PROFESSIONAL DEVELOPMENT
SEMINAR SERIES

GPS-100 GENERATOR SIZING

LEARNER'S GUIDE

GENERAC® INDUSTRIAL POWER

WELCOME

Professional Development Seminar Series

Standby power systems are increasingly in demand. Commercial, industrial, municipal and healthcare facilities are just a few of the markets that require backup power. Generator sizing is a crucial part of the process when designing a system.

The ever-changing requirements of the power generation industry, coupled with requests for additional training, has prompted Generac Power Systems to develop this training program.

Titled the Generac Power Systems Professional Development Seminar Series, this program consists of individual training modules that provide both theoretical and practical information. Each module is 90 minutes in length and each incorporate proven learning methodology to ensure a positive experience. These modules are designed to broaden the learner's understanding of topics such as:

- Current Technologies
- Sizing
- Codes & Standards
- Switching Technologies
- Reliable Design Characteristics
- Paralleling
- Engines and Alternators
- Controls
- Emissions

THE MODULE IN PERSPECTIVE

PURPOSE:

This course presents methods and calculations for proper sizing of generators. Participants will explore the alternator's and engine's response to different types of loads while investigating different techniques to optimize the generator's performance.

TIME:

- 90 minutes of Classroom Instruction
- 30 minutes for Final Assessment

LEARNING OBJECTIVES:

Upon completion of this seminar, participants should be able to:

- Describe what traditional sizing programs do well
- Describe the limitations of traditional sizing programs
- Describe the basis for sizing new construction
- Explain the methodology used when sizing existing facilities
- Describe the affects of leading power factor on generators
- Explain alternator starting kVA requirements for across the line motor starts
- Explain the factors involved in determining inrush current
- Describe IEC and NEMA starting differences
- Describe rules of thumb for upsizing alternators for improved motor starting
- Explain how electro-mechanical reduced voltage starting operates
- Explain the affects of harmonics on generator voltage
- Describe how non-linear loads affect generators
- Explain various techniques used to reduce harmonic levels
- Explain the use of IGBT rectifiers
- Describe the function of an electronic soft starter
- Explain sizing requirements for use with variable frequency drives
- Explain regeneration as it applies to certain applications of variable frequency drives
- Explain the factors involved in sizing for UPS's
- Describe the three main UPS classifications
- Describe typical methods used to solve UPS problems

CONTINUING EDUCATION:

Upon successful completion of this seminar, participants will be awarded a certificate of achievement identifying the seminar title, 2.0 PDHs (Professional Development Hours) and 0.2 CEUs (Continuing Education Units).

Successful completion of a PDSS seminar requires that the participant have:

1. Attended the complete seminar
2. A minimum score of 80% on the Final Assessment

TRAINING AT A GLANCE

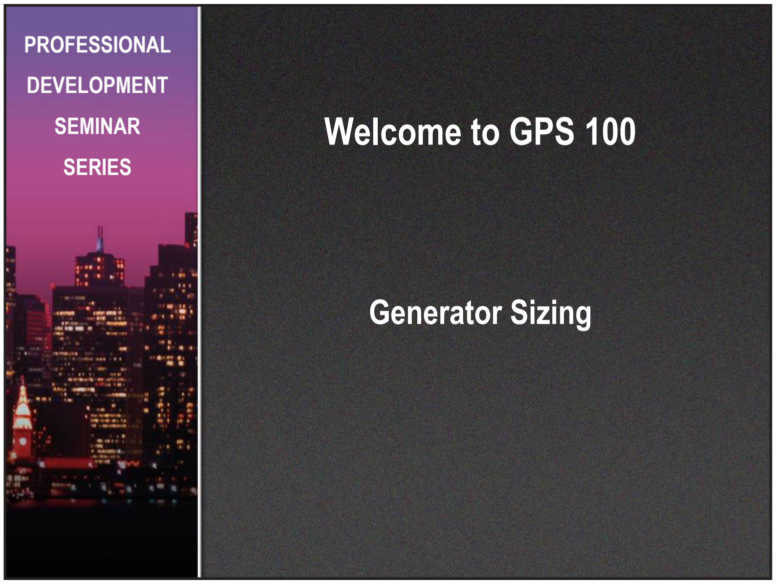
TIME	LESSON	DESCRIPTION
5 minutes	Introductions	Get to know other participants and the trainer. The trainer welcomes participants and conducts an opening activity.
15 minutes	Lesson 1 Sizing Programs & Loads	This lesson will present basic generator sizing and discuss issues relative to specific loads types. The goals is to help prevent mistakes when matching certain types of loads to generators.
20 minutes	Lesson 2 Motor Starting	Motors are a significant load on a generator. This lesson discusses the affects of motors and various motor starting methods. The goal is to provide you with general rules of thumb and help identify various motor starting issues when designing a system.
15 minutes	Lesson 3 Harmonics	The generator is a clean power source, but when applied to loads with high harmonic content, the generator voltage may become significantly compromised with harmonic voltage distortion. This lesson discusses various methods used to reduce these harmonic issues.
15 minutes	Lesson 4 Soft Starters & Variable Frequency Drives	This lesson describes how soft starters are used to start motors at a reduced voltage, thereby limiting the harmful affects caused by across the line full voltage starting. Variable Frequency Drives are also discussed and the affects they cause when controlling electric motors.
15 minutes	Lesson 5 UPS Sizing	This lesson discusses the three classifications of UPS's along with methods used to limit their affects on generator operation.
5 minutes	Conclusion	The trainer will review the objectives of the class and discuss how each objective was accomplished. An evaluation will be given out with which participants can provide feedback about the course. An assessment will also be given to each participant to evaluate the skills and knowledge they received from the course.

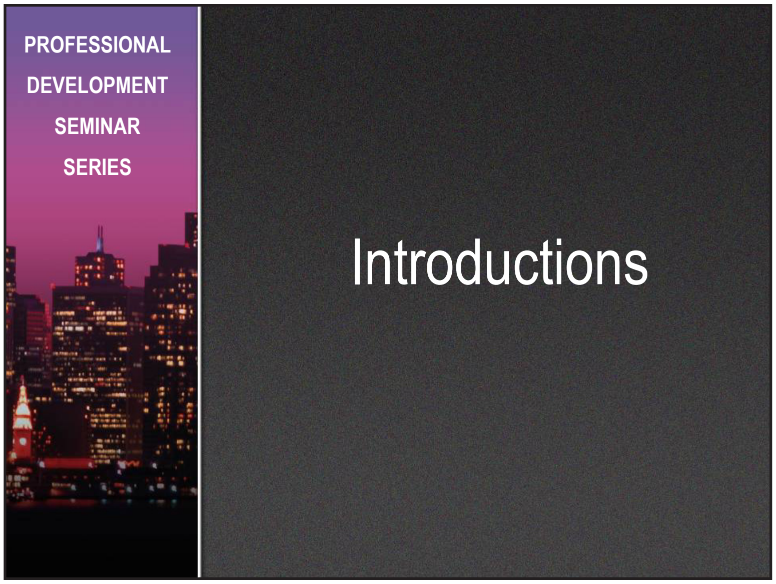
INTRODUCTION

TIME: 5 minutes

OBJECTIVE:

The introduction is an opportunity for the trainer and participants to become familiar with each other. This period will discuss the topics to be covered, capture initial questions and introduce generator sizing.





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What You Will Learn

Upon completion of this seminar, participants will be familiar with the various factors involved with generator sizing. Specifically, they will be able to:

- **Describe what traditional sizing programs do well**
- **Describe the limitations of traditional sizing programs**
- **Describe the basis for sizing new construction**
- **Explain the methodology used when sizing existing facilities**
- **Describe the affects of leading power factor on generators**
- **Explain alternator starting kVA requirements for across the line motor starts**
- **Explain the factors involved in determining inrush current**
- **Describe IEC and NEMA starting differences**
- **Describe rules of thumb for upsizing alternators for improved motor starting**
- **Explain how electro-mechanical reduced voltage starting operates**

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What You Will Learn (continued)

Upon completion of this seminar, participants will be familiar with the various factors involved with generator sizing. Specifically, they will be able to:

- **Explain the affects of harmonics on generator voltage**
- **Describe how non-linear loads affect generators**
- **Explain various techniques used to reduce harmonic levels**
- **Explain the use of IGBT rectifiers**
- **Describe the function of an electronic soft starter**
- **Explain sizing requirements for use with variable frequency drives**
- **Explain regeneration as it applies to certain applications of variable frequency drives**
- **Explain the factors involved in sizing for UPS's**
- **Describe the three main UPS classifications**
- **Describe typical methods used to solve UPS problems**

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NOTES

INTRODUCTION

What You Will Learn

Topics Covered	Estimated Time
Introduction	5 min
Sizing Programs & Loads	15 min
Motor Starting	20 min
Harmonics	15 min
Soft Starters & Variable Frequency Drives	15 min
UPS Sizing	15 min
Conclusion	5 min

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Ten Points of Sizing Pain

1. **Limitations of Traditional Sizing Programs**
2. **Load Uncertainty in New Construction**
3. **Leading Power Factor Problems**
4. **Managing Motor Starting Transients**
5. **Avoiding Reduced Voltage Surprises**
6. **Planning for Harmonics**
7. **IGBT Rectification Surprises**
8. **Soft Starters**
9. **VFDs and Regeneration – Elevators & Cranes**
10. **UPS Sizing**

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NOTES

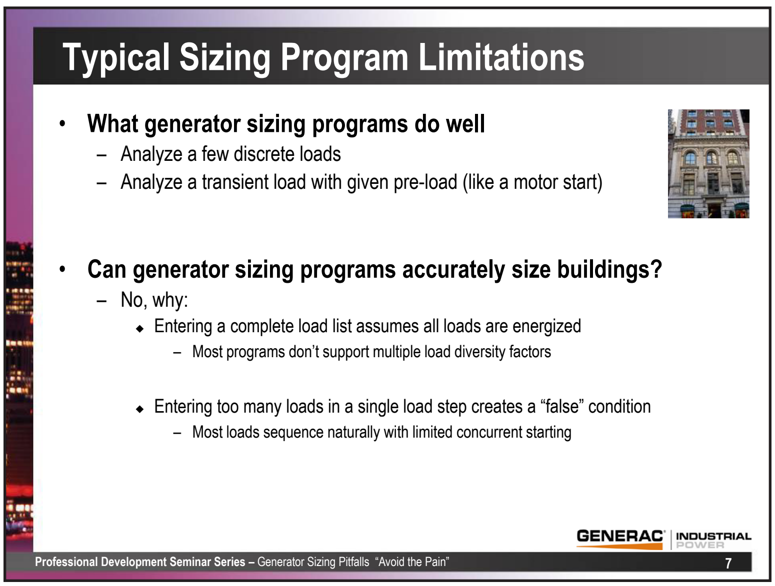
1. SIZING PROGRAMS & LOADS

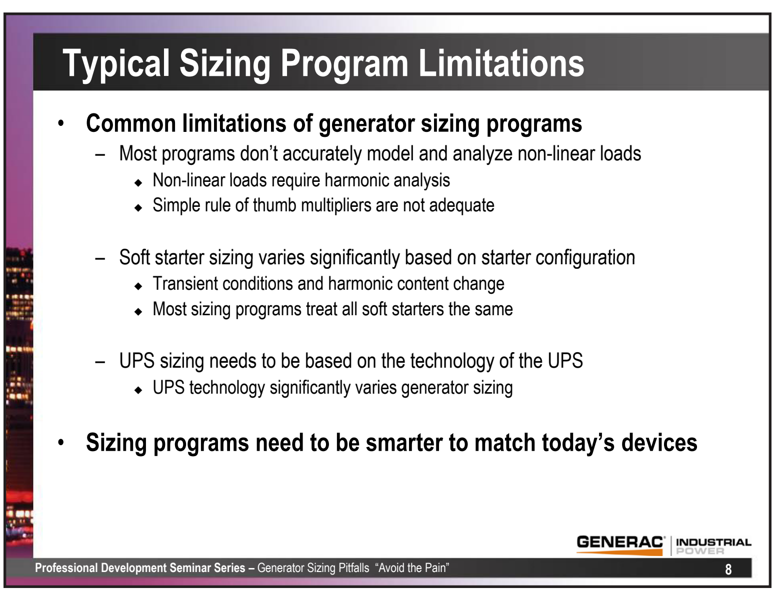
TIME: 15 minutes

OBJECTIVES:

Upon completion of this lesson, participants should be able to:

- Describe what traditional sizing programs do well
- Describe the limitations of traditional sizing programs
- Describe the basis for sizing new construction
- Explain the methodology used when sizing existing facilities
- Describe the affects of leading power factor on generators





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Load Uncertainty – New Construction

- **What types of loads will be connected?**
  - Resistive
  - Motor Loads
  - Non-Linear
- **What is the anticipated load level (new construction)?**
  - Often services are sized conservatively (actual loads of 50% are not uncommon)
  - Typically, the generator is sized less robust than the service
- **What circuits are going to be connected?**
  - End users often want a large load list initially
  - What loads are essential & what are optional?
- **New construction should be sized using engineering judgment**

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Load Uncertainty – Load Growth

- **What is the expected load growth?**
  - Does the end user have an aggressive growth plan?
  - How certain is the business model?
  - What is the value of different capital expenditures?
- **Would the end user benefit from an expandable solution?**
  - Is paralleled generation an option?

