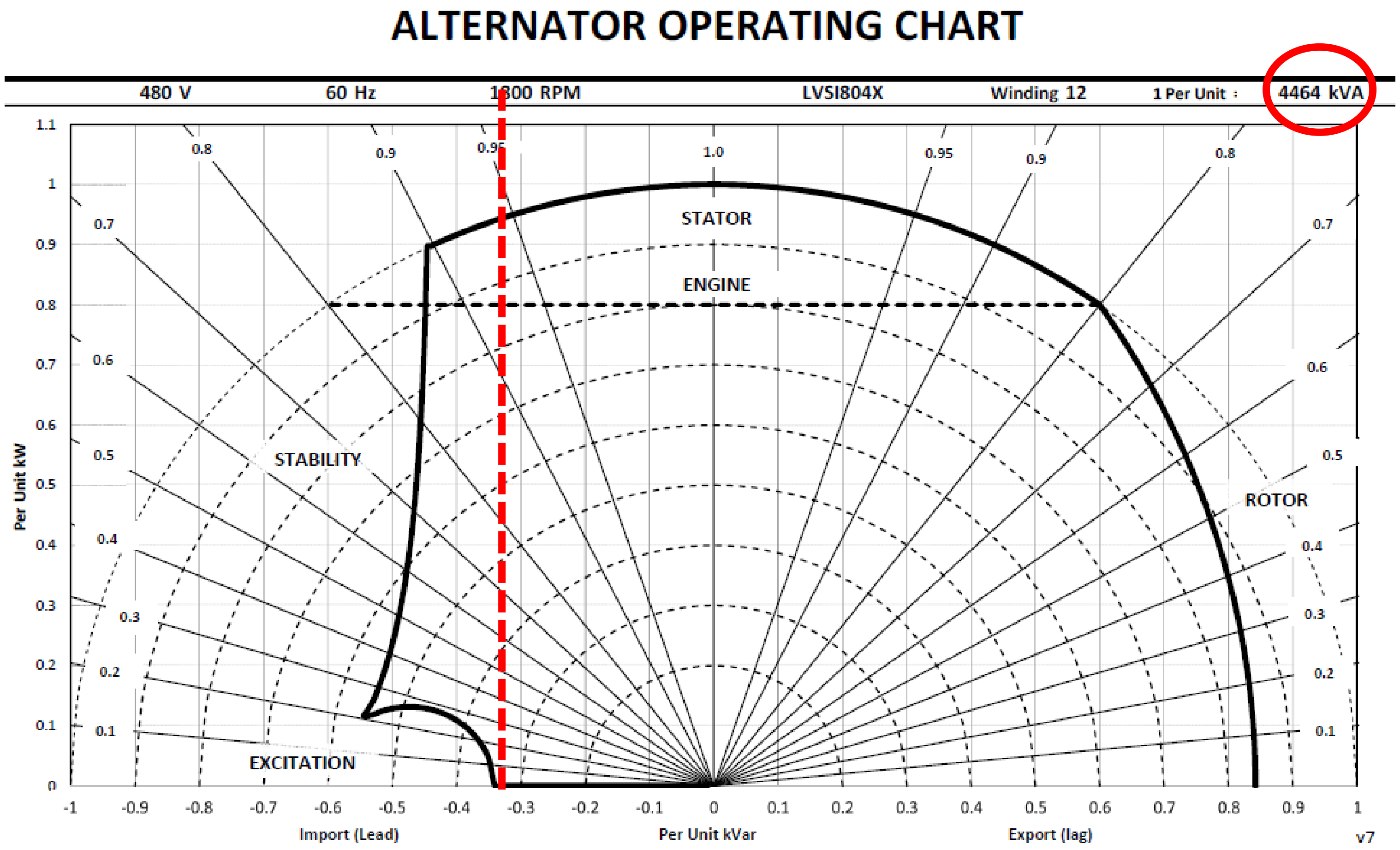


FIGURE 2 – Green area is normal operating range of a typical synchronous machine, yellow is abnormal but not damaging, and operating in

- 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

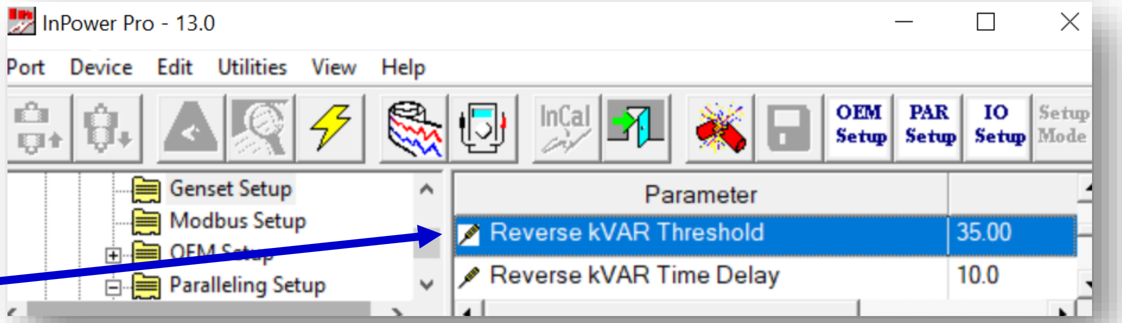
1562/3750 = .41

Leading VAR capability = .41 pu based on genset rating

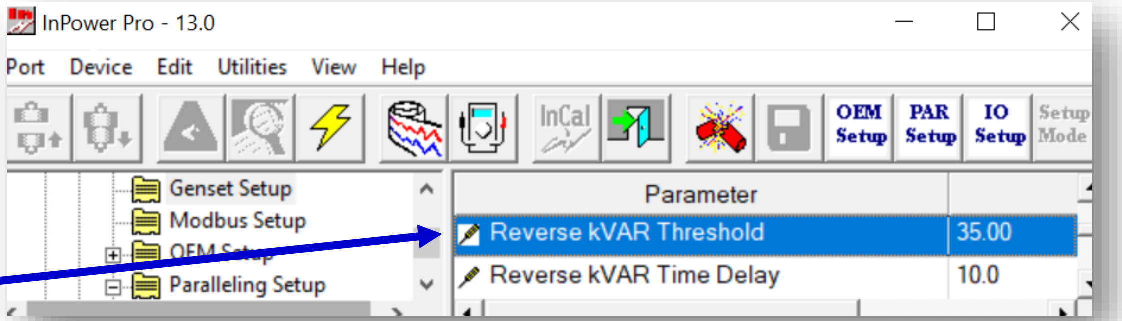
Leading PF Takeaways

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

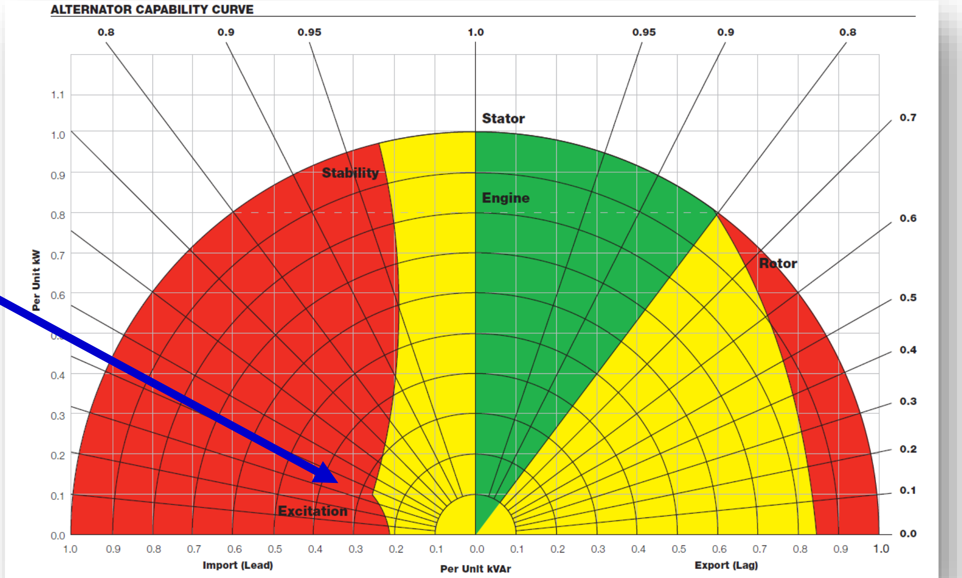


FIGURE 2 – Green area is normal operating range of a typical synchronous machine, yellow is abnormal but not damaging, and operating in

