PROFESSIONAL DEVELOPMENT
SEMINAR SERIES

GPS-180 CONTROLS

LEARNER'S GUIDE

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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 control systems are 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:

The purpose of this course is to provide you with a basic overview of the various control functions associated with generators. You'll see how control panels have evolved over the years. You'll learn the important role the control panel plays in sensing, controlling, monitoring and protecting. Intelligent communications will also be covered including, data logging, trending and predictive maintenance.

TIME:

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

LEARNING OBJECTIVES:

Upon completion of this module, participants will be able to:

- Explain how speed governors operate
- Describe the function of the ECM (Engine Control Module)
- Describe the function of the AFR (Air-Fuel-Ratio) control
- Explain the purpose of a Float Equalized Charger
- Explain how a voltage regulator works
- List and describe the typical functions a control panel
- Describe four key design features for control panels
- Explain how a 4-20 ma sensor operates
- Describe the advantages of current sensors over voltage sensors
- Explain the benefits of integrating all control functions into a single circuit board
- Explain "Predictive Maintenance" as it applies to control systems
- Explain synchronizing as it applies to paralleled generators
- Describe how load sharing is controled when paralleling generators
- Describe the differences between real and reactive power
- Explain protective relaying in paralleled generators

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

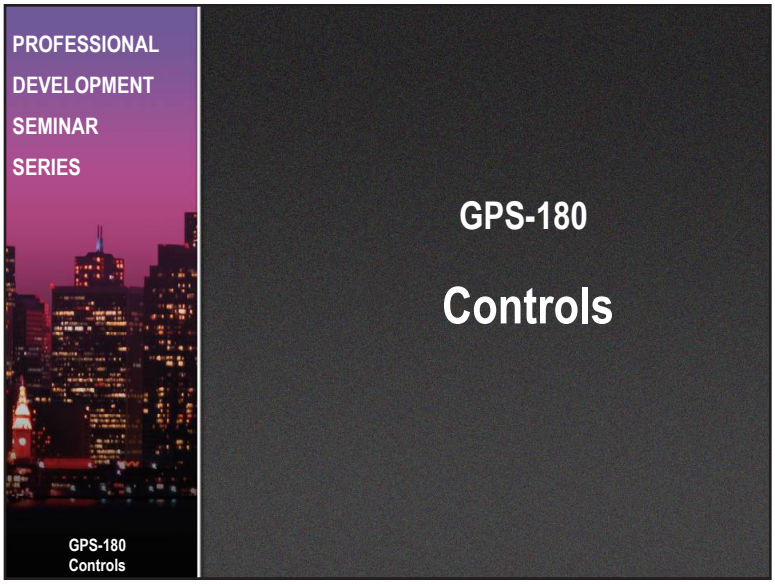
TIME	LESSON	DESCRIPTION
5 minutes	Introductions	Participants and trainer should become briefly acquainted. The trainer welcomes participants and conducts an opening icebreaker activity.
15 minutes	Lesson 1 Engine Controls	This lesson will discuss the control functions directly tied to the engine operation. Controls covered include governors, ECMs, AFRs and battery charging.
30 minutes	Lesson 2 Genset Controls	This lesson will discuss the control functions associated with the genset. Control elements covered include analog and digital control panels, communications, voltage and current sensors, predictive maintenance and protection.
35 minutes	Lesson 3 Paralleling Controls	This lesson will discuss the control functions associated with paralleling of generators. Control elements covered will include synchronization, load sharing, protection and integrated paralleling design.
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.