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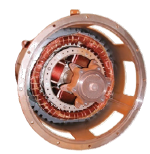
NOTES

NOTES

Load Uncertainty – Transient Loads

- **What are the largest load steps on the generator?**
  - Starting large motor loads can challenge system sizing
- **What are the acceptable transient limits?**
  - Generators are not infinite sources
  - Expect voltage & frequency dips
  - Size for total power and transient performance
    - Size based upon largest load step while powering the building
    - For general (non-dedicated) loads, limit the voltage dip to 15%
    - For general (non-dedicated) loads, limit the frequency dip to 5 to 10%



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Load Uncertainty – Existing Facilities

- **Billing History**
  - Demand charges (capture peak kW)
    - Captures seasonality & business cycles
    - Peak power over 15 minute average
- **Power Analyzer**
  - Snapshot / short history (measures transient spikes)
  - Capture power quality
    - Harmonic content
    - Power factor
- **Existing facilities should utilize historical & measurement data**

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Leading Power Factor (PF)

- **Generators are rated for .8 pf (lagging) to 1.0 pf**
- **Leading power factor can cause self excitation resulting in**
  - Voltage instability
  - Over-voltage shutdowns
- **Sources of leading power factor**
  - Power factor correction capacitors at the service
  - Lightly loaded (less than 30%) UPS's with filtering
- **If power factor is leading**
  - Remove the leading power factor elements
  - Add offsetting lagging power factor loads

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Key Point Summary

- **Recognize the limitations of the sizing program you utilize**
  - Be cautious of entering too many loads into a single load step
- **When sizing a building**
  - Matching the service size will often oversize the generator
  - Use billing history & actual data (when available)
  - Consider expandable, paralleled solutions if load growth is uncertain
- **Leading power factor can cause generator voltage issues**

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NOTES

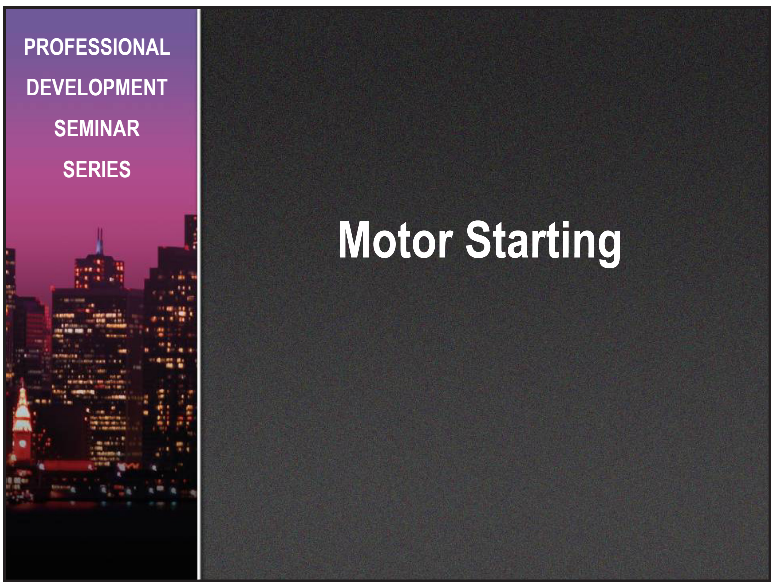
2. MOTOR STARTING

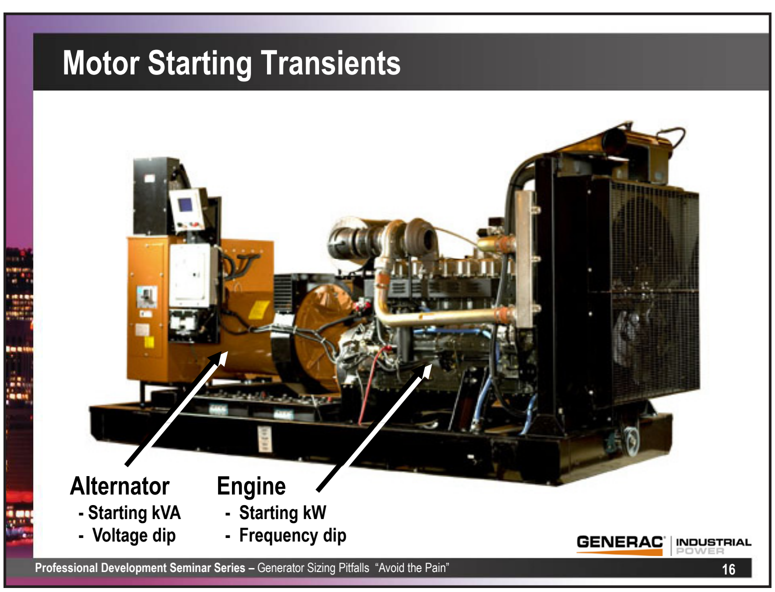
TIME: 20 minutes

OBJECTIVES:

Upon completion of this lesson, participants should be able to:

- Explain alternator starting kVA requirements for across the line motor starts
- Explain the factors involved in determining inrush current
- Describe IEC and NEMA starting differences
- Describe rules of thumb for upsizing alternators for improved motor starting
- Explain how electro-mechanical reduced voltage starting operates





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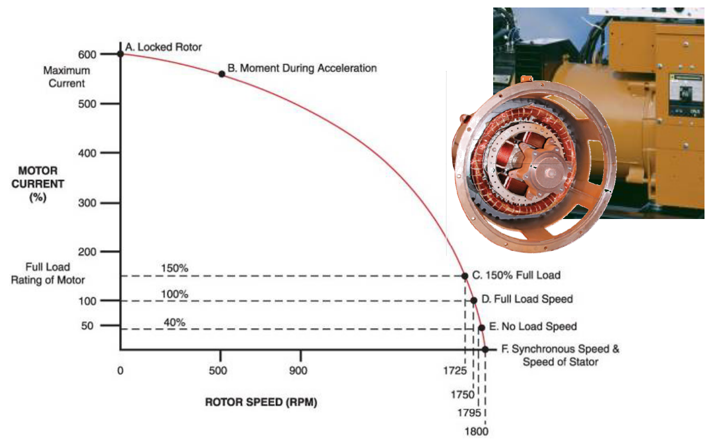
Motor Starting Transients (starting kVA)



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Motor Starting Transients (starting kVA)

- **What happens when a contactor closes to start an electric motor?**
  - Immediate inrush of current
  - Inrush is referenced as:
    - Locked rotor current
    - Inrush current
    - Motor starting current
    - Start kVA

$$skVA = \frac{V_{LL} * I_{LR} * \sqrt{3}}{1000}$$

$$623 = \frac{480 * 750 * \sqrt{3}}{1000}$$

Note: **"s" indicates the motors starting period**
"r" indicates the motors running period

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2. MOTOR STARTING

Motor Starting Transients (starting kVA)

- **Starting codes**
  - Determines skVA
  - NEMA standard
    - Always check motor plate for NEMA Code
- **Example:**
  - 100hp x 6.0 skVA/hp = 600 skVA (Code G Motor)

Letter Designation	kVA per hp
A	0 – 3.15
B	3.15 – 3.55
C	3.55 – 4.0
D	4.0 – 4.5
E	4.5 – 5.0
F	5.0 – 5.6
G	***5.6 – 6.3***
H	6.3 – 7.1
J	7.1 – 8.0
K	8.0 – 9.0
L	9.0 – 10.0
M	10.0 – 11.2
N	11.2 – 12.5
P	12.5 – 14.0
R	14.0 – 16.0
S	16.0 – 18.0
T	18.0 – 20.0
U	20.0 – 22.4
V	22.4 and up

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Motor Starting Transients (starting kVA)

- **Starting codes**
  - Three phase
    - Typically have a NEMA starting code
  - Single phase
    - May not have a NEMA starting code
    - Starting kVAs vary broadly
  - IEC vs. NEMA
    - European motors (IEC) typically have higher starting currents
  - High efficiency
    - High efficiency motors have higher starting currents

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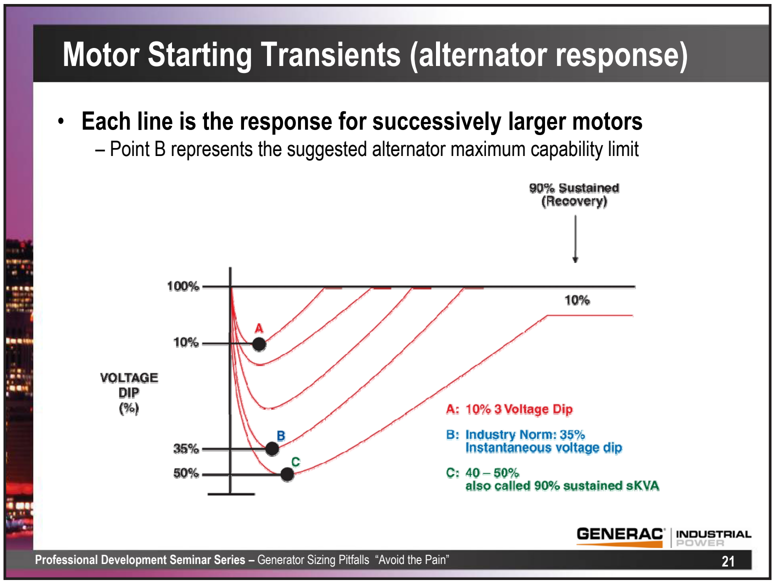

Motor Starting Transients (alternator response)
Each line is the response for successively larger motors
– Point B represents the suggested alternator maximum capability limit
90% Sustained (Recovery)
100%
10%
VOLTAGE DIP (%)
35%
50%
A
B
C
10%
A: 10% 3 Voltage Dip
B: Industry Norm: 35% Instantaneous voltage dip
C: 40 – 50% also called 90% sustained sKVA
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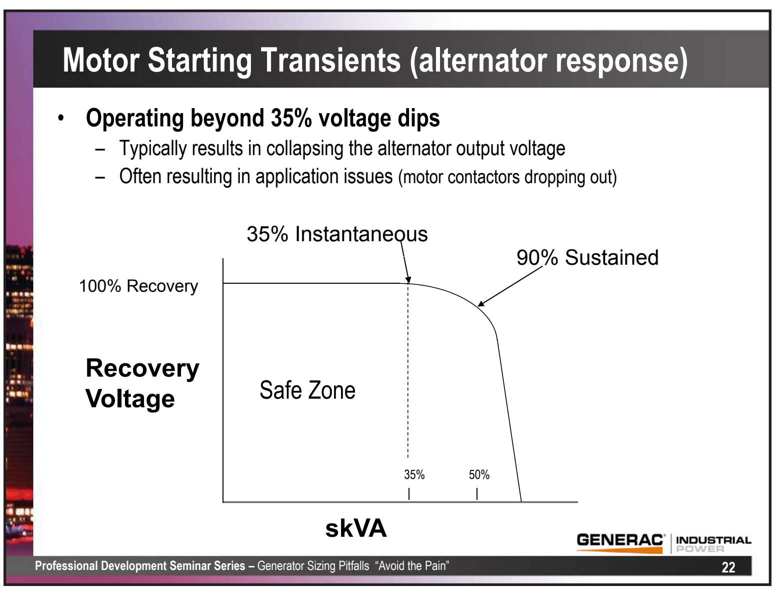
21



Motor Starting Transients (alternator response)
Operating beyond 35% voltage dips
– Typically results in collapsing the alternator output voltage
– Often resulting in application issues (motor contactors dropping out)
35% Instantaneous
90% Sustained
100% Recovery
Recovery Voltage
Safe Zone
35%
50%
skVA
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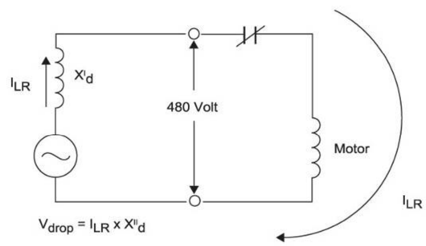
Motor Starting Transients (alternator response)

- **Why does the alternator voltage dip?**
  - Ohm's law : V = IR



- **How do we minimize the voltage dip?**

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Motor Starting Transients (alternator response)

- **Improve motor starting**
  - Minimize X "$_d$ (generator reactance)

Upsize the Alternator

Rule of Thumb Formula

100hp x 6.0 skVA /hp = 600 skVA

Vdip	35%	25%	20%	10%
Alternator Model	**175**	**230**	**275**	**750**

Minimize voltage dip by upsizing alternator

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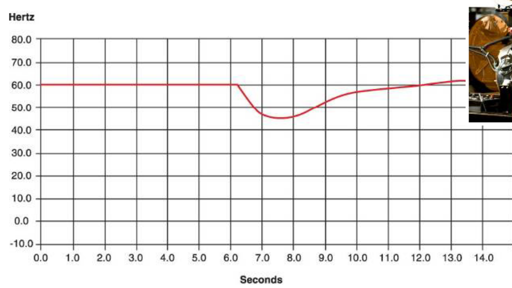
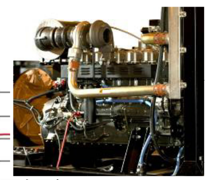
Motor Starting Transients (engine response)

- **How does the engine respond to motor starting?**
  - Frequency dips
    - Level of dip is engine size, type, and technology dependant





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Motor Starting Transients (engine response)

- **Why does the engine speed dip during a motor start?**
  - PF = kW/kVA
    - skW = skVA x sPF
  - Example of skW (Start kW)
    - 100 hp x 6.0 (skVA/hp) = 600 skVA
    - 600 skVA x .3 sPF = 180 skW
  - Starting PF
    - Function of motor size & design
    - Typical three phase 1000hp~5hp (.25 to .45)
    - Increases when kVA decreases

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Motor Starting Transients (engine response)

- **Engine speed (frequency)**
  - Frequency will dip
  - $kW_{starting}$ = 2 x motor hp (conservative estimate for across line starting)
- **Engine performance**
  - 10 hertz dip @ 100% load step (average diesel performance)
- **Load acceptance**
  - Most loads are tolerant of frequency dips
  - Some loads are not
    - Be careful with some UPS technologies (more on UPS systems later in presentation)

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Motor Starting Transients (rules of thumb)

- **Alternator**
  - skVA $\cong$ hp x 6.0
  - rkVA $\cong$ hp
- **Engine**
  - skW $\cong$ hp x 2
  - rkW $\cong$ hp x .85

EXCEPTIONS: SPECIALTY MOTORS

Submersible Pumps

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Motor Starting Transients (exercise)

- If these three motors are at a pump station, which would you start first?
  - 50hp, 100hp, 200hp
- Exercise 1 (start sequence 200hp, 100hp, 50hp)
- Exercise 2 (start sequence 50hp, 100hp, 200hp)
- Exercise 3 (start all the motors simultaneously)

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Motor Starting Transients (exercise)

Example 1 Start sequence – 200hp 1st, 100hp 2nd, 50hp 3rd

Start 200hp x 2 = 400 skW (need 400 kW genset minimum)

Run 200hp x .85 = 170 rkW (preload for next load step)

Start 100hp x 2 = 200 skW + 170 rkW = 370 skW (400 kW genset is still enough)

Run 300hp total x .85 = 255 rkW (preload for next step)

Start 50hp x 2 = 100 skW + 255 rkW = 355 skW (400 kW engine)

To determine alternator size for voltage dip
assume skVA = 6 x hp = 6 x 200hp = 1200 skVA