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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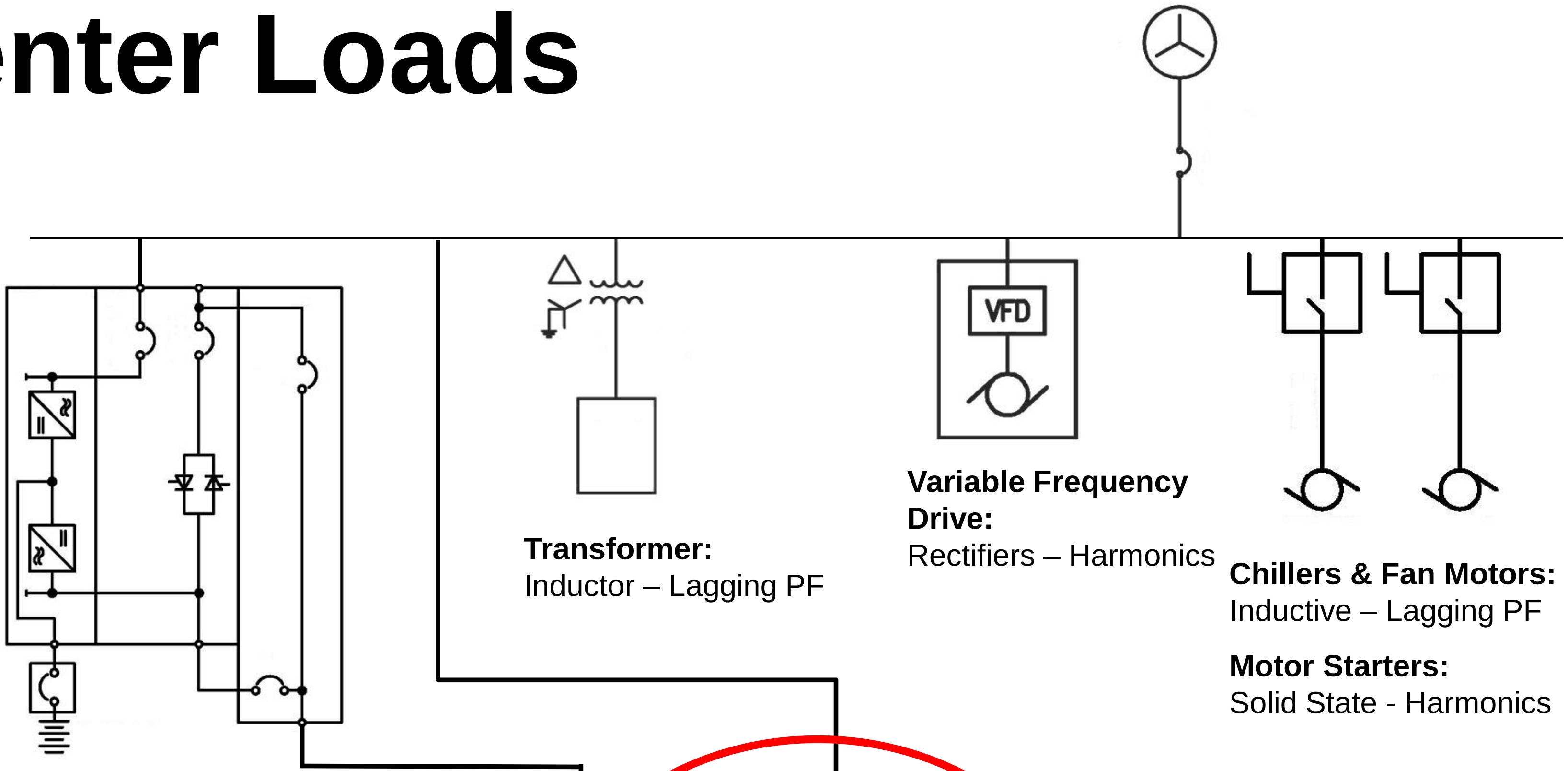
Data Center Loads



Transformer:
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SMPS – Leading PF,
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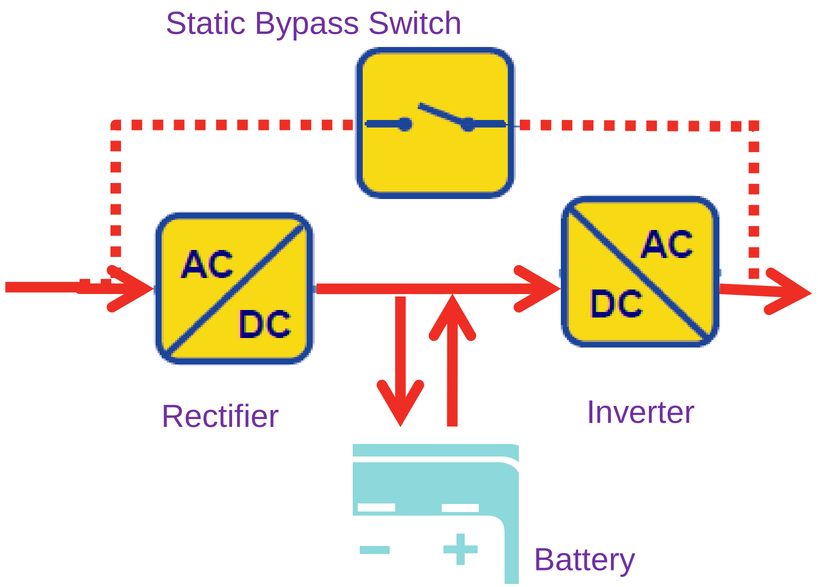
UPS with Walk-In Function

Server Switched Mode Power Supplies are active loads

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



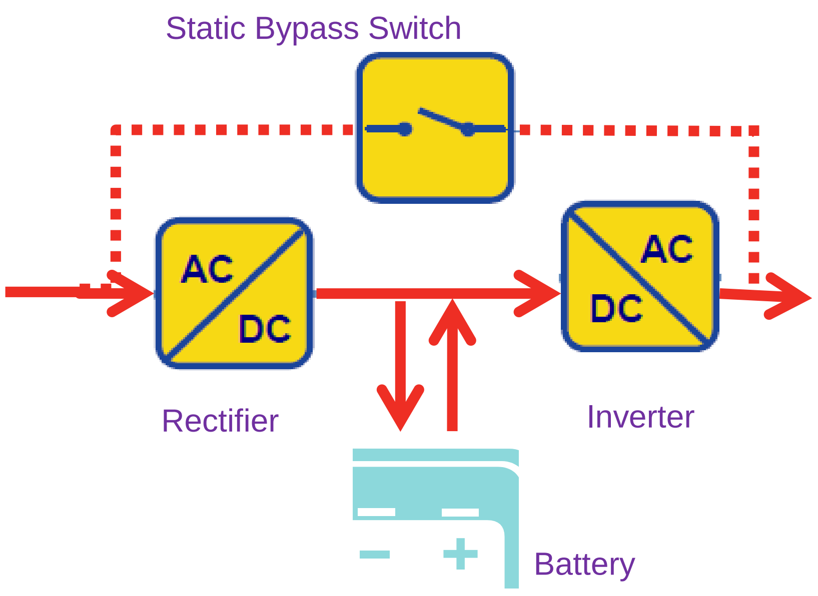
UPS with Walk-In Function

Server Switched Mode Power Supplies are active loads

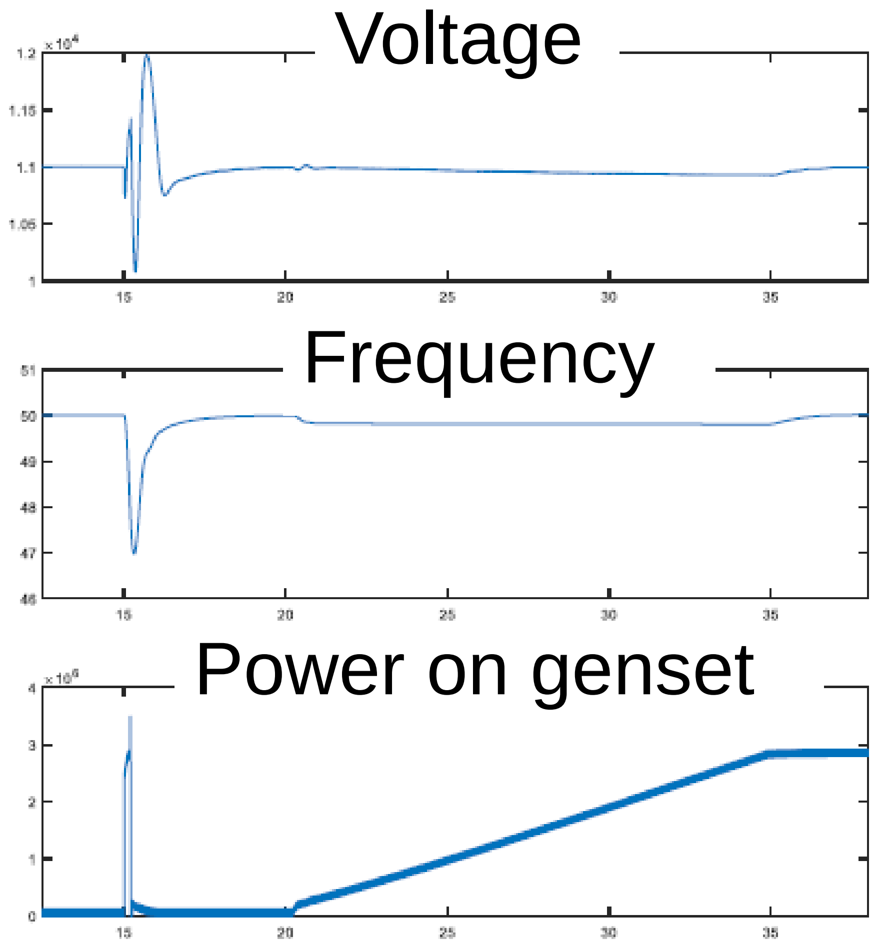
- Draw constant power
- As voltage drops current is increased
- V/Hz doesn't help