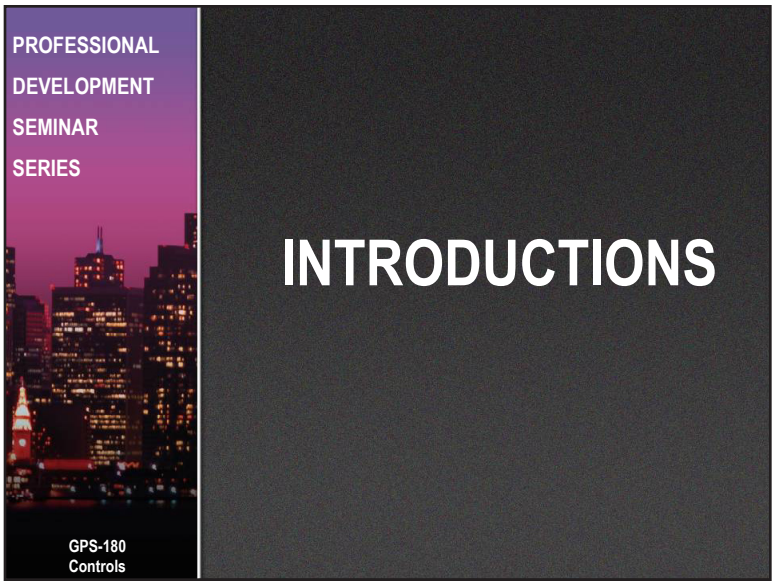
INTRODUCTION

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 controls.





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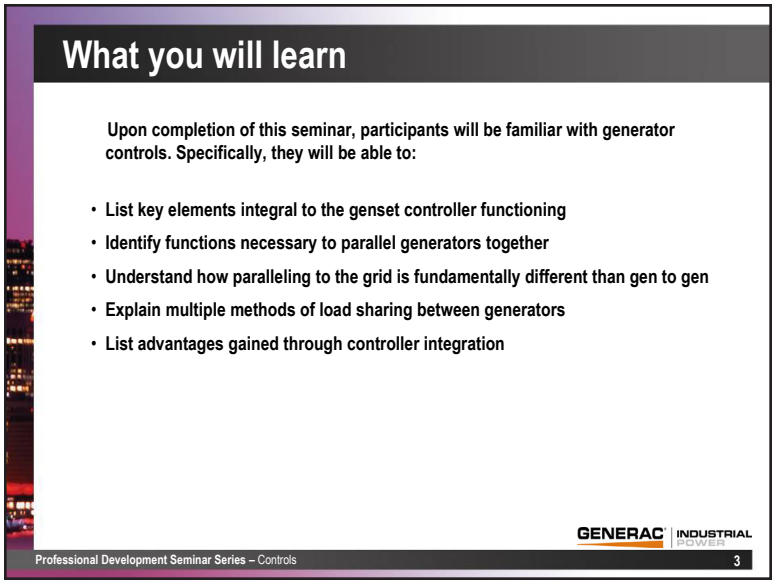
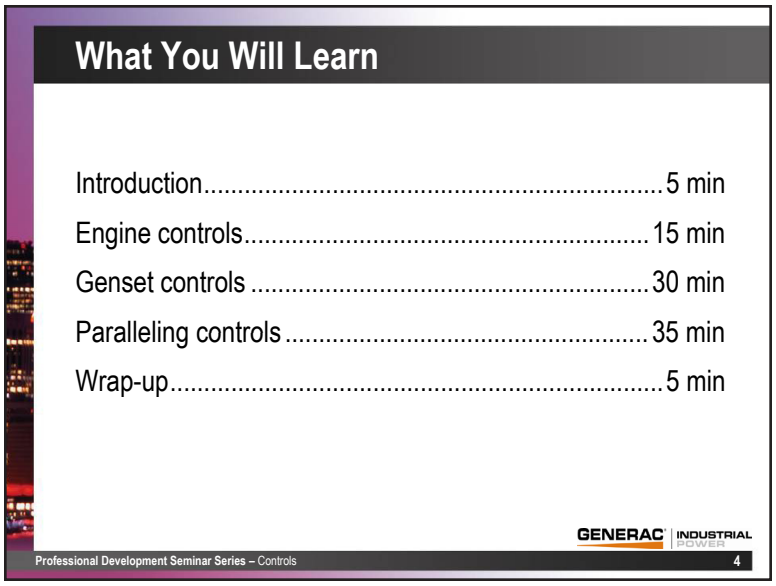
INTRODUCTION