To determine voltage dip, use alternator motor starting table / specs

Recommended Size 400 kW

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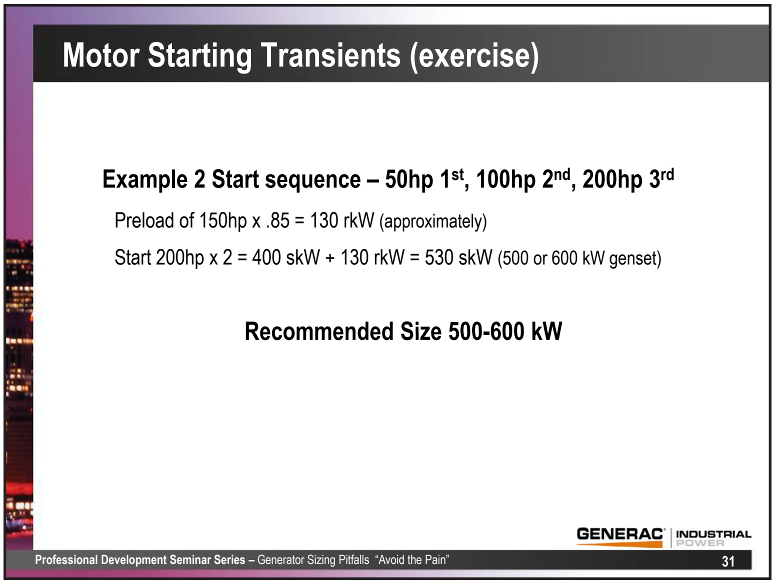

Motor Starting Transients (exercise)
Example 2 Start sequence – 50hp 1st, 100hp 2nd, 200hp 3rd
Preload of 150hp x .85 = 130 rkW (approximately)
Start 200hp x 2 = 400 skW + 130 rkW = 530 skW (500 or 600 kW genset)
Recommended Size 500-600 kW
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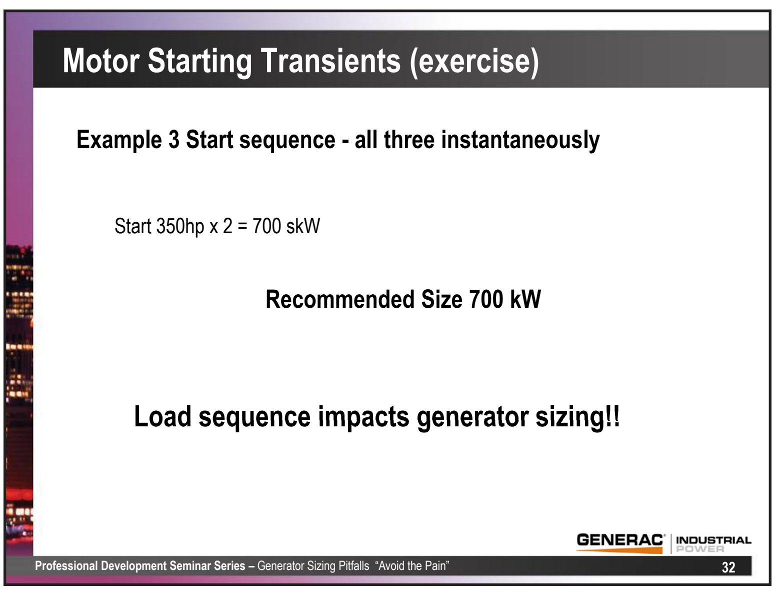
31



Motor Starting Transients (exercise)
Example 3 Start sequence - all three instantaneously
Start 350hp x 2 = 700 skW
Recommended Size 700 kW
Load sequence impacts generator sizing!!
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32

NOTES

Reduced Voltage Starting

- **Electro-Mechanical reduced voltage starters**
  - Reduce voltage & current
  - Significantly reduce skVA & skW
  - Also reduce starting torque

Starting Method	% volts at motor	% skVA	% LR Torque
Full Voltage	100	100	100
Autotrans.			
80% tap	80	64	64
65% tap	65	42	42
50% tap	50	25	25
Star-Delta	57	33	33

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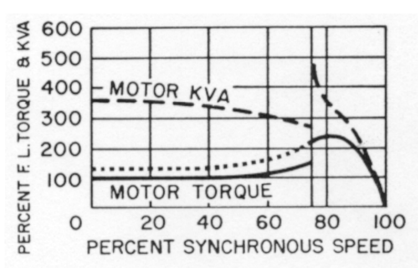
Reduced Voltage Starting

- **What happened at 75% speed? (motor switches to full voltage -- early)**
  - What will happen to the alternator?
  - What is the assumption inside most sizing programs?
  - This effect is typically problematic only in single motor load applications.



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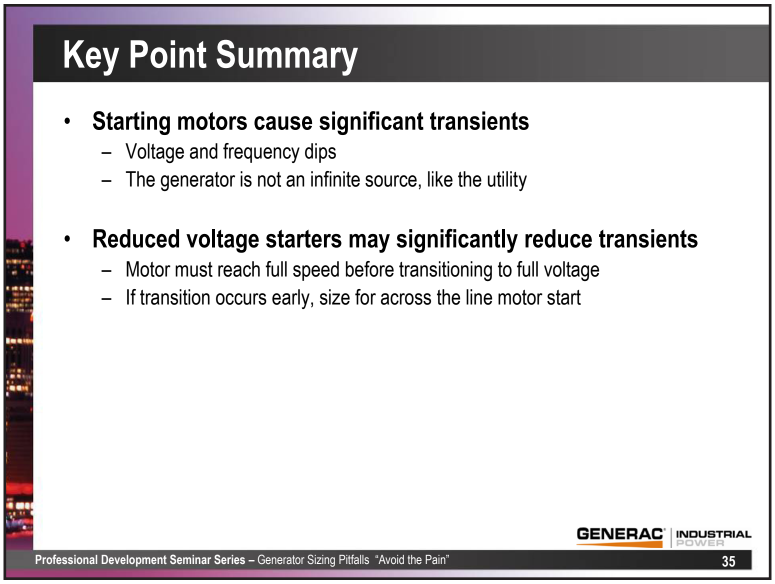
NOTES


Key Point Summary
• Starting motors cause significant transients
– Voltage and frequency dips
– The generator is not an infinite source, like the utility
• Reduced voltage starters may significantly reduce transients
– Motor must reach full speed before transitioning to full voltage
– If transition occurs early, size for across the line motor start
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35

NOTES

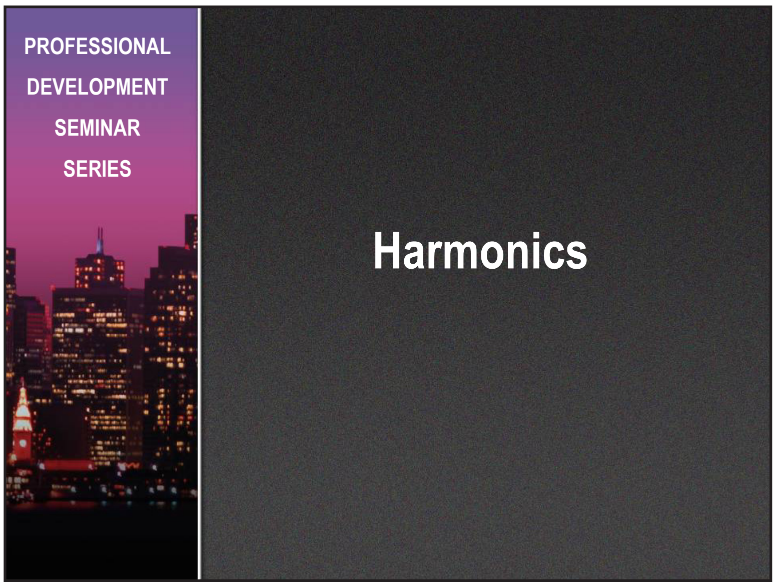
3. HARMONICS

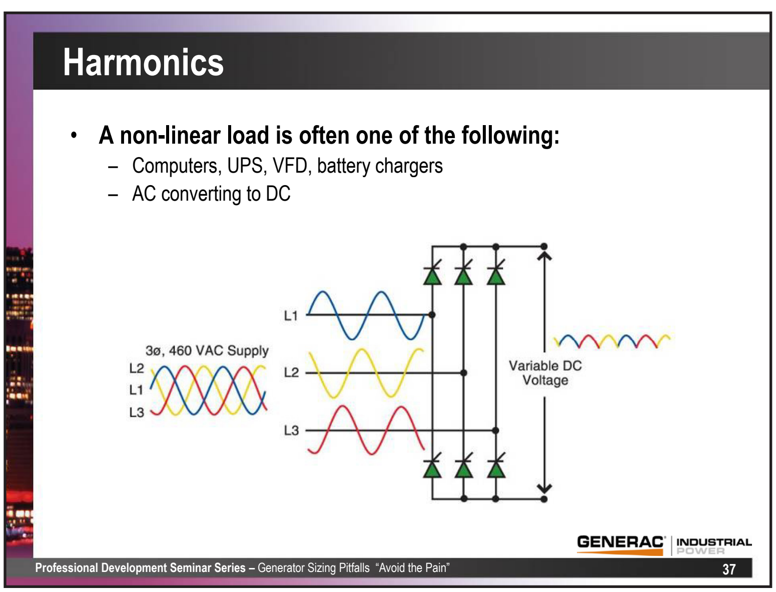
TIME: 15 minutes

OBJECTIVES:

Upon completion of this lesson, participants should be able to:

- Explain the affects of harmonics on generator voltage
- Describe how non-linear loads affect generators
- Explain various techniques used to reduce harmonic levels
- Explain the use of IGBT rectifiers





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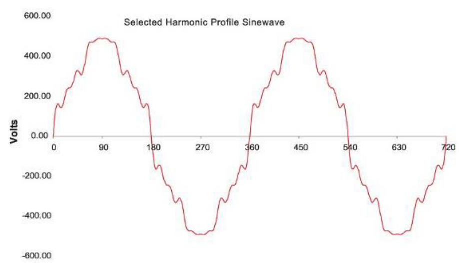
3. HARMONICS

Harmonics

- **How does a non-linear load affect a generator?**
  - It causes harmonic voltage distortion (THVD)
  - This is 10% voltage distortion – maximum limit of IEEE 519



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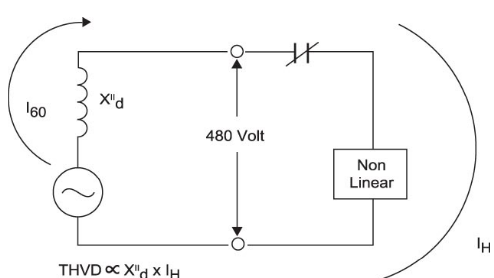
Harmonics

- **Why are generators affected?**
  - Load generates harmonic currents
    - Harmonic currents flow through the alternator's source impedance
    - Ohm's Law: $V = I \times R$ or $THVD \propto X''_d \times I_H$



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NOTES

NOTES

Harmonics

- **How to minimize harmonics to acceptable levels?**
  - Active or passive filtering
  - Upsizing the alternator (minimize the source impedance – x''_d)
  - Rules of thumb for typical 6 pulse, **unfiltered** loads (35% THID)
    - Upsize the alternator (2 to 2.5 x non-linear load @ 480V)
    - Upsize the alternator (3 to 3.5 x non-linear load @ 208V)
    - Upsize the alternator (5 x for small single phase units)
  - Rules of thumb for typical 6 pulse, **filtered** loads (10% THID)
    - No upsized alternator required
  - Rules of thumb vary significantly based on:
    - The device's harmonic current level
    - Size & voltage of the alternator

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Harmonics

- **Don't rely heavily on "Rules of Thumb" for harmonic loads**
  - Rely on harmonic analysis
    - Inputs are harmonic current spectrum and alternator reactance
    - Output is an estimated voltage distortion

Non-Linear Load Sizing
Estimating Voltage Distortion

GENERAC POWER SYSTEMS, INC.

Select an Alternator	Select Voltage	Select Load Characteristics
230 kW	480/277 Wye 3 Phase	6 Pulse Rectifier Typical (no filtering)

Input Non-linear Load kVA (non-linear only)	100
Generator THVD	3.0%
Generator Base KVA	313
Generators Reactance	13.0%
Alternator Reactance on non-linear base (target < 6% for typical)	4.2%

Enter your custom harmonic profile (percent of fundamental)

Harmonic Number	Custom Harmonic Profile	Selected Load Characteristics
3	0.0%	0.0%
5	0.0%	30.0%
7	0.0%	12.0%
9	0.0%	0.0%
11	0.0%	8.9%
13	0.0%	5.6%
15	0.0%	0.0%
17	0.0%	4.4%
19	0.0%	4.1%
Total Harmonic Current (load)	0.00%	34.51%
Estimated THVD (load induced)	0.00%	9.04%
Estimated THVD	NA	9.52%

Alternator is sized to limit estimated voltage distortion to approximately 10%

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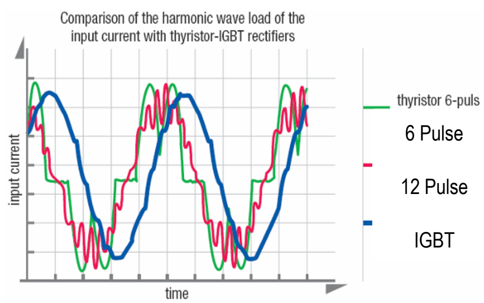
IGBT Rectifiers

- **A new type of rectifier is appearing in drives & UPSs**
  - IGBT (Insulated Gate Bipolar Transistor) technology
  - Active power factor correction (.99 pf)
  - Spec'd as very low distortion



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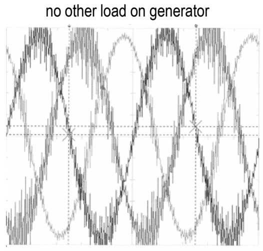
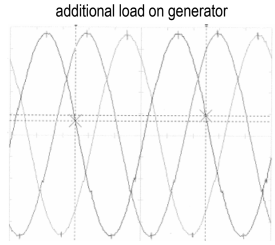
IGBT Rectifiers

- **Noise problem when IGBT is the only load on generator**
  - Connecting other loads solves the problem (15 – 20% of device rating)
  - We have seen this with multiple suppliers (UPS & Drives)

IGBT UPS with no other load on generator



Same UPS with additional load on generator



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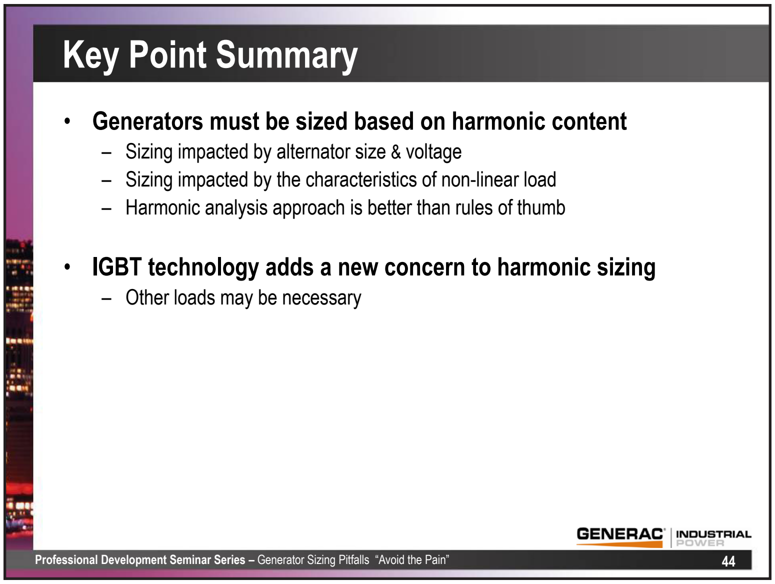
Key Point Summary
• Generators must be sized based on harmonic content
– Sizing impacted by alternator size & voltage
– Sizing impacted by the characteristics of non-linear load
– Harmonic analysis approach is better than rules of thumb
• IGBT technology adds a new concern to harmonic sizing
– Other loads may be necessary
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44