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



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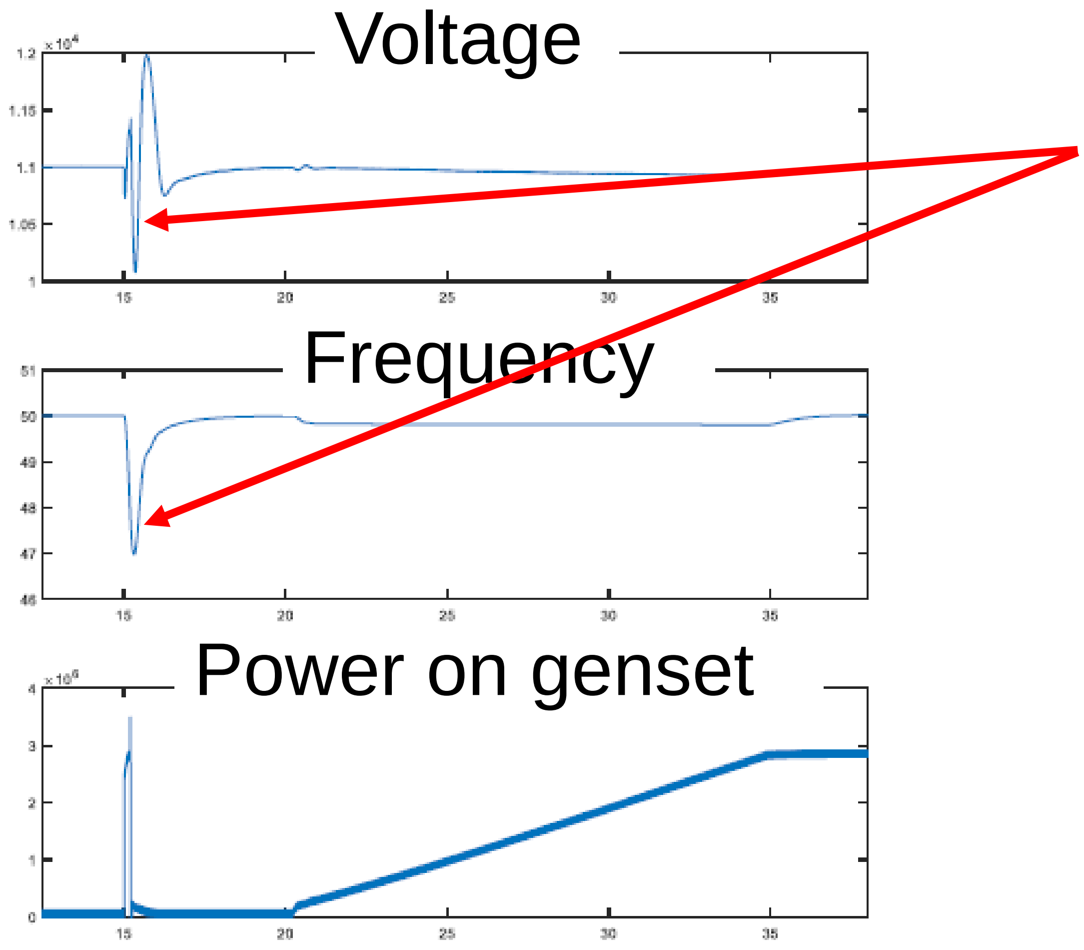
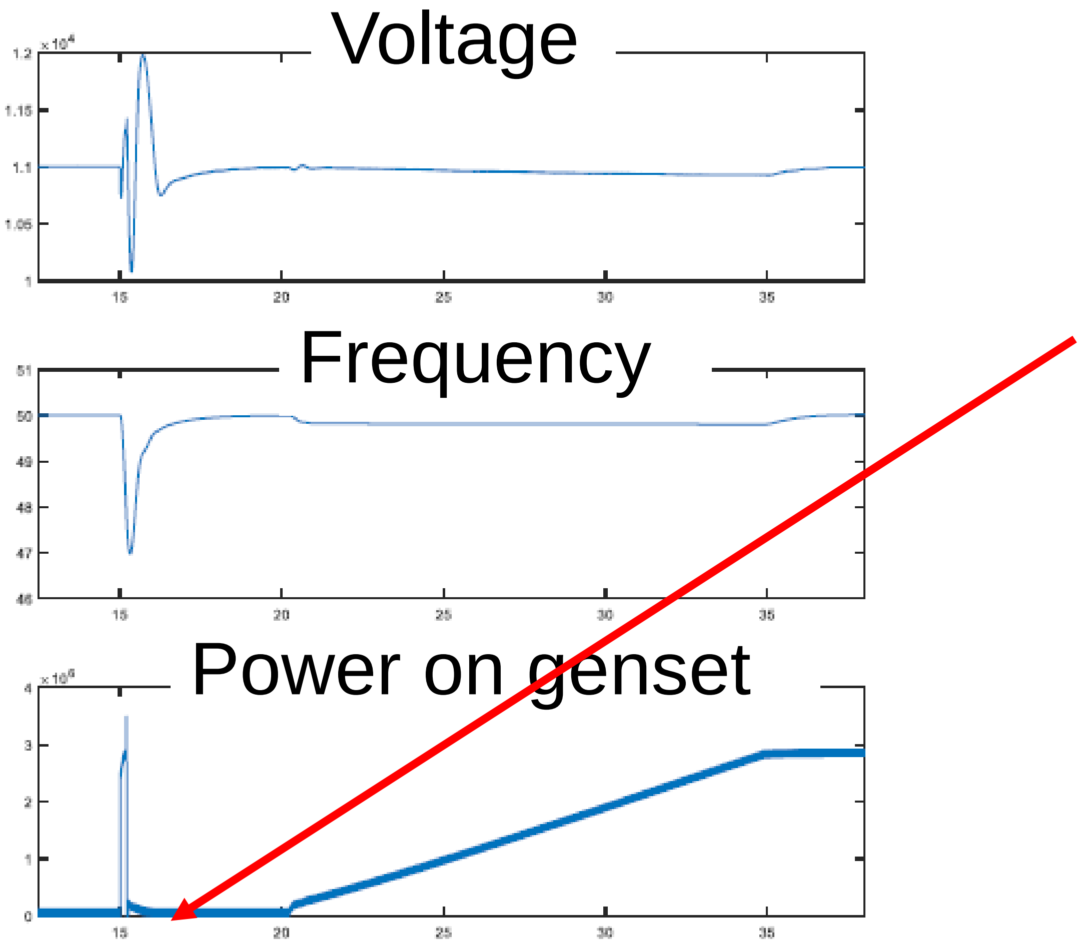


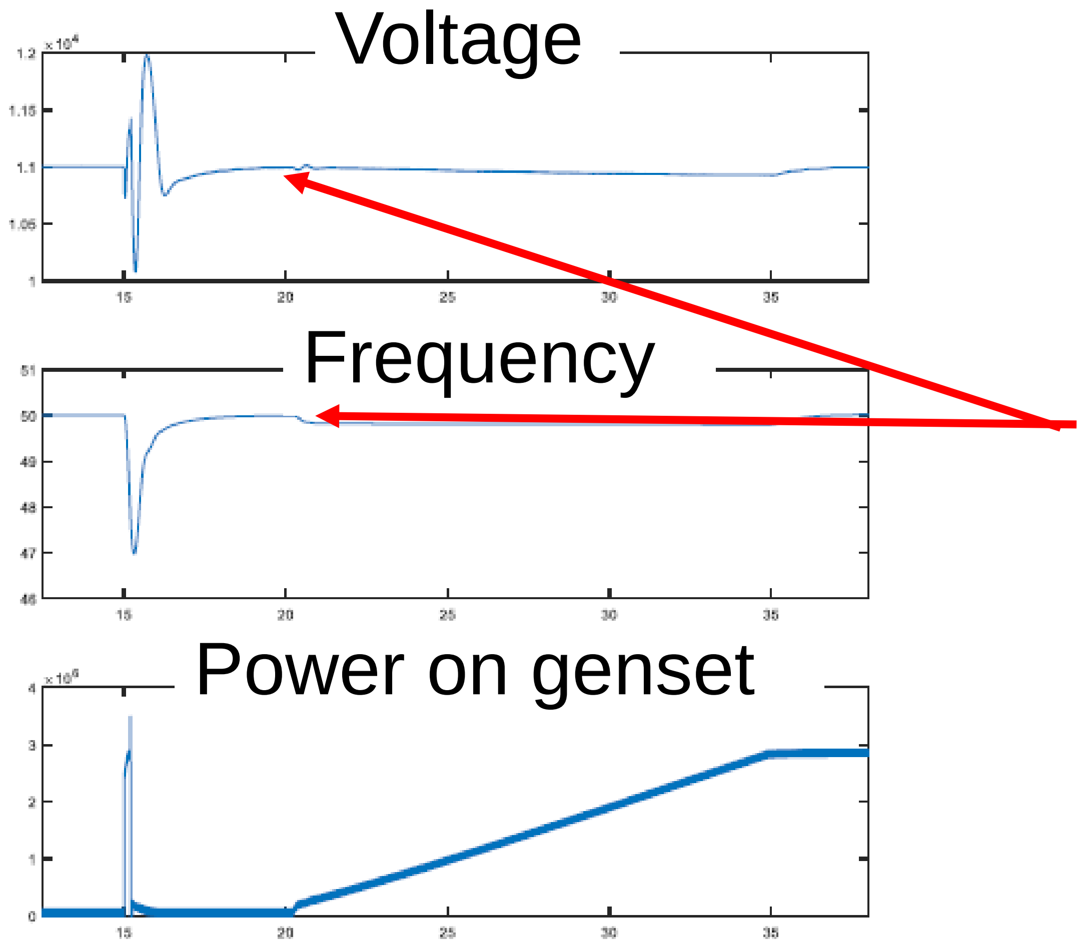
- UPS senses voltage and frequency excursion