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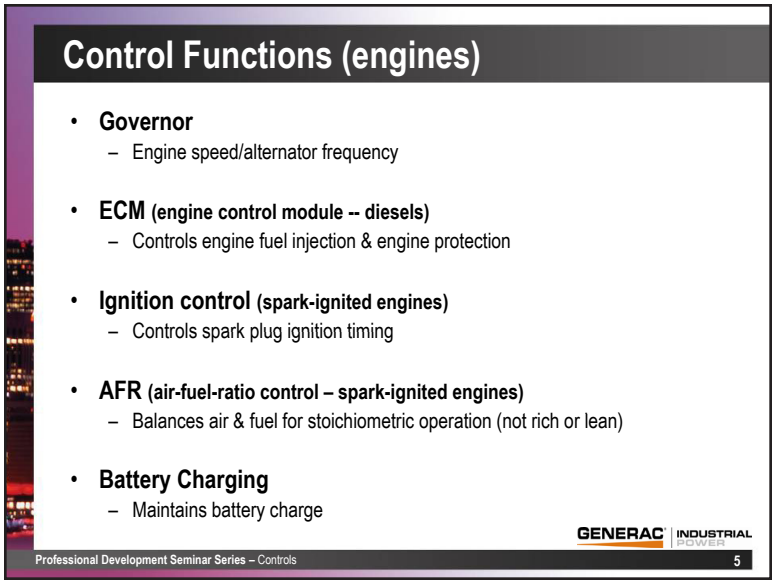
Control Functions (engines)
• Governor
– Engine speed/alternator frequency
• ECM (engine control module -- diesels)
– Controls engine fuel injection & engine protection
• Ignition control (spark-ignited engines)
– Controls spark plug ignition timing
• AFR (air-fuel-ratio control – spark-ignited engines)
– Balances air & fuel for stoichiometric operation (not rich or lean)
• Battery Charging
– Maintains battery charge
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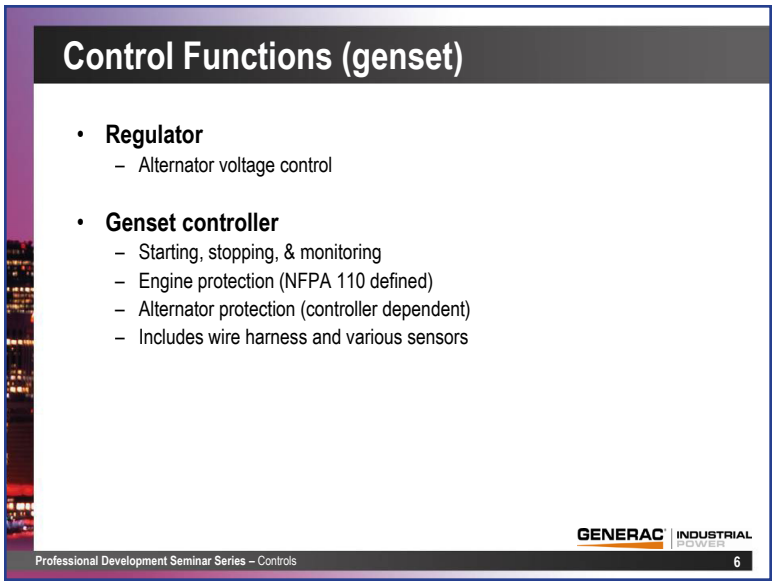
Control Functions (genset)
• Regulator
– Alternator voltage control
• Genset controller
– Starting, stopping, & monitoring
– Engine protection (NFPA 110 defined)
– Alternator protection (controller dependent)
– Includes wire harness and various sensors
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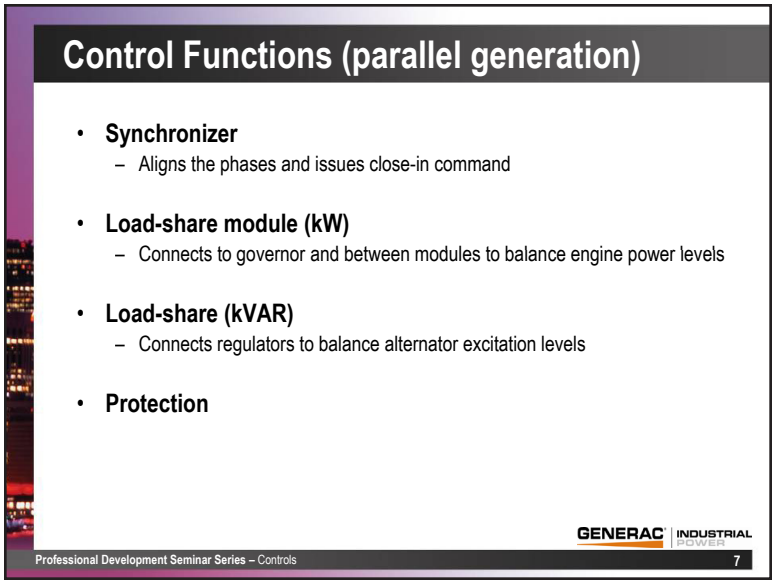
Control Functions (parallel generation)
• Synchronizer
– Aligns the phases and issues close-in command
• Load-share module (kW)
– Connects to governor and between modules to balance engine power levels
• Load-share (kVAR)
– Connects regulators to balance alternator excitation levels
• Protection
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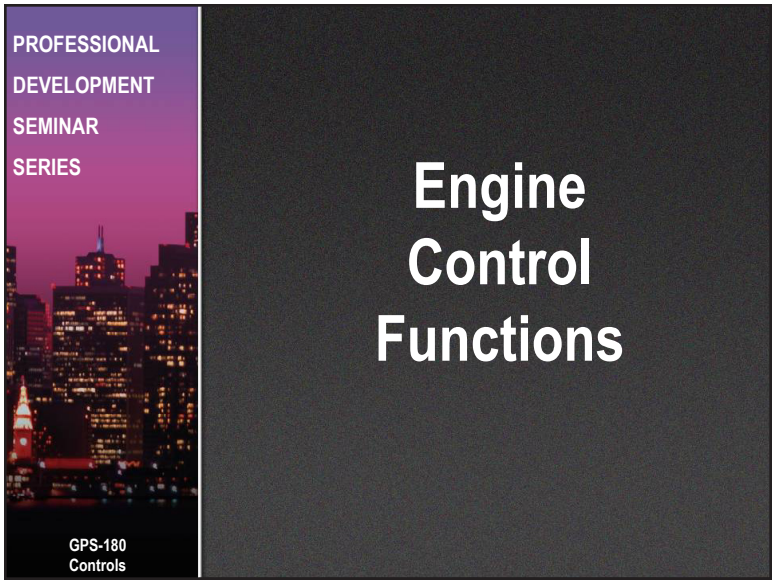
1. ENGINE CONTROLS