NOTES

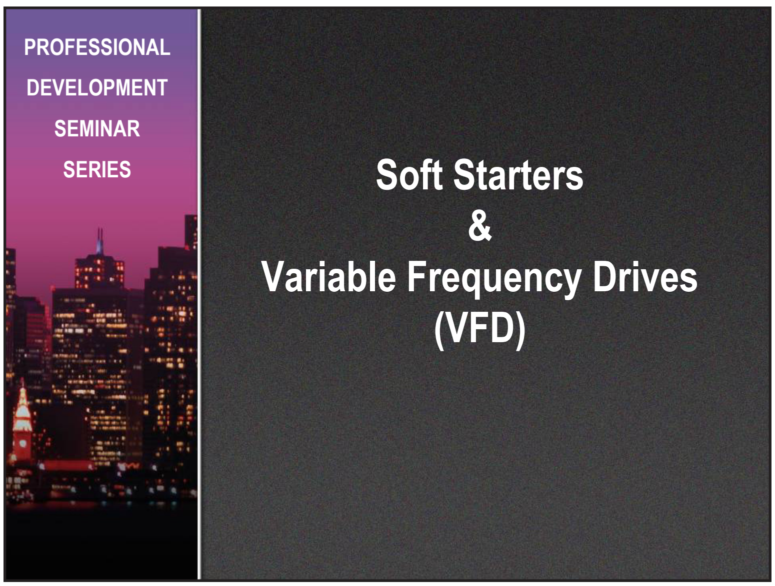
4. SOFT STARTERS & VARIABLE FREQUENCY DRIVES

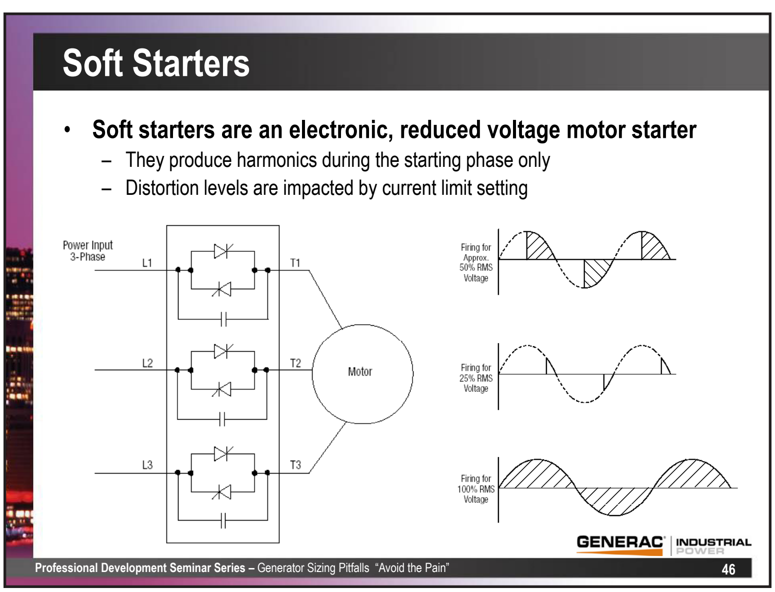
TIME: 15 minutes

OBJECTIVES:

Upon completion of this lesson, participants should be able to:

- Describe the function of an electronic soft starter
- Explain sizing requirements for use with variable frequency drives
- Explain regeneration as it applies to certain applications of variable frequency drives





NOTES

Soft Starters

- **Harmonics (alternator sizing)**
  - At 300% current limit, estimated distortion is 30 % THID
    - The minimum alternator size is 2 to 3 times the largest motor being started
    - Higher current limit settings will require a larger alternator
    - Harmonic analysis is preferred to using "rules of thumb"
  - Sequence start when possible
    - Harmonics are only present during the starting phase

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Soft Starters

- **Soft starters can ramp-up voltage or step voltage**
  - To avoid voltage & frequency dips always enable voltage ramping
  - Voltage ramping creates a soft loading of the generator
  - If no voltage ramping is utilized, expect transients as listed below

Current Limit	skVA	skW
200%	2 x Hp	.12 x Hp
300%	3 x Hp	.45 x Hp
400%	4 x Hp	.8 x Hp
500%	5 x Hp	1.25 x Hp

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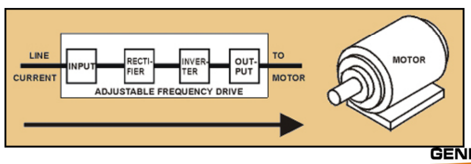
NOTES

VFDs & Regeneration

- **Variable Frequency Drives (VFDs)**
  - VFD is seen as a rectifier by the generator
- **Generator sizing for VFDs**
  - Voltage & frequency transients are not an issue
  - Harmonics are an issue
    - Harmonics are always present
    - Size as if a non-linear load
    - Limit system voltage dips to 15%



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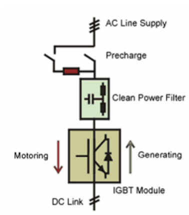
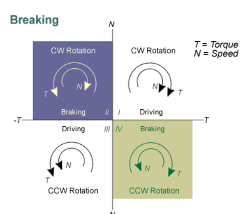
VFDs & Regeneration

- **Cable elevators and cranes regenerate**
  - When the load is going down, the drive is a break
  - Regeneration kW = hp x .8
  - How is the power dissipated?
    - Breaking Resistor
    - Put other loads on the generator
    - Unit mounted load bank
    - Don't rely on the generator as a brake





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NOTES

Key Point Summary

- **Soft Starters**
  - Sequence start to minimize harmonic content
  - Limit harmonics by limiting current limit setting
  - Limit transients by using voltage ramp feature
- **VFDs**
  - Size as non-linear load
  - Plan for regeneration with cable elevators and cranes

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NOTES

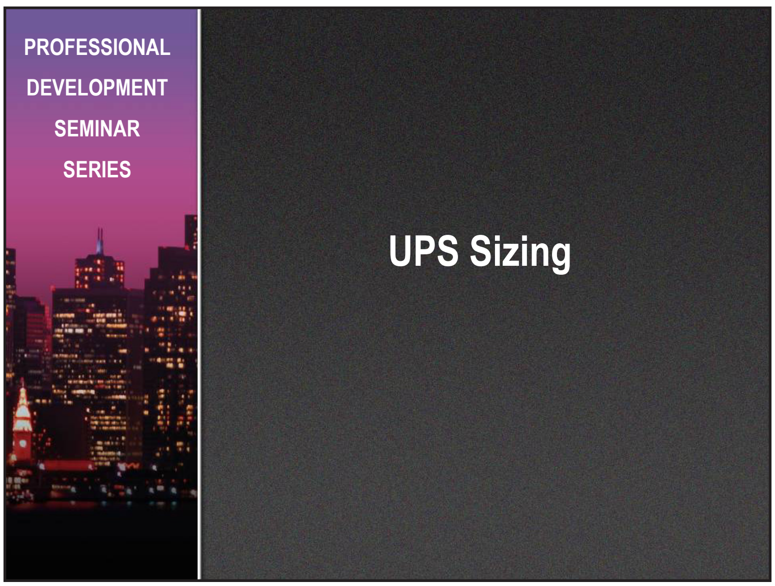
5. UPS SIZING

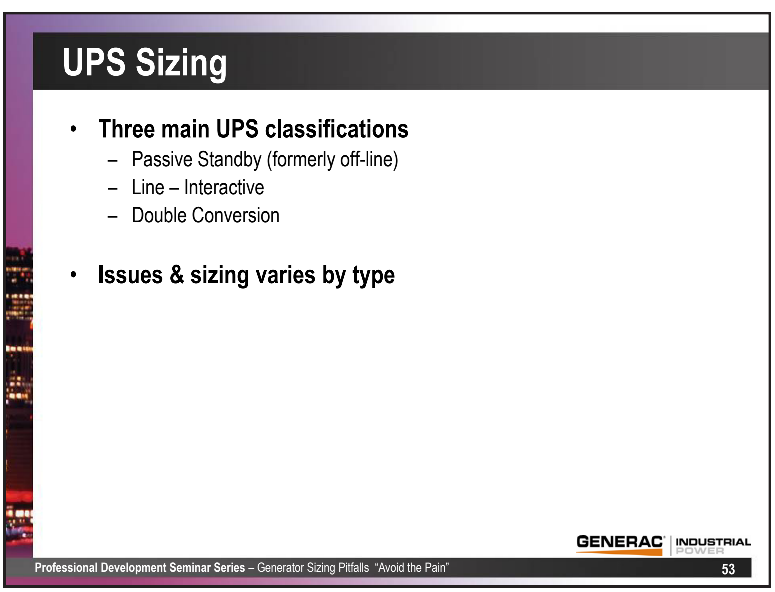
TIME: 15 minutes

OBJECTIVES:

Upon completion of this lesson, participants should be able to:

- Explain the factors involved in sizing for UPS's
- Describe the three main UPS classifications
- Describe typical methods used to solve UPS problems





NOTES

5. UPS SIZING

UPS Sizing

- **Passive UPS**
  - Simple design, low cost and small size
  - Typically single phase, desktop UPS
- **Sizing concerns**
  - Harmonics (multiple units, high THID)
  - Size to control voltage distortion
  - Load is stepped onto generator (not issue, small size)
- **Generator kW rating is UPS x 5 (typically)**

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UPS Sizing

- **Line-Interactive**
  - Provides some output voltage regulation & no frequency regulation
  - Small power applications not utilizing a generator
- **Sizing concerns**
  - UPS sensitive to frequency variations (.5 Hz factory default)
  - Load steps from UPS itself are often the main issue
  - Open UPS frequency window to allowable limits
  - Size based on frequency transient
  - Harmonics may also be extensive (if not filtered)
- **Generator kW rating of UPS x 5 (minimal)**
  - Assumes 2 hertz frequency window

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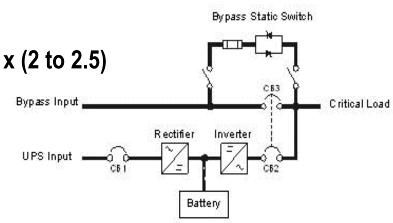
NOTES

5. UPS SIZING

UPS sizing

- **Double conversion**
  - Output voltage & frequency regulation
  - Market norm for critical applications & higher power ratings
- **Sizing Concerns**
  - No UPS load step (rectifier ramps load onto generator)
  - Size alternator based on harmonic content (typically filtered – non issue)
  - Consider battery recharge
  - Consider HVAC requirements
- **Generator kW rating is UPS x (2 to 2.5)**
  - Assumes HVAC on generator



Key Point Summary

- **Passive – Harmonics**
- **Line-Interactive – Harmonics & Frequency Tolerance**
- **Double Conversion – Filtering, Recharge, & HVAC requirements**

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NOTES

LOCKED ROTOR KVA vs. % VOLTAGE DIP 208/240 VOLT

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Locked Rotor kVA vs % Voltage Dip

INDUSTRIAL GENERATORS 208/240 VOLT WYE / DELTA (4 Pole Only)								
Alternator kW	Frame	Part #	Instantaneous Voltage Dip in %					
			10%	15%	20%	25%	30%	35%
10	10"		6	8	11	14	17	20
15	10"		7	12	16	20	24	29
20	10"		11	17	22	27	32	38
25	390		12	19	25	31	37	43
30	390		18	27	36	45	54	63
35	390		18	27	36	45	54	63
40	390		20	31	41	51	61	71
45	390		26	39	52	65	77	90
50	390		26	39	52	65	77	90
55	390		32	47	62	78	94	110
60	390		32	47	62	78	94	110
65	390		44	66	88	110	132	154
70	390		44	66	88	110	132	154
80	390		44	66	88	110	132	154
100	390		59	89	118	148	177	206
125	390		87	131	174	218	261	305
130	390		87	131	174	218	261	305
150	520		100	149	199	249	299	348
175	520		140	210	280	350	420	490
200	520		140	210	280	350	420	490
230	520		197	296	395	494	593	692
250	520		197	296	395	494	593	692
275	520		227	341	454	568	681	794
300	520		227	341	454	568	681	794
350	520		280	410	535	640	770	900
400W	311	0G6298	271	407	543	679	814	950
500W	312	0G6299	429	643	857	1071	1286	1500
600W	352	0G6302	543	814	1086	1357	1629	1900
700W	352	0G6305	571	857	1143	1429	1714	2000

W = WEG/Generac Alt Motor Starting Chart-WEBExcel '09-23-09

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Locked Rotor kVA vs % Voltage Dip 480

INDUSTRIAL GENERATORS 277/480 SERIES WYE (4 Pole Only)

Alternator kW	Frame	Part #	Instantaneous Voltage Dip in %					
			10%	15%	20%	25%	30%	35%
10	250		7	10	13	17	20	24
15	250		8	14	19	24	29	35
20	250		14	22	29	36	43	50
25	390		16	25	33	41	49	57
30	390		24	36	48	60	72	84
35	390		24	36	48	60	72	84
40	390		27	41	54	68	81	95
45	390		34	52	69	86	103	120
50	390		34	52	69	86	103	120
55	390		42	63	83	104	125	146
60	390		42	63	83	104	125	146
65	390		59	88	117	147	176	205
70	390		59	88	117	147	176	205
80	390		59	88	117	147	176	205
100	390		79	118	157	197	236	275
125	390		116	174	232	290	348	406
130	390		116	174	232	290	348	406
150	520		133	199	265	332	398	464
175	520		187	280	373	467	560	653
200	520		187	280	373	467	560	653
230	520		263	395	527	658	790	922
250	520		263	395	527	658	790	922
275	520		303	454	605	757	908	1059
300	520		303	454	605	757	908	1059
350	520		383	575	767	958	1150	1342
400	520		387	581	775	968	1162	1356
500W	312	0G6300	457	686	914	1143	1371	1600
600W	312	0G6303	471	707	943	1179	1414	1650
792W	352	0G6302	743	1114	1486	1857	2229	2600
832W	352	0G6305	757	1136	1514	1893	2271	2650
912W	401	0G6479	771	1157	1543	1929	2314	2700
1000 Gemini		0G6300	914	1371	1829	2286	2743	3200

9/23/2009

Standby Power Generation

(Applications and Transients)

In today's environment with a high reliance on reliable electrical power, it has become a common practice to include engine-generator sets in the design of new facilities. Their purpose is to provide power in the event of a utility power failure and, where local utility rate structures and policies make it a viable option, to reduce overall electrical energy costs. One of the major reasons for this emphasis on emergency/standby power has been the increased use of computers and digital controls in all aspects of commercial and industrial processes. Personal safety, production schedules, and in-process inventory are some of the items adversely affected by the lack of power integrity. It is the intent of this program to help you apply generator sets in a manner that will provide reliable power of the quality and capacity required by the end user.