100% Constant Power Load Acceptance



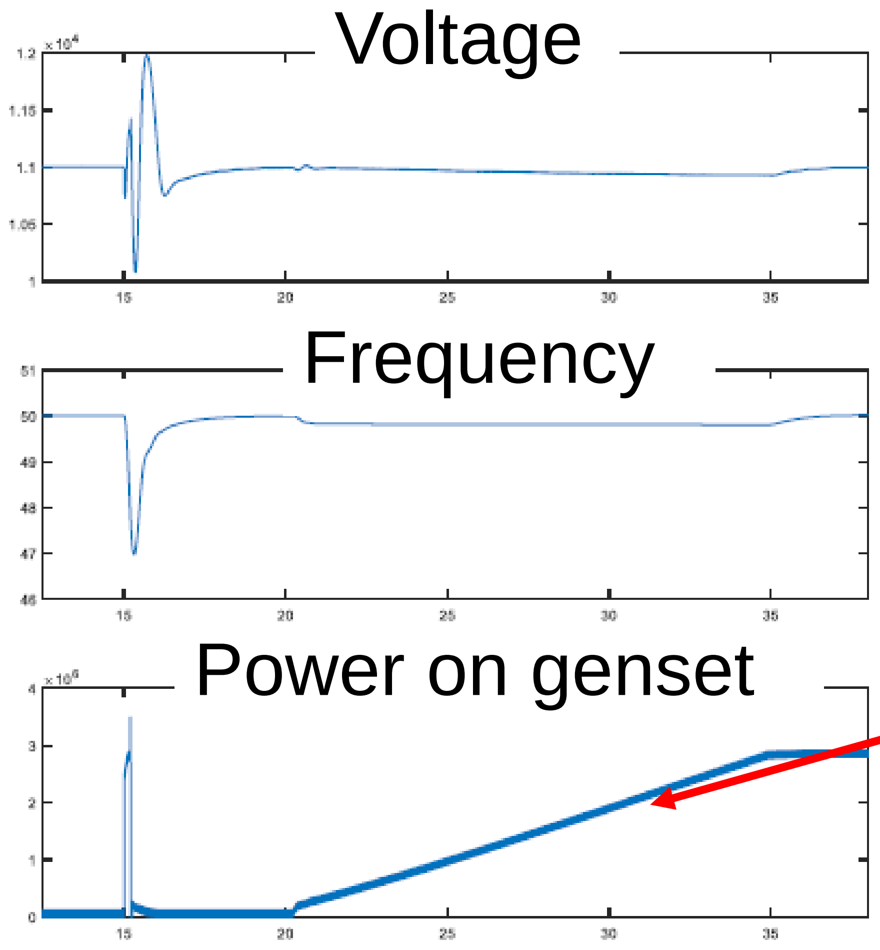
- UPS senses voltage and frequency excursion
- Transfers load to battery

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

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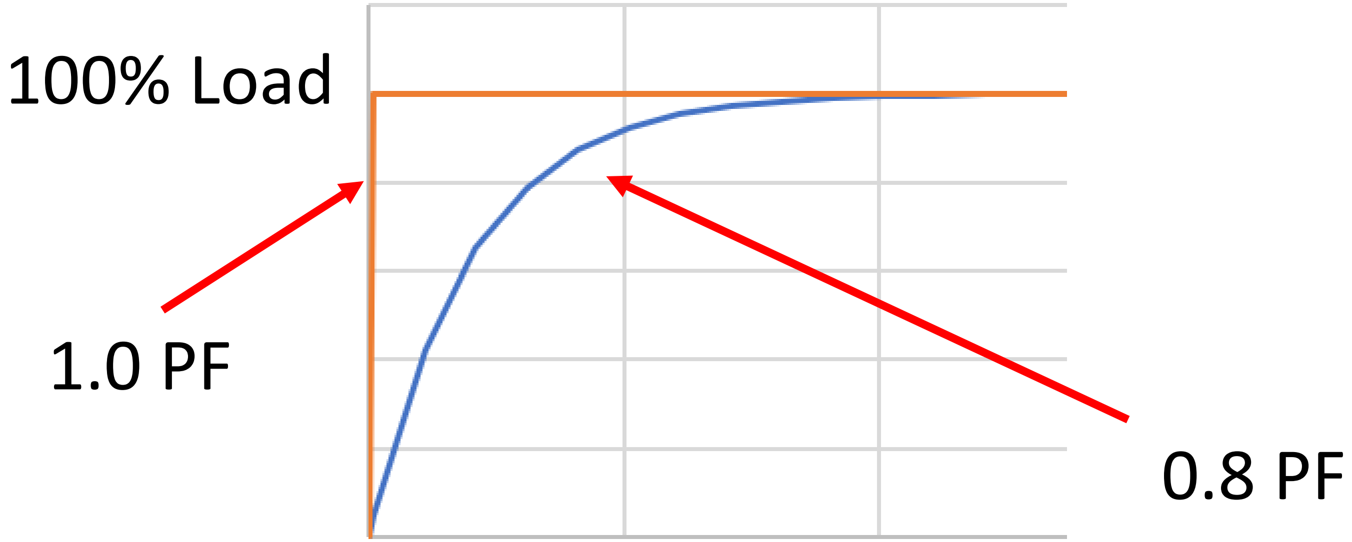
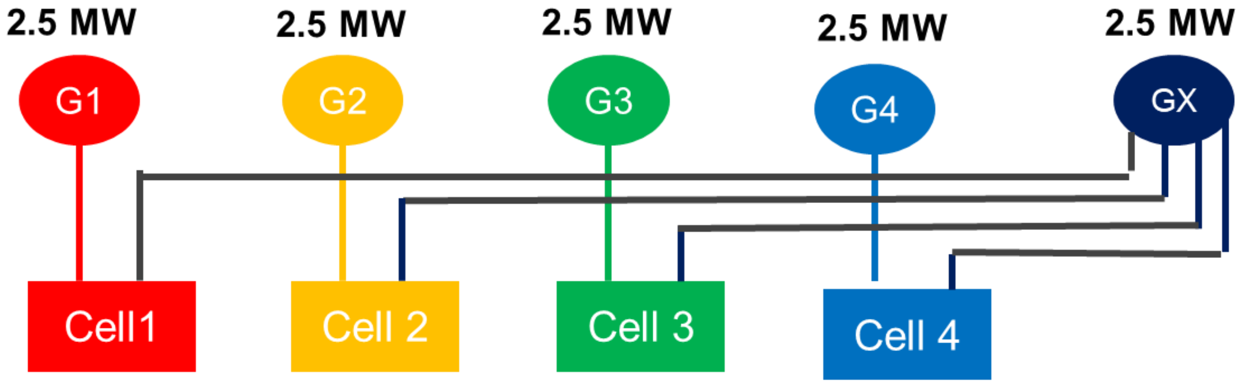