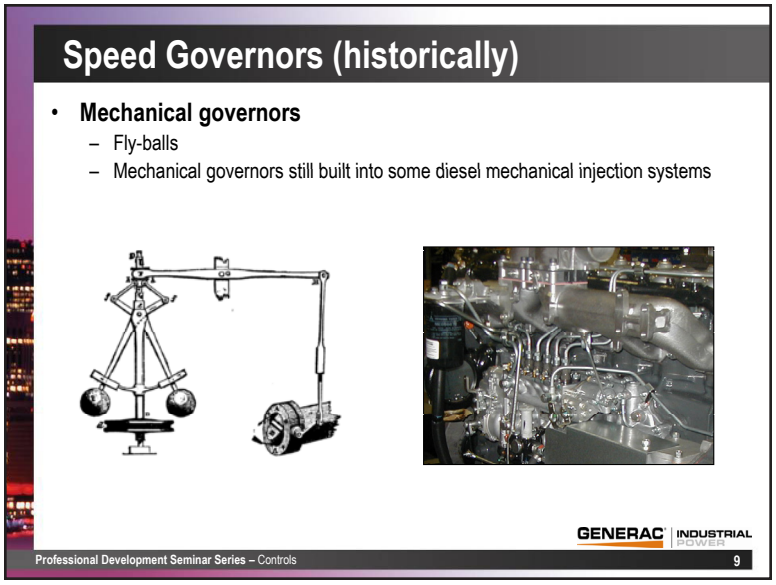
TIME: 15 minutes

OBJECTIVES:

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

- Explain how speed governors operate
- Describe the function of the ECM (Engine Control Module)
- Describe the function of the AFR (Air-Fuel-Ratio) control
- Explain the purpose of a Float Equalized Charger



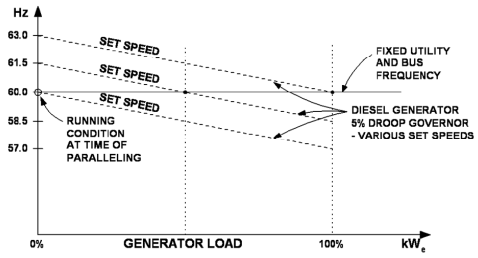


NOTES

1. ENGINE CONTROLS

Speed Governors

- **Mechanical governors "droop"**
  - Engine slows down when load is increased
  - Slope of the line is the droop value
  - The position of the line is the speed set – "speed reference"
    - Increasing speed spring tension causes the engine to run faster
    - Tortoise and Hare on your push lawnmower



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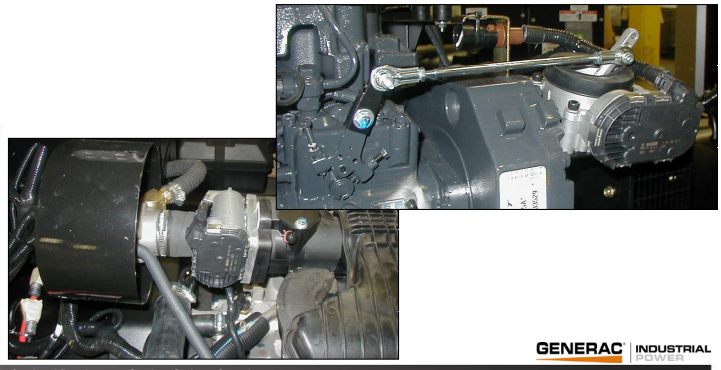
Speed Governors

- **Electronic governors**
  - Electronics & Actuator
  - Electronics may be integrated or stand alone



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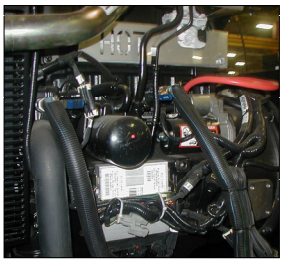
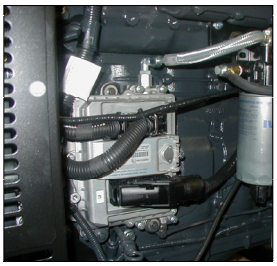
NOTES

ECM (engine control module) -- diesels

- **ECM**
  - Controls electronic injection (emission compliance)
  - Monitors operating temperatures and pressures
  - Communicates with "CAN-bus" (J1939 data protocol back to genset controller)





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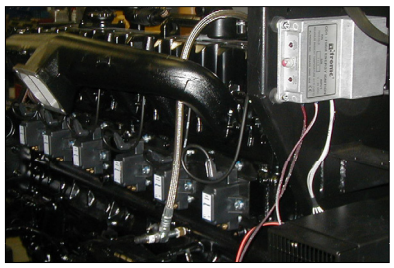
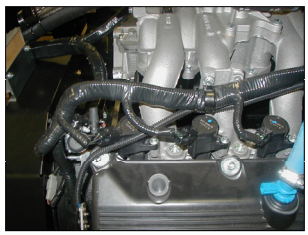
Ignition control (spark-ignited engines)

- **Controlling the firing of the spark plugs**
  - Historically mechanically controlled by distributor
  - Electronic ignition is market norm
    - Coils and ignition module
    - Ignition module may be integral or external





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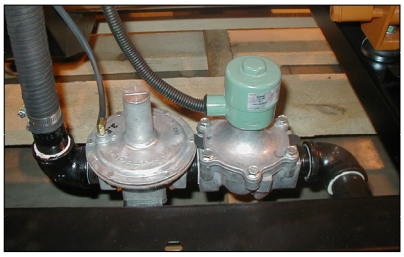
Air-fuel-ratio (spark-ignited engines)