The design of any system utilizing an engine-generator set must take into account the generator size, fuel selection and location of the unit. For the purposes of this discussion, we are going to focus our discussions on the sizing aspects only, and more importantly, to the potential problem areas that have historically surfaced throughout the industry.

General Sizing Considerations

By definition, a standby power system is an independent power system that allows operation of a facility, or parts thereof, in the event of a normal power failure. In order to assure that the final product can adequately provide the required power, an analysis of the load requirements is needed.

If the project is for a new facility, existing empirical data will not be available and assumptions will have to be made based on accepted engineering practices. Currently, there are no software programs that one can use to definitively design a new facility.

If the project is for an existing facility, data can come from a number of sources. One source may be the utility bills, which will provide the actual load requirements and the average peak demand. Utility bills spanning at least 12 to 24 months should be utilized to show possible seasonal requirements and fluctuating business.

The utilization of a power monitor / analyzer at the service entrance is another excellent source of information. In addition to providing a current load profile, the ability to capture available harmonic information will prove valuable later in correctly applying the generator to the system. Examination of the service entrance equipment will be required. The service entrance rating defines the absolute maximum power level and is required to size the automatic transfer switches.

Walking the facility is a critical part of the sizing process. While walking the facility, look for loads that will help define the size of the generator: largest single step load, largest motor, voltage sensitive devices, any significant harmonic distorting loads, building power factor, etc.

Discussions with the customer regarding future load growth vs. load management, size and amount of critical loads (i.e. phones and office lighting, computers, critical processes, and safety equipment, etc.) will have to take place. The end user's participation in the process is essential, because ultimately the discussion will have to center on cost and risk management.

Power Factor

One of the items often overlooked in sizing a generator is the load's power factor. As a review:

> Power factor is the ratio of kilowatts (kW) to kilo-volt-amps (kVA). It is also the cosine of the angle between the voltage sine wave and the current sine wave. For a building with a .9 lagging power factor, the current will lag behind the voltage by 26 degrees (figure 1).

Power factor is not usually a problem because most loads when aggregated together operate within the generator's rated power factor of .8 lagging to 1.0. When a load has a power factor less than .8 lagging, the alternator will need to be larger than the running load to meet the load's kilo-volt-amp-reactive (kVAR) requirements. A typical low power factor load are motors running lightly loaded.

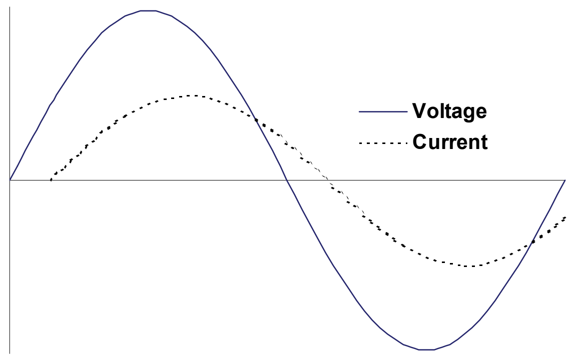


Figure 1. Lagging Power Factor (.9 PF)

Low power factor loads are not very common because most facilities with poor power factor utilize power factor correction capacitors to meet utility requirements. However, power factor correction capacitors can result in a condition known as leading power factor (current leads voltage) (figure 2). A careful review of the building's power factor correction scheme is needed to ensure that under no conditions does the load connected to the generator become leading. <u>Leading power factor loads can cause the alternator to self excite resulting in voltage run-away.</u>

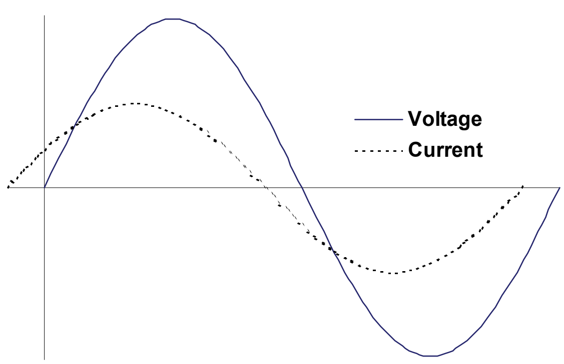


Figure 2. Leading Power Factor (.9 PF)

Since most digital control panels on generators include over voltage protection, leading power factor will typically be denoted by an over voltage shutdown. Sources of leading power factor include some types of high intensity discharge (HID) lighting. When the primary load is HID lighting, inductive load may need to be added to the system to reduce the power factor to an acceptable level (.8 lagging to 1.0).

Basic Generator Set Concepts

Capabilities of both the engine and the alternator are considered individually and collectively when sizing a generator set. Engines produce horsepower (Hp) while controlling speed or frequency.

> Remember that 1Hp is equal to .746 kilowatts (kW_m) of mechanical power. Actual electrical output (kW_e) will be something less due to system losses. Typical rule of thumb is that it takes 1.6 Hp to produce 1.0 kW_e.

The alternator takes the mechanical energy (Hp) of the engine and converts it into electrical energy (kVA).

> Remember that kVA is apparent power and is composed of real and reactive components. The real component is kW created by the engine. The reactive component is kVAR created by the alternator's excitation system.

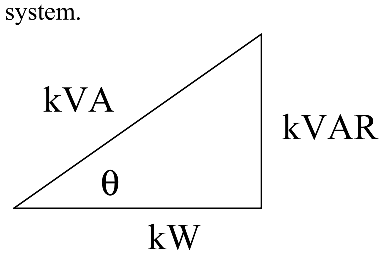


Figure 3. Power Triangle

In addition to converting mechanical power into electrical power, the alternator system controls output voltage and provides high magnetizing current draws (kVAR) necessary to start electrical motors.

Motor Starting

Motor loads have a significant effect on the size of the generator set due to the high currents required while starting. The most common form of motor starting is full voltage -- across the line, because it is simple and low cost. In this method, full line voltage is supplied to the motor resulting in maximum starting. Using this method, an instantaneous inrush of current occurs when the motor is energized. This current is known as inrush current, locked rotor current (I_{LR}), or starting current. This current is also typically referenced by its corresponding skVA. The "s" denotes kVA white starting.

$$skVA = \frac{1.73 \times V_{LL} * I_{LR}}{1000}$$

The duration that the motor requires skVA is a function of motor speed and is independent of time (figure 4). Note that the motor maintains a relatively high level of skVA until close to nominal operating speed.

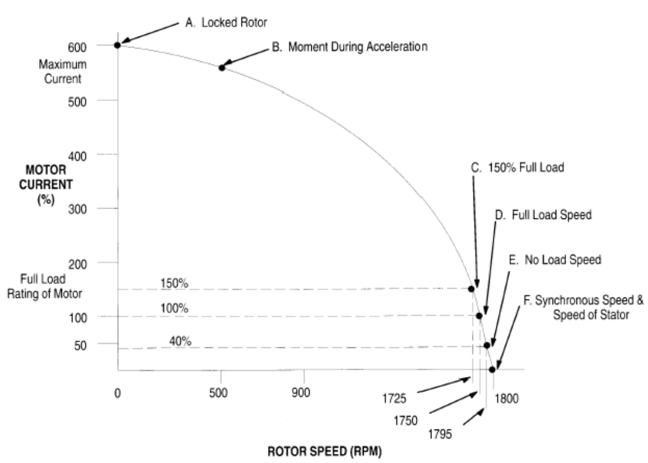


Figure 4. Motor Speed vrs. skVA

The magnitude of the skVA can be calculated from motor nameplate data. Most motors are identified with a NEMA starting code letter that describes their individual starting characteristics (figure 5). The letters correspond to a skVA/Hp. Due to motor design considerations, most motors crowd the upper side of each NEMA starting code range.

Code Letter	skVA / Hp
D	4.0 - 4.5
E	4.5 - 5.0
F	5.0 - 5.6
G	5.6 - 6.3
H	6.3 - 7.1

Figure 5. NEMA Starting Codes

As an example in using the NEMA starting codes, a 100 Hp motor, with a starting code of G, would have an approximate skVA of 600 (100 Hp x 6.0 skVA/Hp = 600 skVA). IEC rated motors, as well as high efficiency motors, tend to have higher starting current requirements than do standard NEMA units.

The alternator must have sufficient motor starting kVA capacity to limit voltage dips to acceptable levels. The basic question now is, “How does the generator respond to the starting requirements and why?” Inrush current to the motor causes a rapid dip in generator output voltage. Figure 6 shows a family of curves with each curve representing a different size motor load. As motor size increases, the voltage dip seen at the generator increases. The majority of the industry has established a maximum voltage dip of 35% as being the acceptable alternator limit. However, some sensitive equipment may only be able to handle as little as a 15% voltage dip.

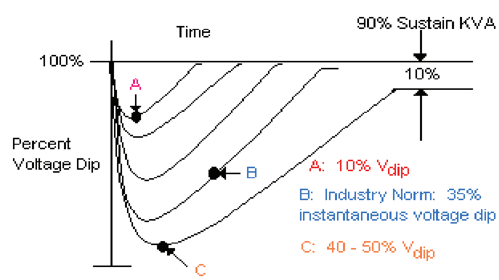


Figure 6. Voltage Dip Characteristics

Some manufactures will specify alternator motor starting capabilities based on a 90% recovery voltage also known as 90% sustained skVA (figure 6, line c). At this skVA load level, the alternator will have a voltage dip between 40 and 50% and will only recover to 90% of the generator's nominal voltage. This is a valid way to specify an alternator's capabilities; however, "90% sustained" is often misunderstood as a 10% voltage dip by many people. It is also specifies the generator at the extreme limit of its skVA capabilities (figure 7).

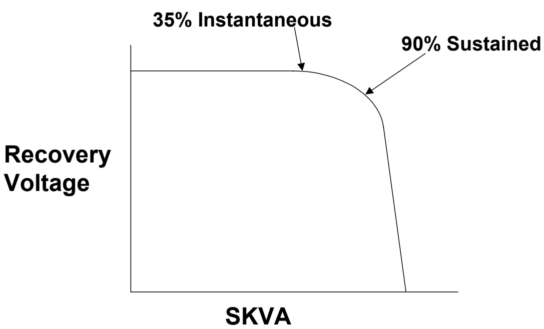


Figure7. Alternator skVA Capability

The alternator's instantaneous transient voltage dip is a function of the impedance of the generator and the skVA required by the motor. Ohm's law states that when a current flows through an impedance, voltage will drop across that impedance (V = IxR). Figure 8 shows that as locked rotor current flows through the generator's internal impedance (x"d), a voltage dip will occur. The voltage dip occurs within a few sine wave cycles upon connecting the motor to the generator output.

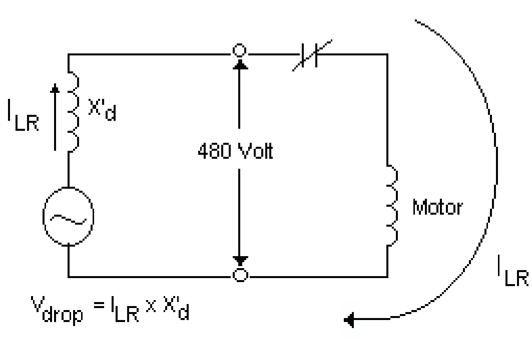


Figure 8. Why Voltage Dips

This voltage dip can be minimized by upsizing the alternator -- larger alternators have lower impedances. The industry publishes a predicted voltage dip on most alternator data sheets. Figure 9 illustrates the effects of upsizing an alternator on minimizing voltage dips. Assuming that frequency is constant, these curves give a snapshot of what might be expected.

100 Hp x 6.0 skVA/Hp = 600 skVA

V_{dip}	35%	25%	20%	10%
Alternator Model	155	230	300	800

Figure 9. Upsizing to minimize voltage dips

Upon sensing the instantaneous transient voltage dip, the alternator excitation system responds by increasing excitation to recover to rated voltage. The electric motor load will accelerate towards running speed provided it produces enough torque to overcome its shaft connected load. For induction motors, torque is directly proportional to the square of the applied voltage. Motor acceleration is a function of the difference between motor torque and the torque requirements of the load. The alternator needs to recover to rated voltage as quickly as possible to avoid excessive acceleration times or motor stall.

The time that it takes the generator voltage to recover is a function of the relative sizes of the generator and motor, engine power (kW) and generator excitation capability. A few milliseconds after sensing the initial transient voltage dip, the voltage regulator applies full forcing voltage to the exciter which results in generator field current build up. Generator set components are designed and matched to achieve the shortest possible response time while maintaining voltage stability and avoiding engine overload. Depending on the severity of the motor load, the generator should recover to rated voltage in a few seconds, if not within a few cycles.

Reduced Voltage Motor Starting

When starting a motor with a reduced voltage or ramp type starter, the locked rotor requirements can be reduced significantly. However, two significant problems occur when using a generator in place of the utility. We'll look at these problems and put safeguards in place to prevent them from occurring.

A simple example of a 70% auto-transformer type motor starter is as follows. The auto-transformer will reduce the voltage at the motor terminals by 30% or 70% of the nominal line voltage for a specific amount of time. That means that when the motor is turned on, it will see 70% of the line voltage. The reduced voltage starter has a built in timer. When the timer times out, the starter will switch from reduced voltage start to full voltage run.

During the initial stage, the line voltage is at 70%. According to Ohm's law, the current will also be reduced to 70% of its nominal value. If voltage (V) is reduced and resistance (R) doesn't change, then I (amps) will be reduced by the same proportion). Now, the skVA delivered to the motor is equal to *voltage times amps;* thus, 70% of the voltage times 70% of the amperage equals 49% of the skVA that would be delivered at full voltage. Figure 10 shows the reduction in skVA values for various voltage reductions.