Testing at 0.8 PF

- 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



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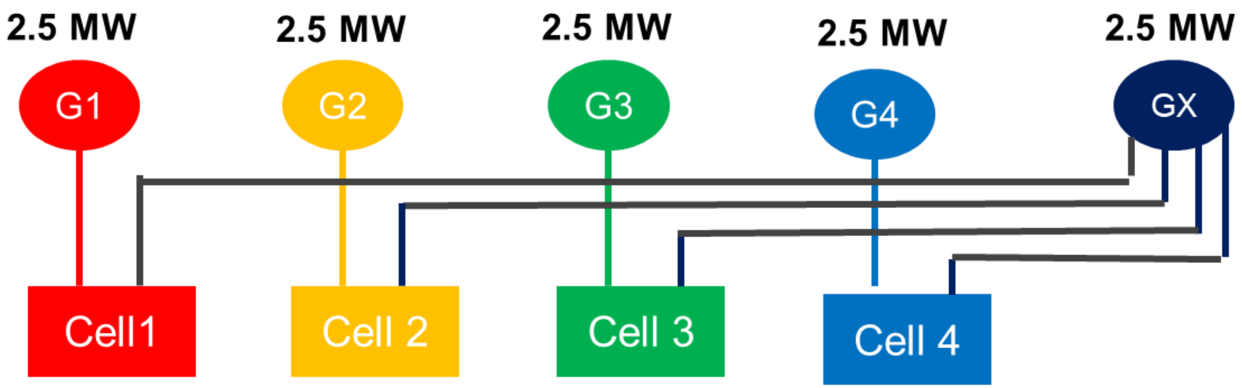
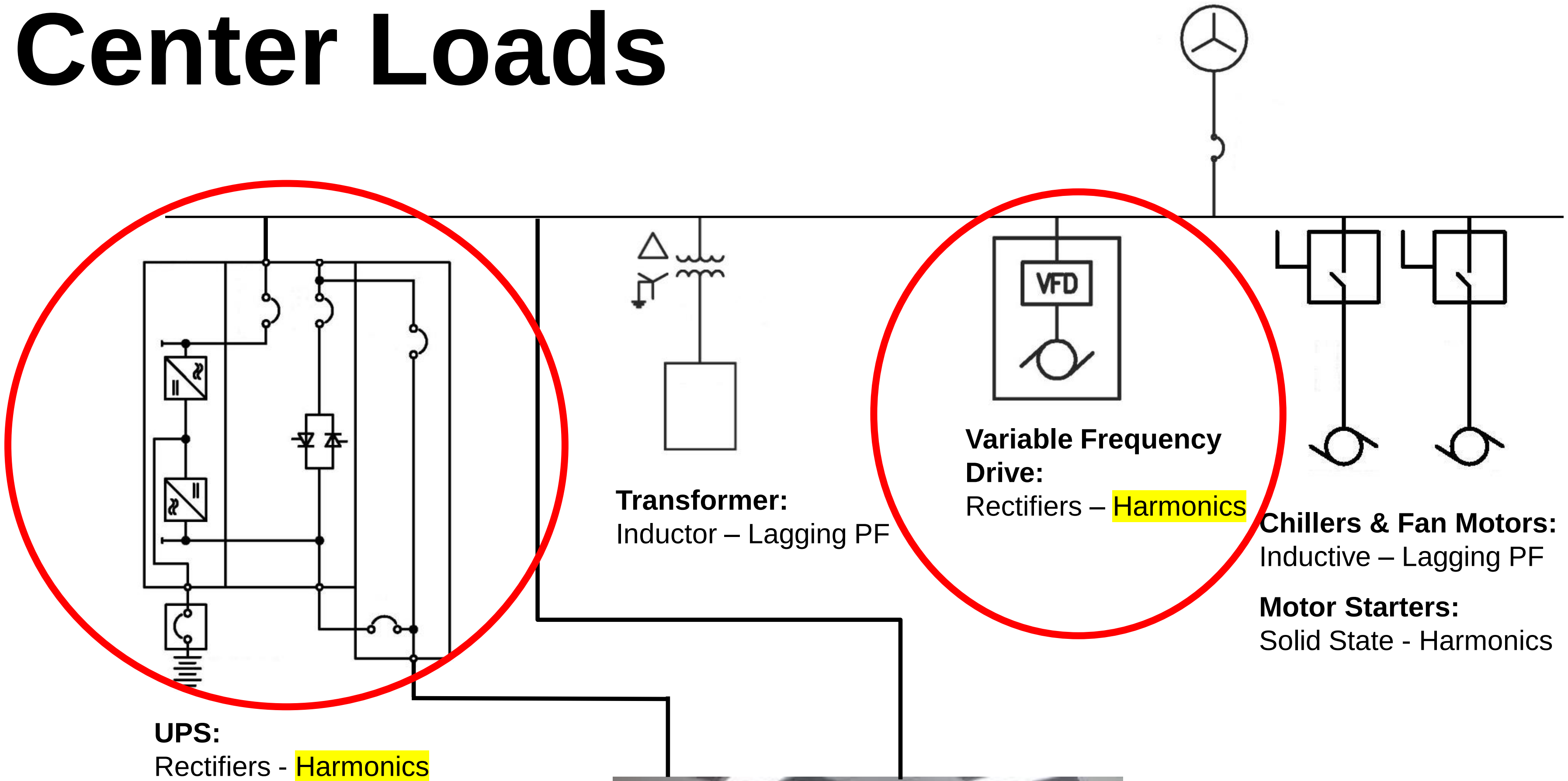


Spec Note Generator set manufacturer shall provide documentation from the manufacturer's sizing software demonstrating compliance with specified transient limits.

Data Center Loads



UPS:
Rectifiers - Harmonics
Capacitive Filters – Leading PF

Transformer:
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Motor Starters:
Solid State - Harmonics

IT Load:
SMPS – Leading PF,
Constant Power
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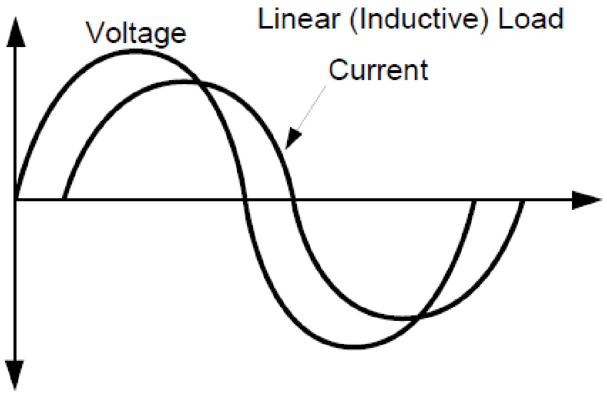
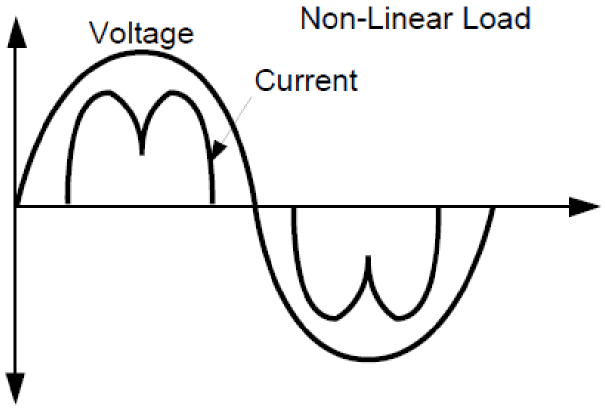
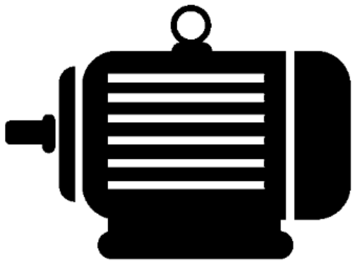
Harmonics and Non-Linear Loads

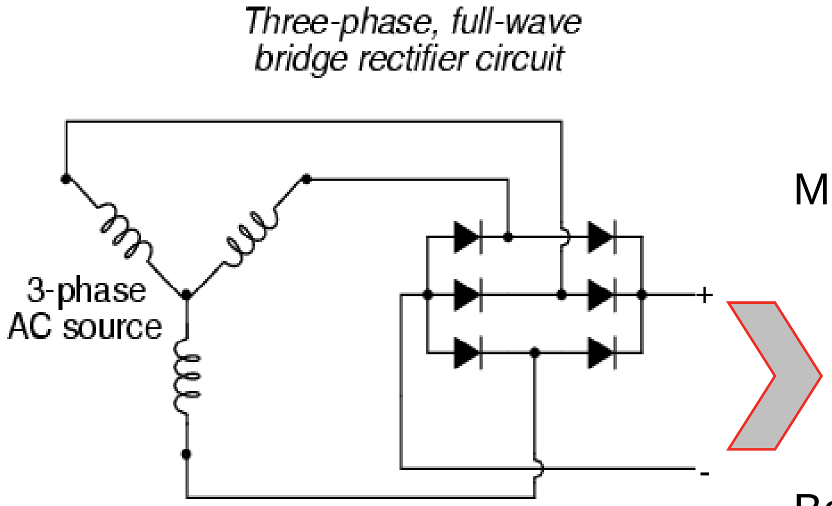


A load in which the relationship between current and voltage is directly proportional.



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





Motor Starters

UPS

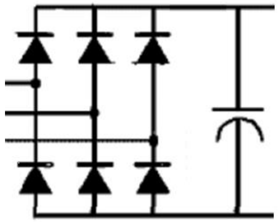
VFDs

Battery Chargers

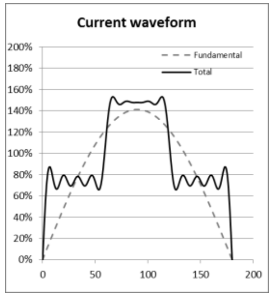
Harmonic Distortion

Supply Type

6 Pulse



Current Waveform



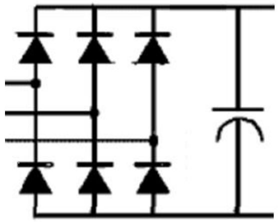
I-THD = 29%

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

Harmonic Distortion

Supply Type

6 Pulse



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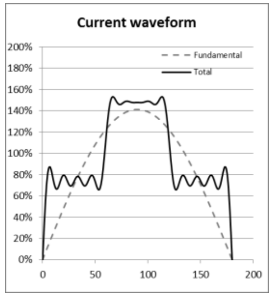
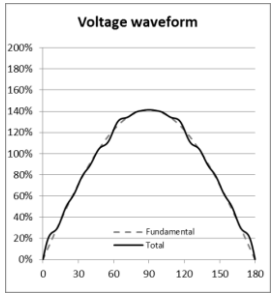


I-THD = 29%

Voltage Waveform

Transformer, SCR = 100



V-THD = 2.8%

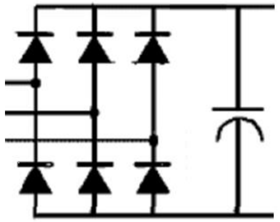
Switching current on a sub-cyclic basis results in a distorted current waveform

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

Harmonic Distortion

Supply Type

6 Pulse



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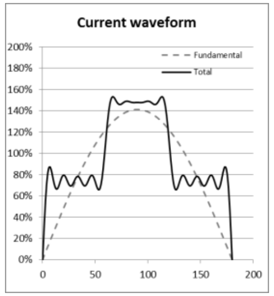

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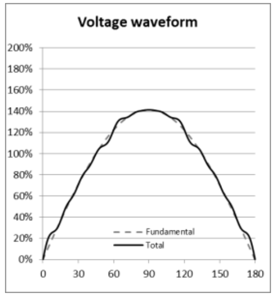
Voltage Waveform

Transformer, SCR = 100

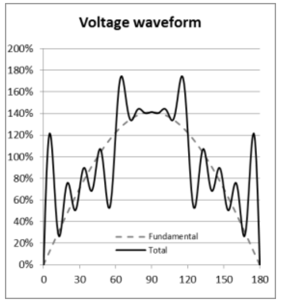


V-THD = 2.8%

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

Voltage Waveform

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

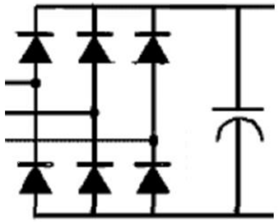
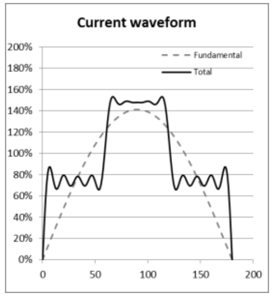
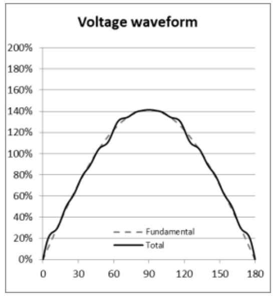
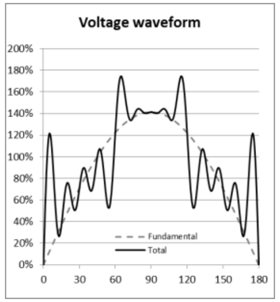
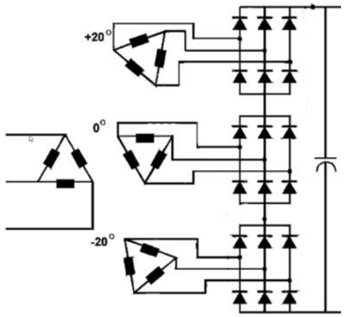
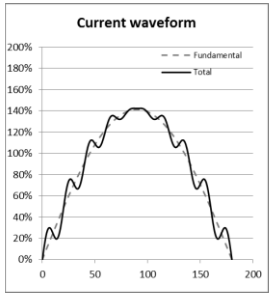
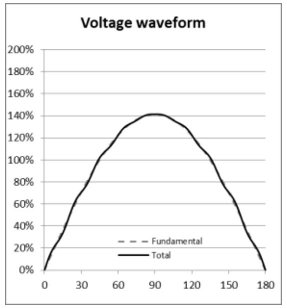
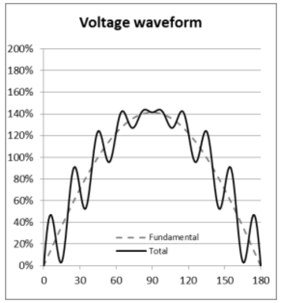


V-THD = 34%

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

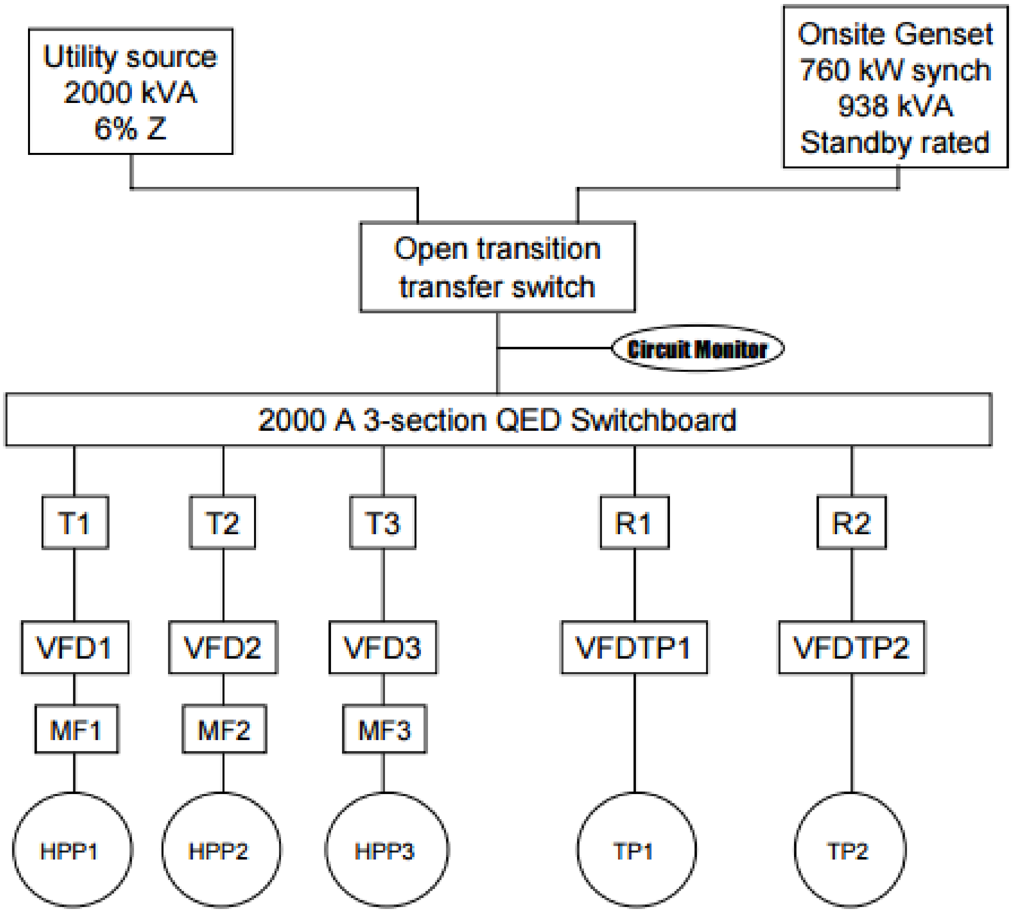
Harmonic Distortion

Switching circuit and the source impedance both affect voltage harmonic distortion

Supply Type	Current Waveform	Voltage Waveform Transformer, SCR = 100	Voltage Waveform Genset X''_d = 12%, SCR = 8
6 Pulse 	 I-THD = 29%	 V-THD = 2.8%	 V-THD = 34%
18 Pulse 	 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

*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

Case Study

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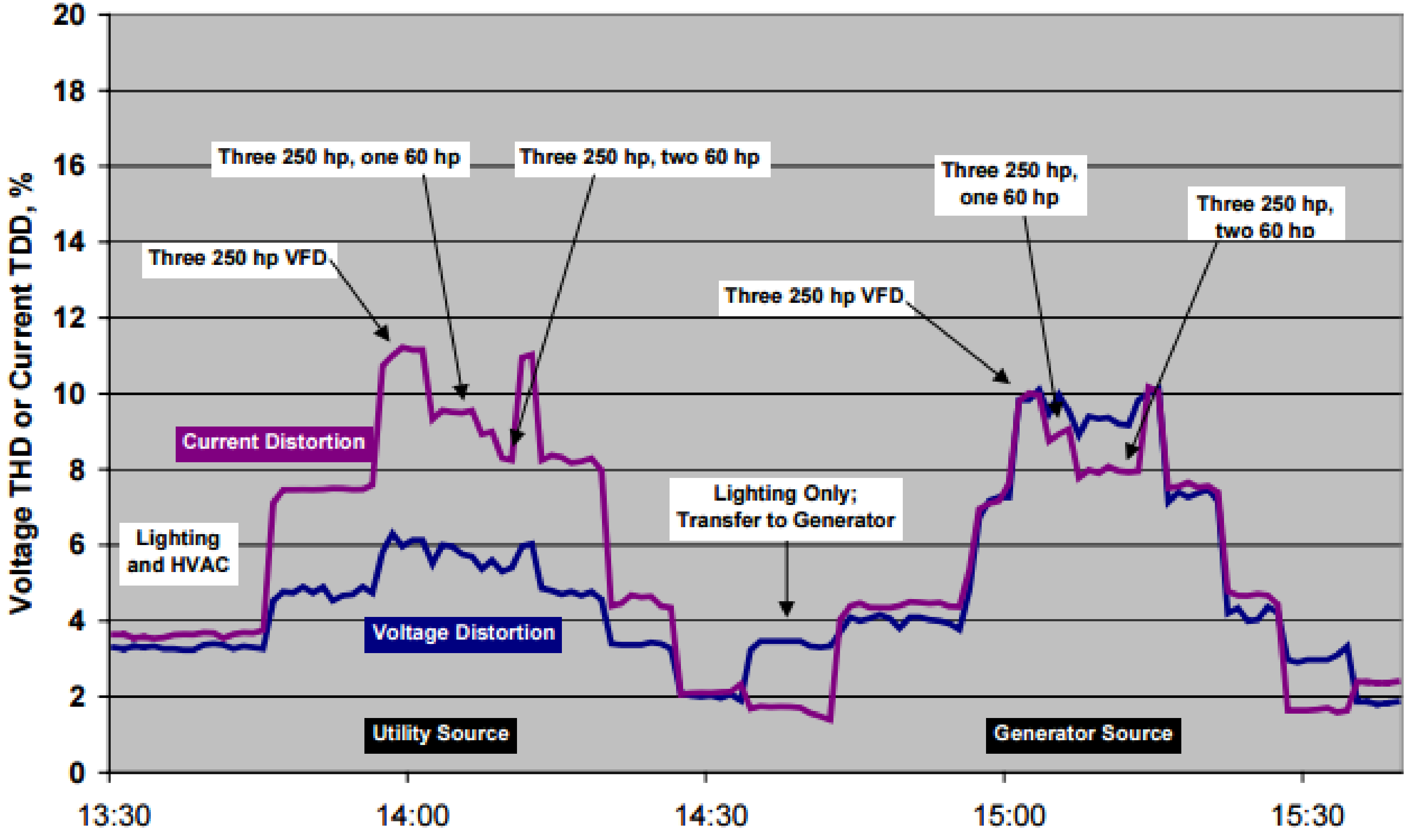