Starting Method	% Voltage	% skVA	% Torque
Across the Line	100	100	100
80% Tap	80	64	64
65% Tap	65	42	42
50% Tap	50	25	25
Star-Delta	58	33	33

Figure 10. skVA vs. Voltage

Figure 10 also shows that the motor's torque is also dramatically reduced. This means that the motor is going to come up to operating speed more slowly, but the reduced starter doesn't know this. The starter only knows that it has a specific time delay. When the delay is finished, it disconnects the transformer section and reconnects across the line. The trouble occurs when the motor is not close to operating or synchronous speed. Because of the reduced voltage, it comes up to speed slowly and by the time the starter times out, the motor may only be at 75% of its operating speed (figure 11).

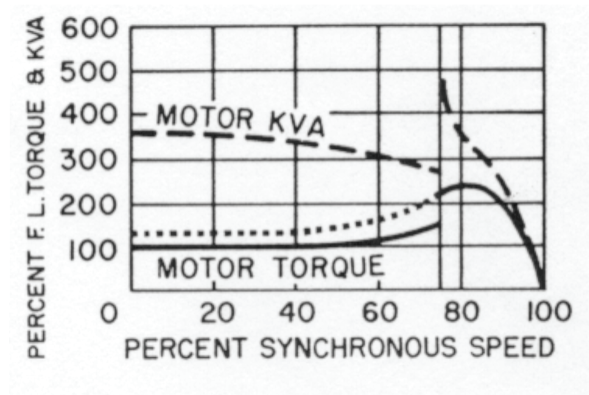


Figure 11. Switching to Full Voltage Run

This means that the locked rotor current will increase significantly when the motor becomes connected to the line rather than the reduced voltage transformer. When this happens, the alternator can no longer supply the required skVA because it has been sized for the lower reduced voltage skVA requirement, not the full locked rotor kVA. The voltage then dips beyond 35% and the contactor drops out. As soon as the contactor drops out, the voltage snaps back and pulls the contactor in and thus pulls the voltage back down. Basically, the contactor is clapping in and out at full locked rotor current. This is not good for the contactor, the motor or anyone in close proximity to the equipment. <u>To prevent this problem from occurring, confirm that the motor can reach full voltage on reduced voltage</u>. If the motor can not reach full speed on reduced voltage, size the generator as if the motor is starting across the line.

Engine Loading

Engines also respond according to the load requirements of the generator. The normal response is a change in frequency. There is a corresponding drop in frequency as the engine seeks to respond to the requirement for starting kVA from the alternator. The reaction is a function of the start power factor of the motor. Most typical three phase motors have a starting power factor (sPF) of .25 to .45. Given that:

PF = kW/kVA, then
skW = skVA x sPF.

If we take an example of a 100 Hp motor and assume a skVA of 600, we can calculate the skW. (600 skVA x .3 sPF = 180 skW) <u>A good rule of thumb for estimating engine size is that the generator's kW should be twice the motors Hp</u>. The following are some typical rules of thumb for starting and running motors on a generator:

Starting
$\mathbf{kVA_{gen} \cong Hp_{motor}\ x\ 6.0}$
$\mathbf{kW_{gen} \cong Hp_{motor}\ x\ 2.0}$

Running
$\mathbf{kVA_{gen} \cong Hp_{motor}}$
$\mathbf{kW_{gen} \cong Hp_{motor}\ x\ .85}$

Voltage Regulator Unloading

Upon close examination of the corresponding voltage dip and frequency dip graphs of a block loaded genset, one could see that the deviations correspond (figure 12).

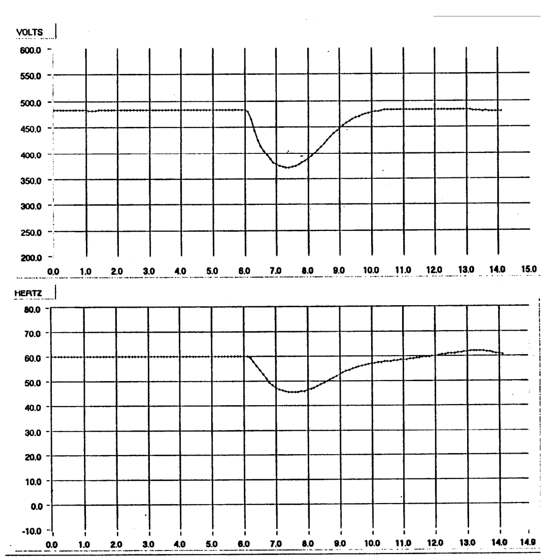


Figure 12. Block Load Characteristics

This is due to an effect called regulator unloading. The generators voltage regulator intentionally lowers voltage in an attempt to help the engine recover. If the voltage regulator does not shed voltage, some engines would not recover and would stall. The voltage regulator will begin to shed voltage at the point when engine speed intersects the voltage regulators under frequency protection (figure 13). Under frequency protection is also know as a volts per hertz because the regulator reduces voltage proportionately with a reduction in frequency.

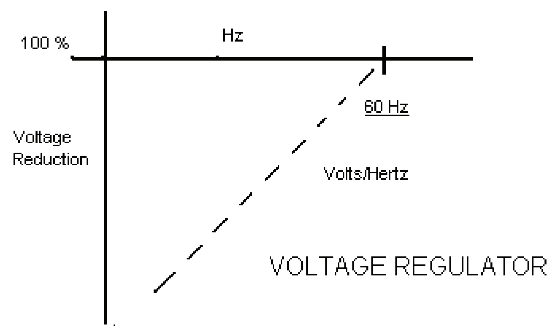


Figure 13. Voltage Regulator Unloading

Remembering from the discussion earlier on reduced voltage starters that a reduction in voltage reduces the required skVA by the square of the remaining voltage requirement. As a result, the skW requirement is also reduced, allowing the engine to recover faster. For example, a 30% reduction in voltage by the regulator will result in a skVA reduced by a multiplier factor of .49 $[(.70)^2 = .49]$

Non-Linear Loads

The second significant component for generator sizing is the magnitude of non-linear loads to be carried by the engine/generator. Common non-linear loads encountered are computers, battery chargers, uninterruptible power supplies (UPS), variable frequency drives (VFD), medical imaging equipment and some forms of fluorescent lighting. EGSA defines a *linear load* as an "AC electrical load where the voltage and current waveforms are sinusoidal, and the current at any time is proportional to voltage." It further defines *non-linear loads* as "AC loads where the current is not proportional to voltage." The nature of a non-linear load generates harmonics in the current waveform, which leads to distortion of the voltage waveform (figure 14). It is this harmonic distortion that must be accounted for in the sizing of the generator.

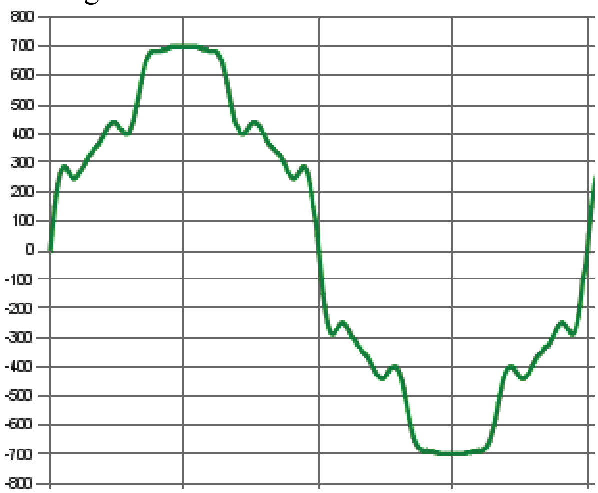


Figure 14. Harmonic Distortion

Variable frequency drives (VFD's) are utilized to control the speed of induction motors. There are three commonly used types of variable speed drives: VSI (voltage source inverters), CSI (current source inverters) and PWM (pulse width modulated), with the most common being the PWM. To help deal with the harmonic effects of nonlinear loads, IEEE 519 provides guidelines as to acceptable voltage distortion levels. For general loads, the acceptable level of distortion is 5%. For dedicated loads, the acceptable level is 10%. Since the generator is only in service for limited hours, most generator systems can withstand more than 10% distortion; however, the common practice in the industry is to limit the THVD (total harmonic voltage distortion) level to less than 15%. Above that level, the generator system could experience problems.

In analyzing nonlinear load applications, it should be noted that the same constraints that caused the generator's voltage to dip during motor starting will contribute to an increase in harmonic voltage distortion. The generator provides 60 hertz current to the nonlinear load. The nonlinear load produces harmonic currents as a byproduct of its operation. These harmonic currents flow through the generator's impedance resulting in a corresponding voltage distortion (figure 15).

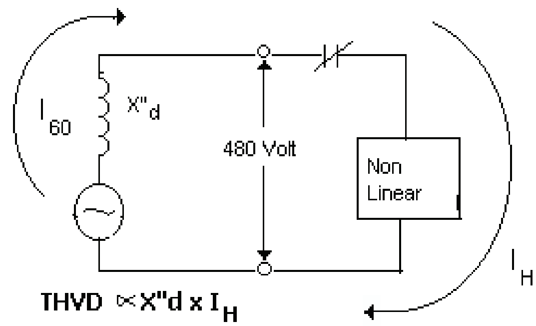


Figure 15. Nonlinear Load Circuit

To minimize this distortion, the generator's impedance needs to be held within acceptable limits. In a typical application of a 6-pulse PWM unit, the base kVA of the alternator selected should be adequate to limit the subtransient reactance (X"d) to 6-8%, when compared to the total non-linear load. Generally, if the generator is sized to minimize harmonic distortion, alternator overheating due to harmonic currents is no longer an issue.

Other solutions for controlling harmonic distortion include active or passive filtering technologies to remove the harmonic currents. Also, additional loads that can be added to the system prior to starting the nonlinear load will help minimize distortion.

A general rule of thumb is that VFD loads on a generator should be less than 50% of generator capacity to limit total harmonic voltage distortion to 15%. An additional point to remember is that in VFD applications, size the generator for the full nameplate rating of the drive and not the motor. Harmonic distortion levels may be higher when the drive is being utilized partially loaded and a larger motor may be installed in the future to utilize the full drive capabilities.

Online Final Assessment

Final assessments are available for each PDSS session. These assessments are Web-based and can be accessed using Generac's online learning system *"The Learning Center"* (http:// learning.generac.com). PDSS participants are required to obtain a score of at least 80% to pass an assessment. Each online assessment also contains a training survey. The survey provides each participant an opportunity to rate various components of the learning experience along with information relative to business development. Instructions for how to register and log in to this system, take the final assessment and print a certificate, are described in the Registering in *"The Learning Center"* section below.

Continuing Education

Upon successful completion of a seminar, participants will be awarded 2.0 PDHs (Professional Development Hours) and 0.2 CEUs (Continuing Education Units). Successful completion of a seminar requires that the participant have:

- Attended the complete seminar
- Received a minimum score of 80% on the Final Assessment

Certificate of Accomplishment

Participants who successfully complete the seminar and receive a passing score on the online final assessment are entitled to a "Certificate of Accomplishment." Certificates are available for printing directly from the participant's account screen on Generac's online training system *"The Learning Center".* Instructions for how to register and log in to this system, take the final assessment and print a certificate, are described beginning in the following section.

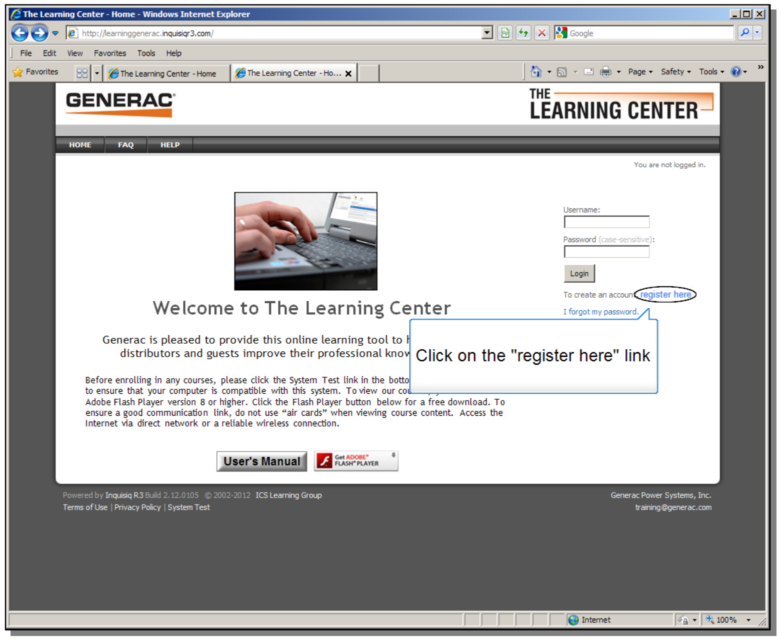
Registering in *"The Learning Center"*

To gain access to *"The Learning Center*", you are required to register and set up a user account. During your account setup you will create a *Username* and *Password*. Your username and password can then be used to log in on subsequent visits.

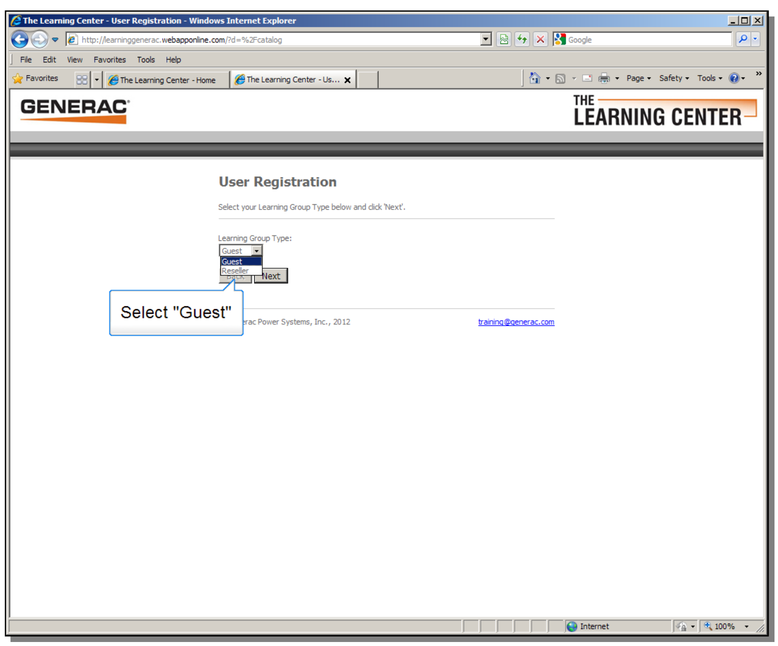
The following pages will aid you in the registration process along with the Final Assessment, Survey and Certificate procedures.

To begin the registration process, open your computer's browser and enter http:// learning.generac.com. This should take you to *"The Learning Center"* home page. This page is displayed at the top of the next page. From this point you can follow illustrated steps.