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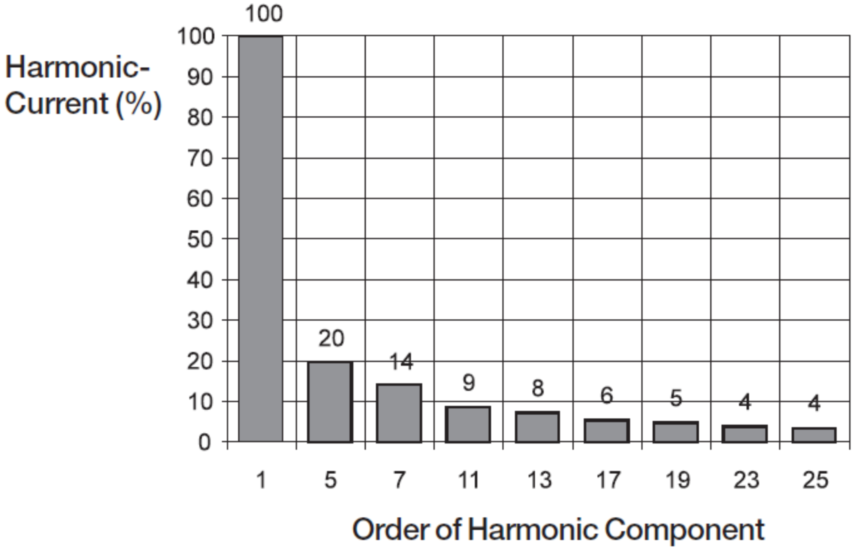
Power System Harmonics

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



$$V_{THD} = X * I_{THD}$$

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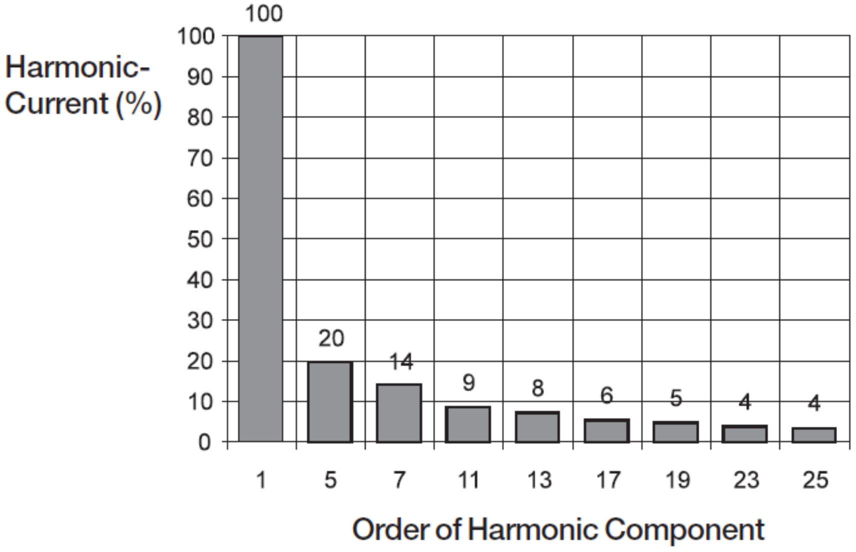

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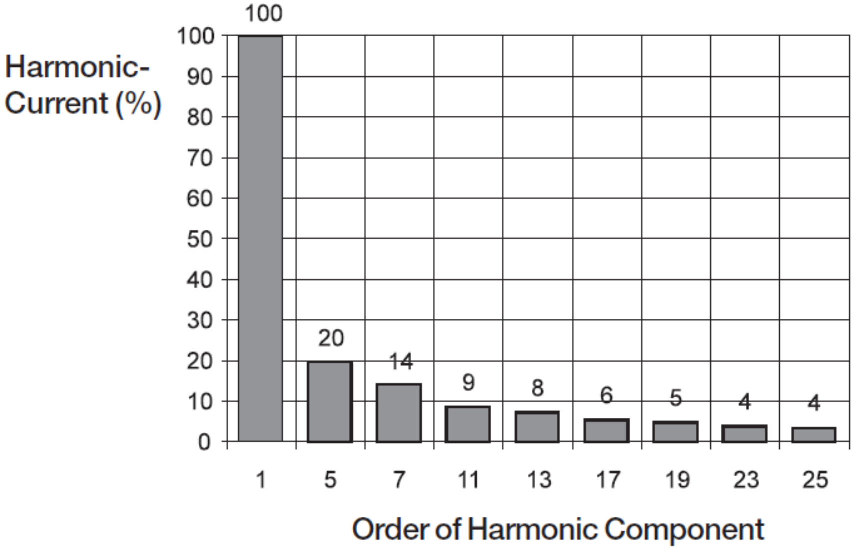
  - This results in an optimally sized alternator



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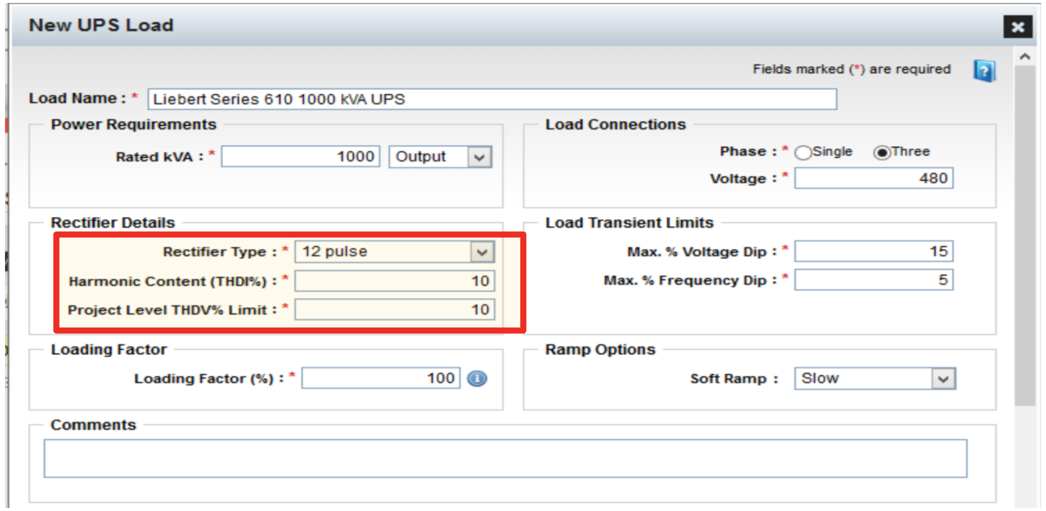

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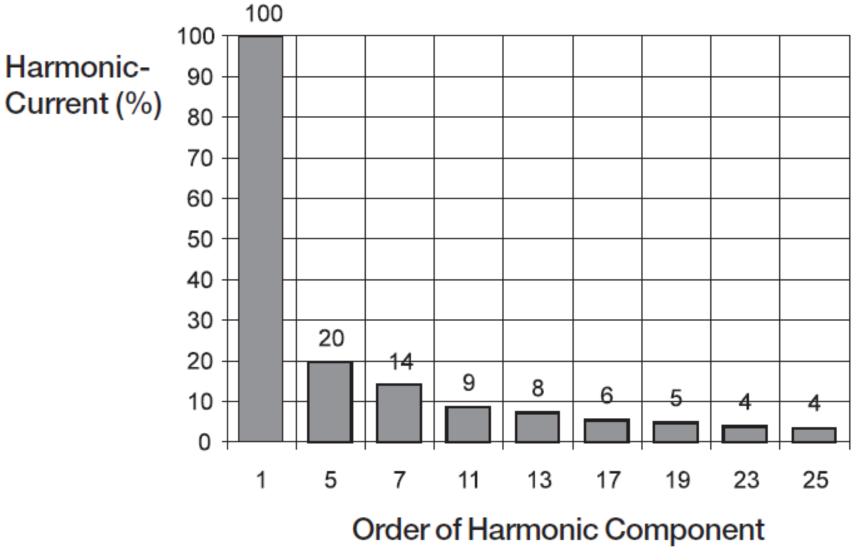

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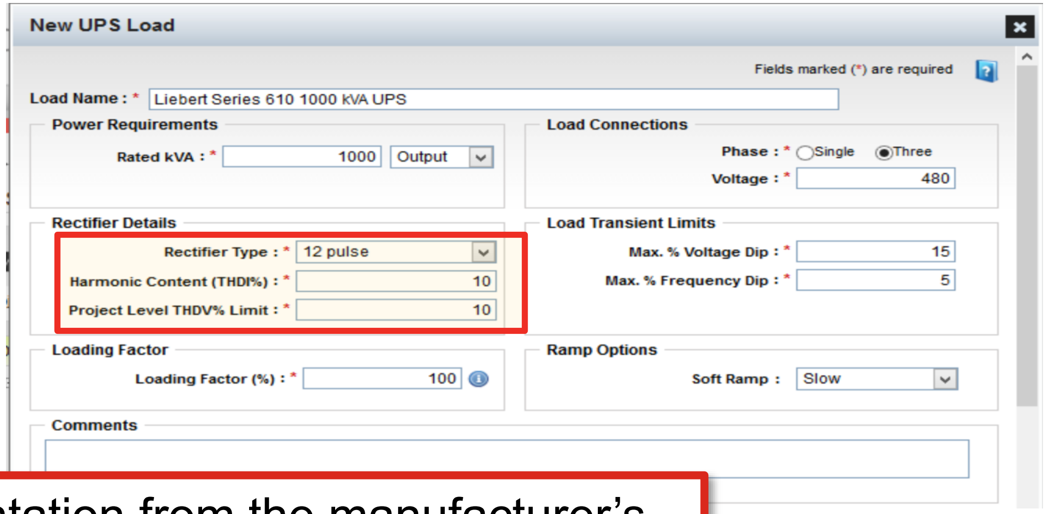

Spec Note Generator set manufacturer shall provide documentation from the manufacturer's sizing software demonstrating compliance with specified harmonic distortion limits.

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.

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Temperature Rise

Insulation system:	Class H throughout						
3 ø Ratings	(0.8 power factor)		60 Hz (wind				
			416 (12)	440 (12)	480 (12)	600 (07)
163° C rise ratings	@ 27° C	kW	3680	3592	3920	3920
		kVA	4600	4490	4900	4900
150° C rise ratings	@ 40° C	kW	3304	3496	3816	3816
		kVA	4130	4370	4770	4770
125° C rise ratings	@ 40° C	kW	3096	3272	3571	3571
		kVA	3870	4090	4464	4464
105° C rise ratings	@ 40° C	kW	2892	3056	3338	3338
		kVA	3615	3820	4172	4172
80° C rise ratings	@ 40° C	kW	2512	2640	2900	2900
		kVA	3140	3300	3625	3625

Voltage Class	< 10 kV	> 10 kV
Insulation Class	H	F
Total Temperature	180 C	160 C
Nominal Temp Rise	125 C	105 C
Nominal Ambient Temp	40 C	40 C
Hot Spot Allowance	15 C	15 C

4464 kVA is maximum load for 180 C insulation class

125 + 40 + 15 = 180

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

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
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Spec Note Specify generator performance criteria, not manufacturing method.

Specification Example

Specification Requirement:

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

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		kVA	4000	3840	4060	4430
125° C rise ratings	@ 40° C	kW	3000	2872	3040	3314
		kVA	3750	3590	3800	4142
105° C rise ratings	@ 40° C	kW	2760	2680	2840	3097
		kVA	3450	3350	3550	3871
80° C rise ratings	@ 40° C	kW	2424	2332	2468	2691
		kVA	3030	2915	3085	3364

3 Ø Reactances	380 (13)	416 (12)	440 (12)	480 (12)
(Based on full load at 125° C rise rating)				
Synchronous	2.700	3.120	2.948	2.700
Transient	0.193	0.220	0.208	0.191
Subtransient	0.142	0.161	0.152	0.140
Negative sequence	0.205	0.233	0.221	0.202
Zero sequence	0.027	0.031	0.029	0.027

Reactances at genset rating (3750 kVA)

Synchronous = 2.4 pu

Subtransient = .126 pu

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An oversized alternator may have…

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An oversized alternator may also have…

- Higher fault current
- Slower start time
- and may be more expensive!

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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

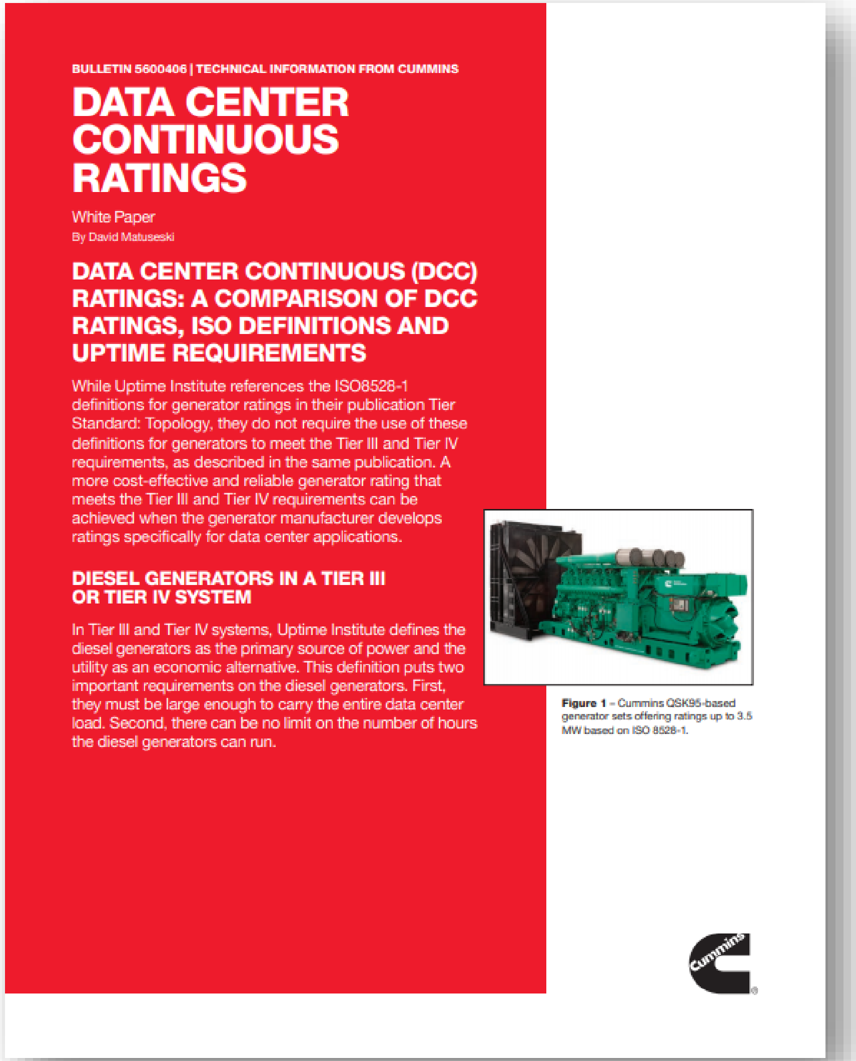
Additional Resources

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



BULLETIN 5600406 | TECHNICAL INFORMATION FROM CUMMINS

DATA CENTER CONTINUOUS RATINGS

White Paper

By David Matuseski

DATA CENTER CONTINUOUS (DCC) RATINGS: A COMPARISON OF DCC RATINGS, ISO DEFINITIONS AND UPTIME REQUIREMENTS

While Uptime Institute references the ISO8528-1 definitions for generator ratings in their publication Tier Standard: Topology, they do not require the use of these definitions for generators to meet the Tier III and Tier IV requirements, as described in the same publication. A more cost-effective and reliable generator rating that meets the Tier III and Tier IV requirements can be achieved when the generator manufacturer develops ratings specifically for data center applications.

DIESEL GENERATORS IN A TIER III OR TIER IV SYSTEM

In Tier III and Tier IV systems, Uptime Institute defines the diesel generators as the primary source of power and the utility as an economic alternative. This definition puts two important requirements on the diesel generators. First, they must be large enough to carry the entire data center load. Second, there can be no limit on the number of hours the diesel generators can run.

Figure 1 – Cummins QSK95-based generator sets offering ratings up to 3.5 MW based on ISO 8528-1.

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.

Rich Scroggins
Technical Advisor - Data Center Markets
Cummins Inc.

Michael Sanford
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Your local Cummins contacts:

- AZ, ID, NM, NV: Carl Knapp (carl.knapp@cummins.com)
- CO, MT, ND, UT, WY: Christopher Scott (christopher.l.scott@cummins.com)
- CA, WA, OR, AK, HI: Brian Pumphrey (brian.pumphrey@cummins.com)
- MA, ME, NH, RI, VT: Jim Howard (james.howard@cummins.com)
- CT, MD, NJ, NY : Charles Attisani (charles.attisani@cummins.com)
- Northern IL, MI : John Kilinskis (john.a.kilinskis@cummins.com)
- NE, SD, KS: Earnest Glaser (earnest.a.glaser@cummins.com)
- IL, IN, KY, MO: Jeff Yates (jeffrey.yates@cummins.com)
- IA, MO: Kirby Holden (kirby.holden@cummins.com)
- DE, MD, MN, ND, OH, PA, WI, WV: Michael Munson (michael.s.munson@cummins.com)
- TX: Scott Thomas (m.scott.thomas@cummins.com)
- OK, AR: Wes Ruebman (wes.ruebman@cummins.com)
- LA, MS, AL: Trina Casbon (trina.casbon@cummins.com)
- TN, GA: Mariano Rojas (mariano.rojas@cummins.com)
- FL: Bob Kelly (robert.kelly@cummins.com)
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Closing

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

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October – Emergency Power System Installations in Healthcare Applications

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