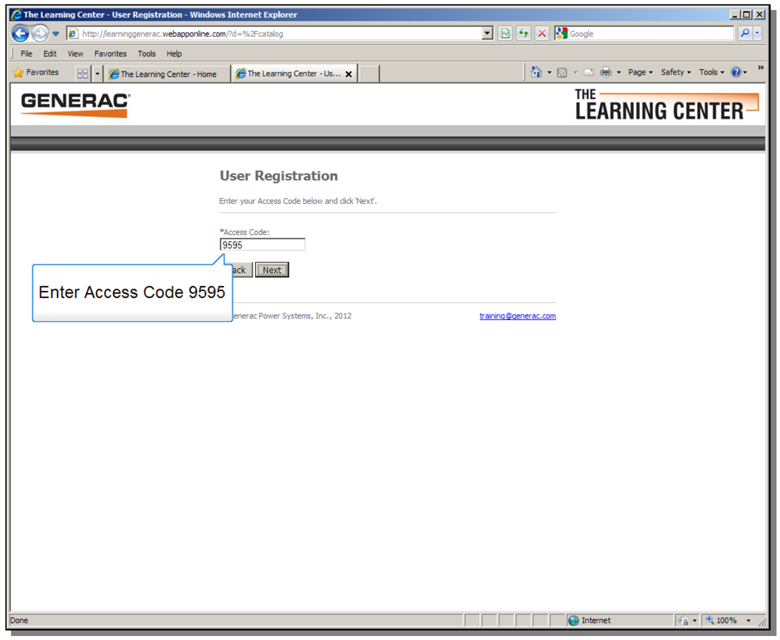
Begin by entering http://learning.generac.com in your computer's browser. The screen below will be displayed. Click on the "register here" link to begin the registration process.



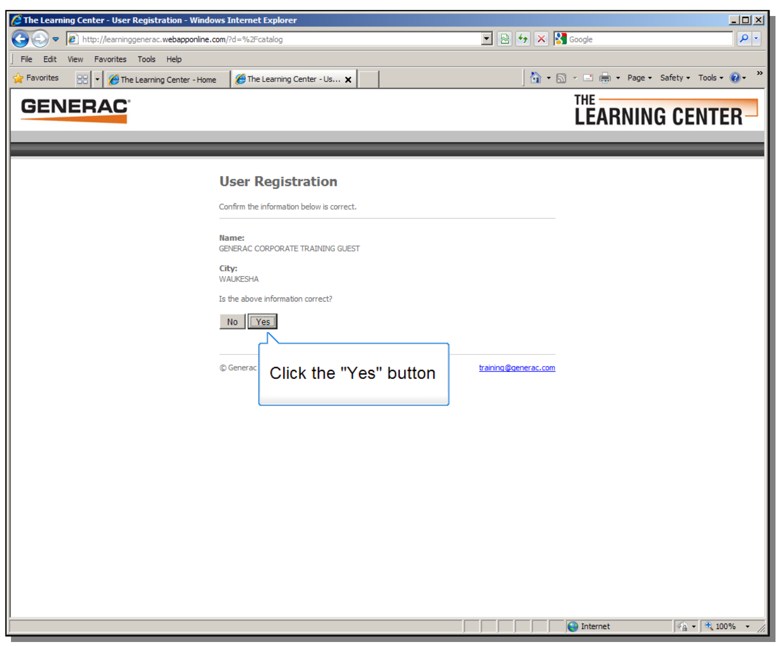
On this screen you will select "Guest" from the drop down box and click the "Next" button.



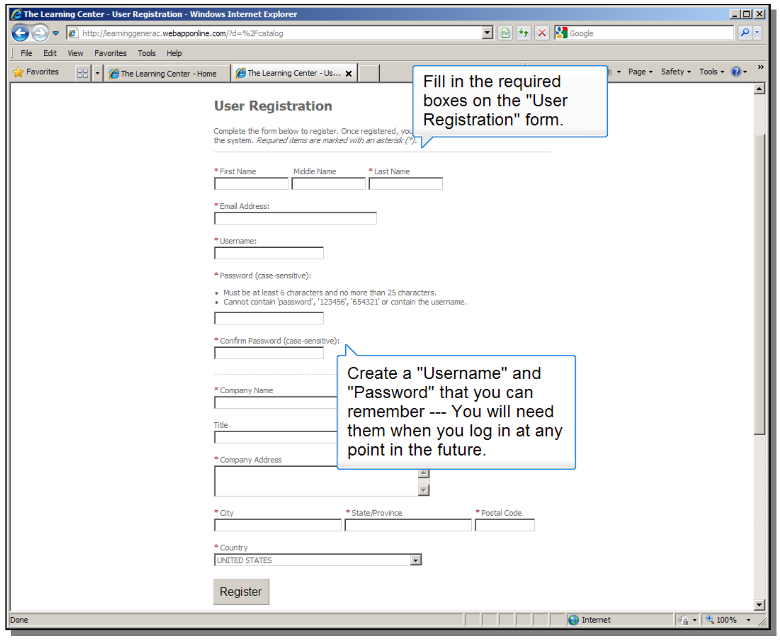
In this next screen enter **Access Code 9595** and click the "Next" button. Please keep this code private.



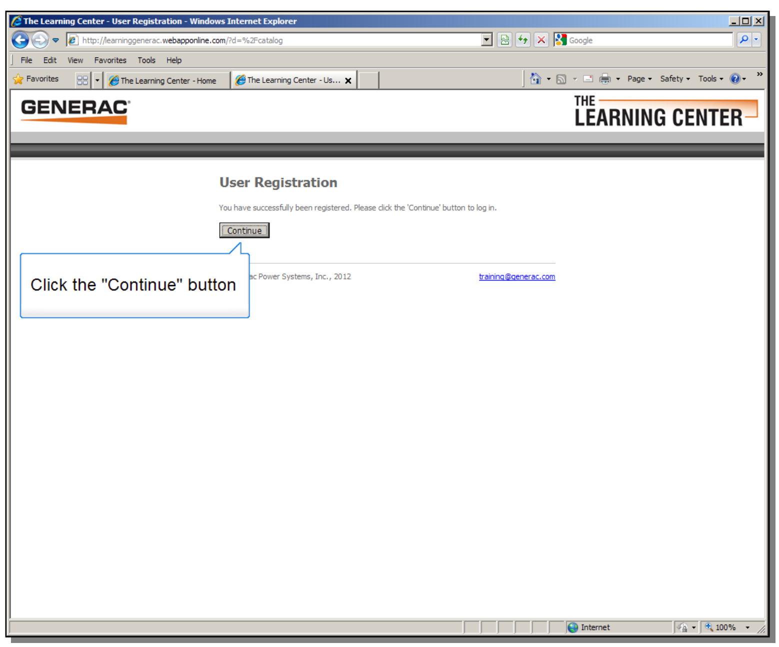
This screen confirms the correct access code entry. Click the "Yes" button to proceed.



The next screen contains the “User Registration” form. Fill in the required boxes, and then click the “Register” button.

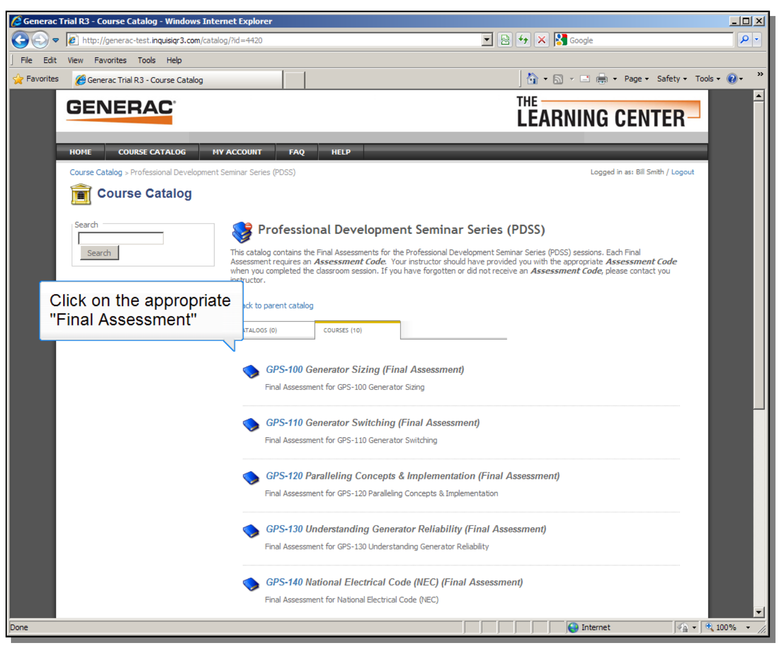


The next screen confirms your registration. Click the “Continue” button to proceed.

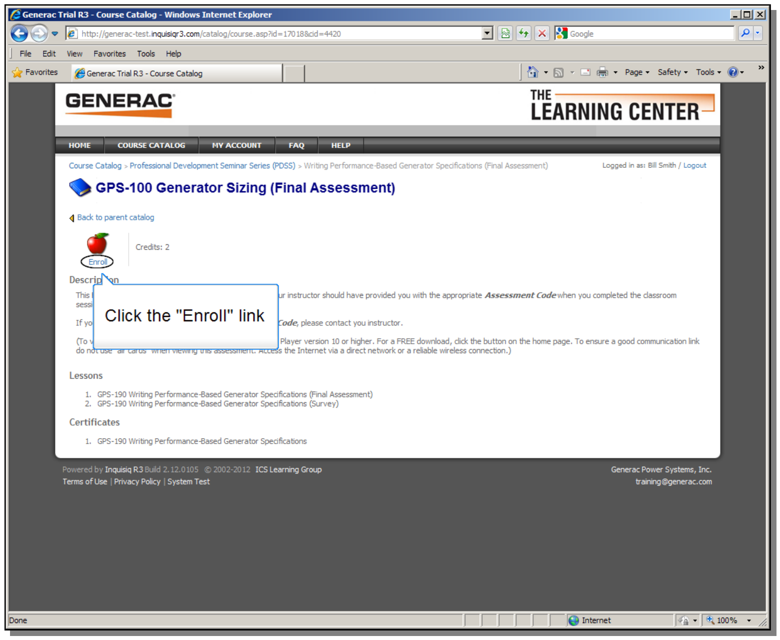


The next screen displays the “Course Catalog.” Click on the “Professional Development Seminar Series” link.

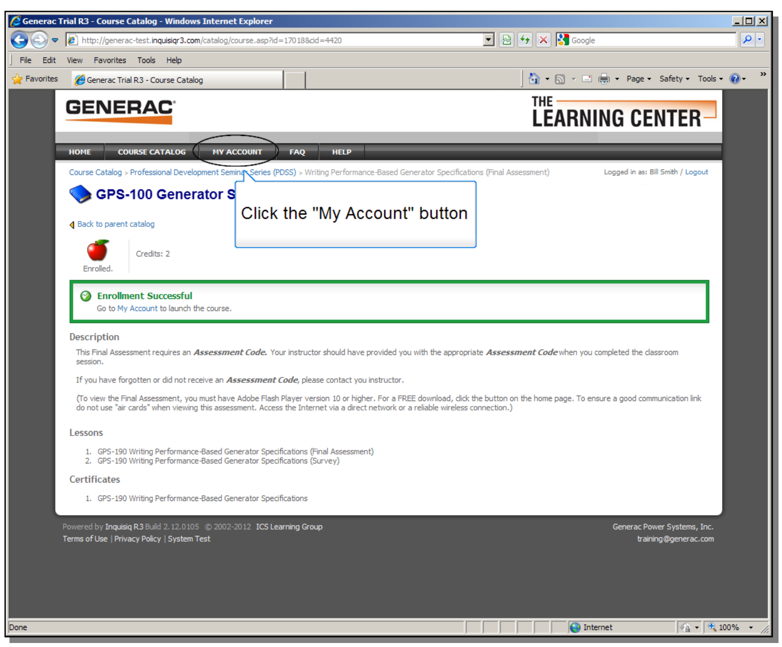
This next screen lists all currently available Final Assessments. Click on the Final Assessment that is tied to the course name and number you completed.



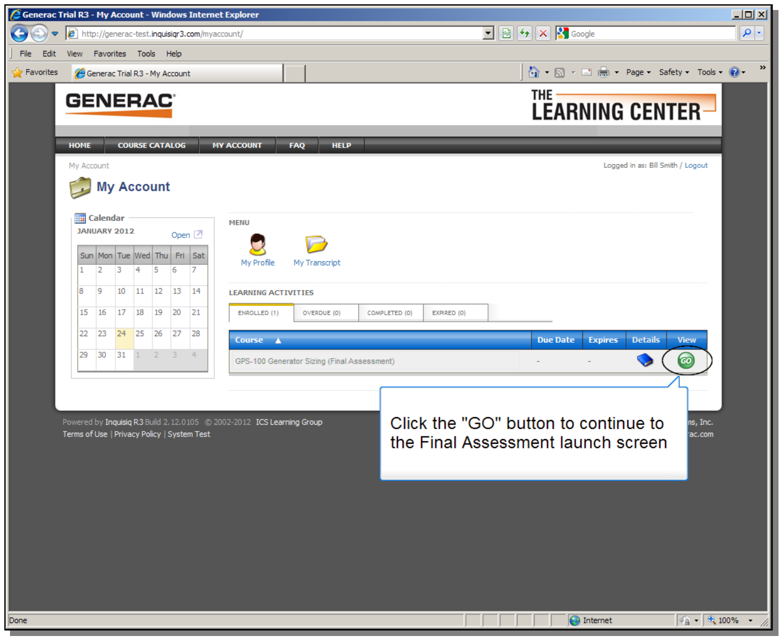
The next screen is the “Enrollment” screen for the Final Assessment that you selected. Click the “Enroll” link to proceed.



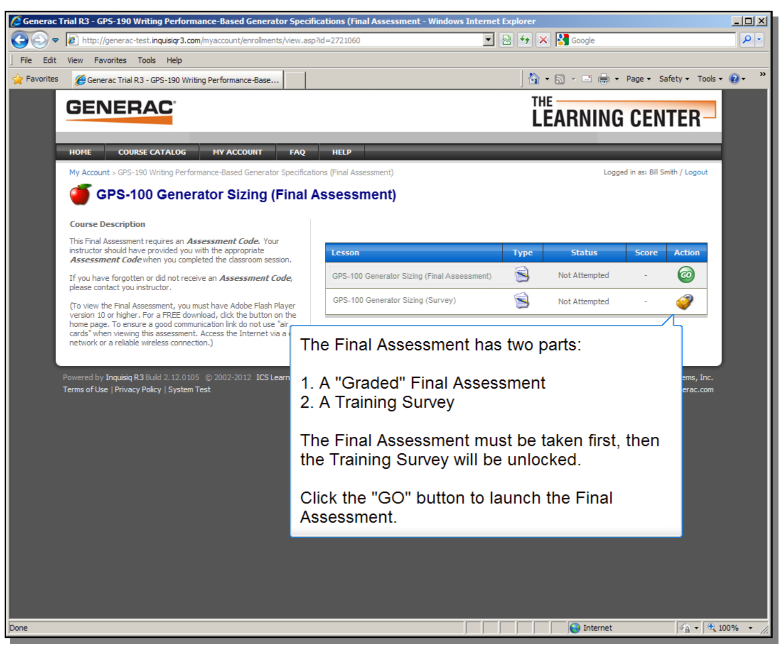
This screen confirms your enrollment. Click the “My Account” button to proceed.



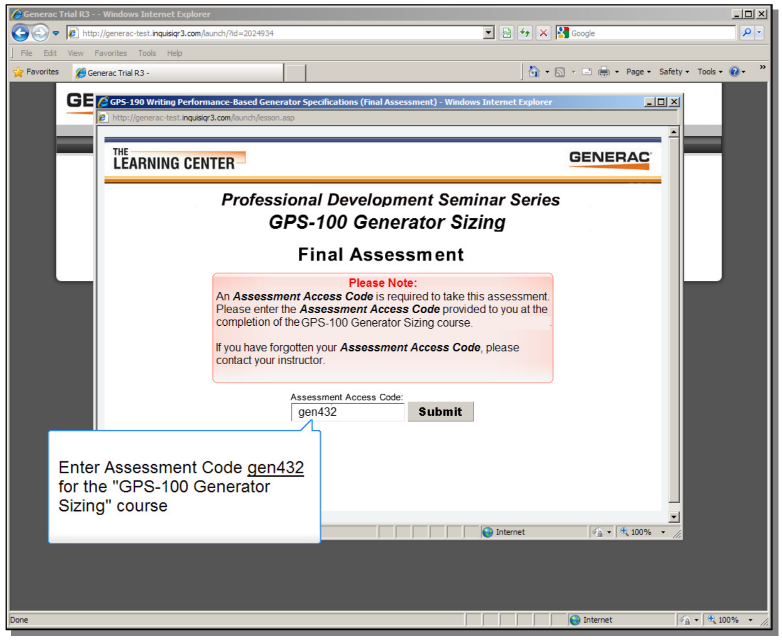
This is your “My Account” screen. Note that the Final Assessment you selected is displayed under the “Enrollment” tab. Click the “GO” button to proceed.



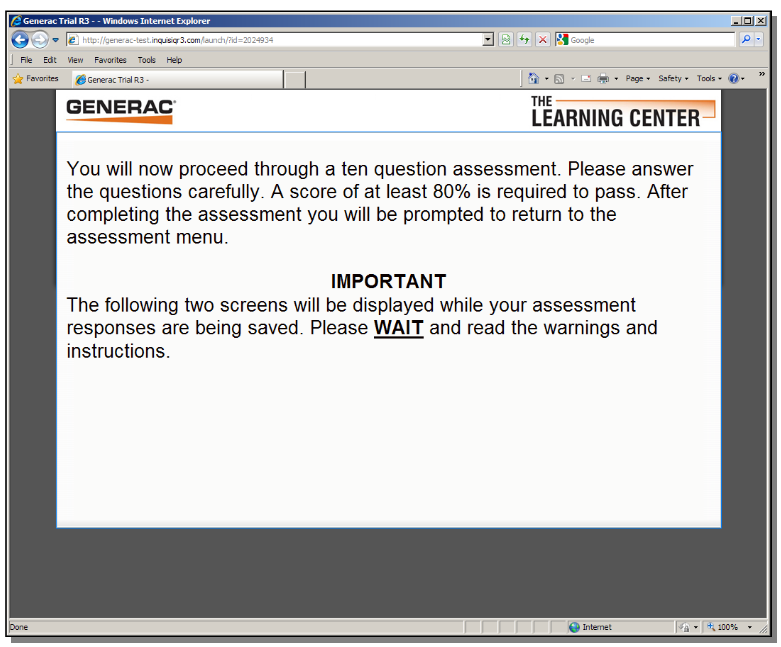
This screen lists the two parts to the Final Assessment. You must take the “Graded” Assessment first, then the Training Survey.



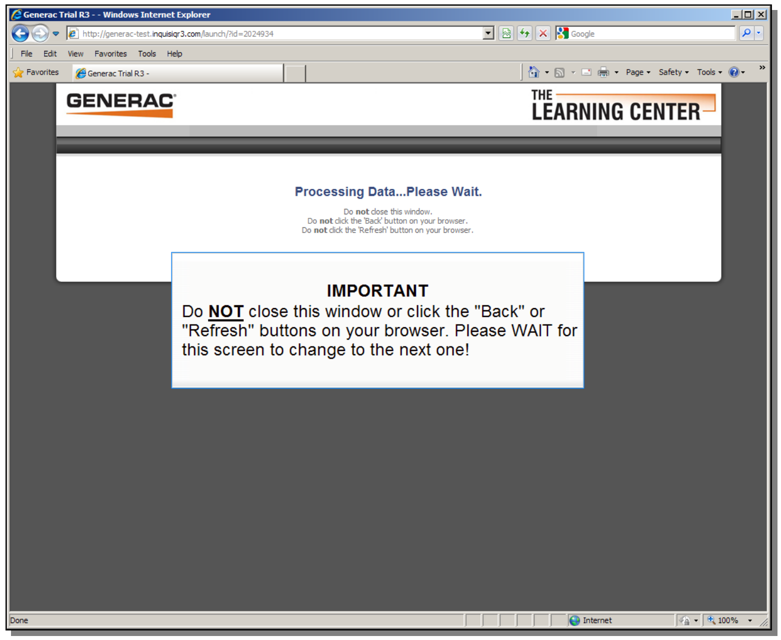
In the next screen an “Assessment Code” is required before you can continue. The code for GPS-100 Generator Sizing is **gen432**. Enter the code in the box and click the “Submit” button to continue.



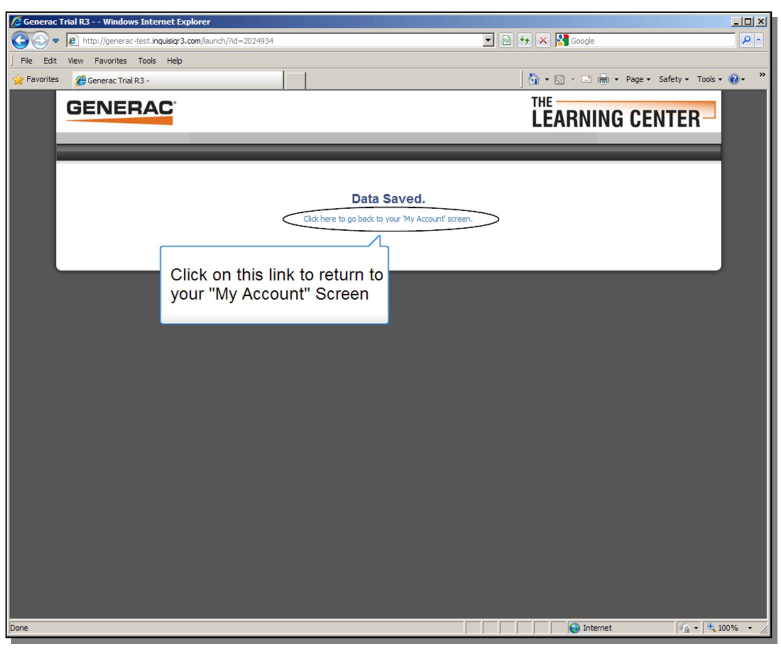
You will now proceed through a ten question assessment. Please read the warnings below.



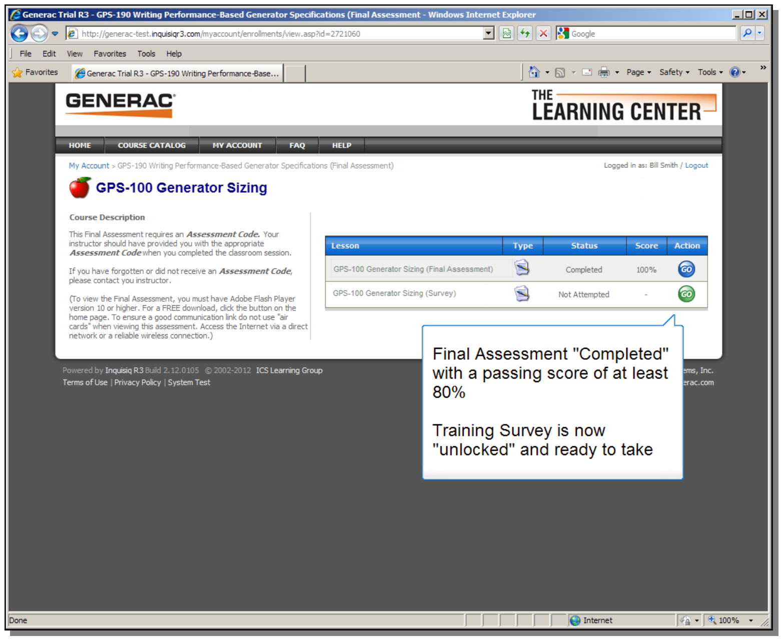
Please follow the instructions on this screen. You must wait for your assessment data to be saved. Do not close this window or click the 'Back' of 'Refresh' buttons on your browser.



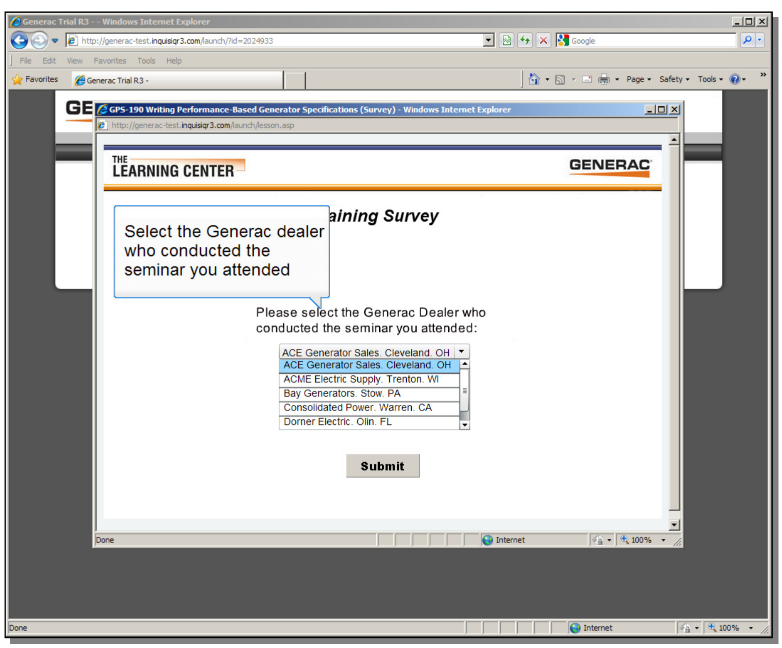
This screen confirms that your data was saved. Click on the link shown here to proceed.



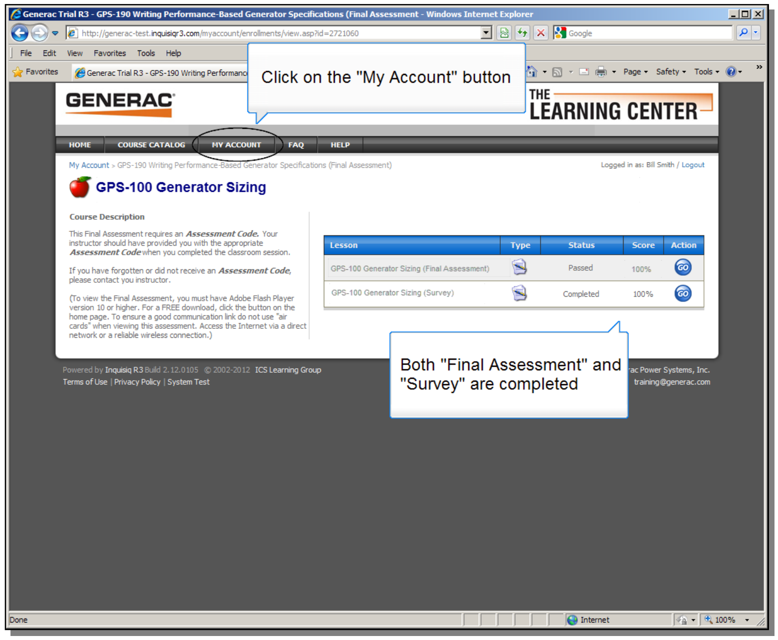
This screen will be displayed after your assessment data is saved. Note that in this example the assessment was passed with a score of 100% and the Survey is unlocked and ready to launch.



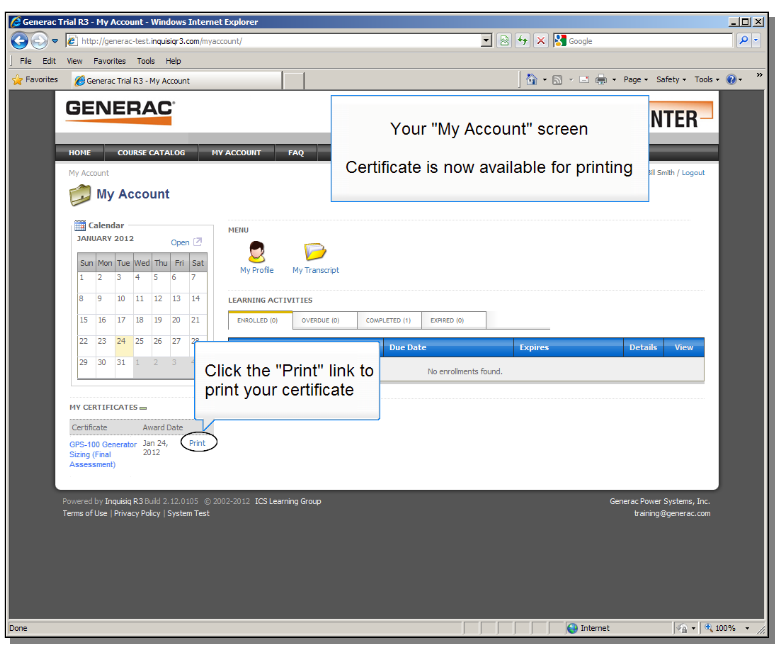
Upon launching the Survey, this screen will be displayed. Select the Generac dealer who conducted the seminar you attended.



After completing the survey you will be prompted to return to the assessment menu. Your response data will be saved as before, and you will see the screen below. Click the “My Account” button to continue.



Your “My Account” screen will look similar to the one shown here. Click the “Print” link to print your certificate.



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