- **AFR control**
  - Creates the optimal mix of air and fuel in the engine
  - Required when using 3-way catalytic convertors for emission control
  - Oxygen sensor in exhaust stream
  - Fuel mixture controlled via vacuum control of regulator diaphragm
  - AFR control module may be integrated or external



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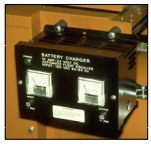
Battery charging

- **Float equalized charger**
  - Maintains battery charge
  - Equalizes cells for maximum cranking amps
  - Usually 10 amps
  - Integrated or external

- **Engine charging alternator**
  - Fast battery recovery after cranking
  - Adds reliability to system (failed charger)



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NOTES

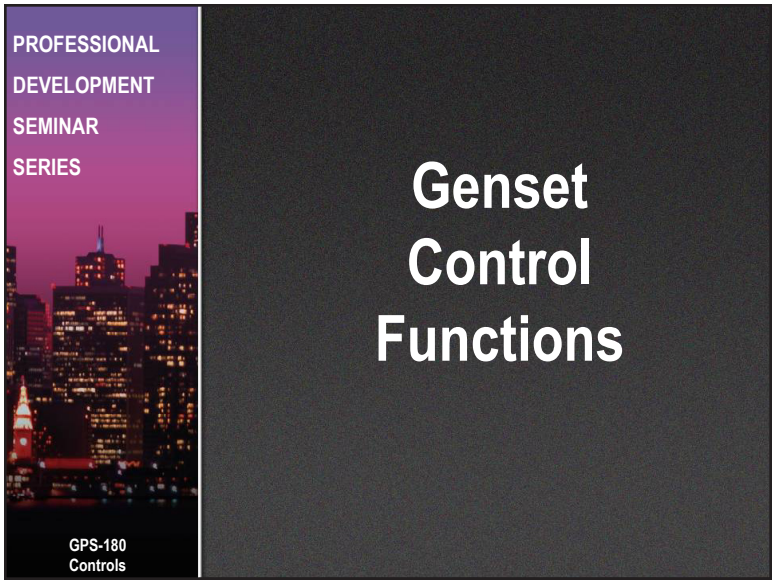
2. GENSET CONTROLS

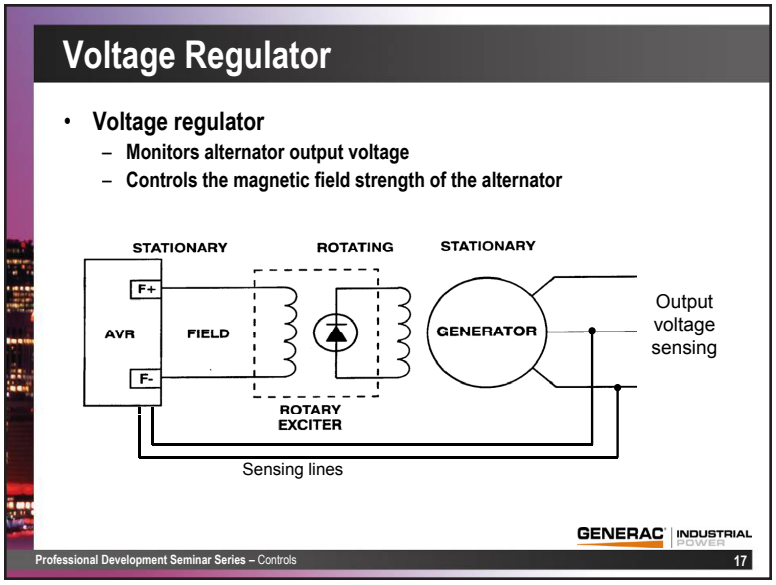
TIME: 35 minutes

OBJECTIVES:

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

- Explain how a voltage regulator works
- List and describe the typical functions a control panel
- Describe four key design features for control panels
- Explain how a 4-20 ma sensor operates
- Describe the advantages of current sensors over voltage sensors
- Explain the benefits of integrating all control functions into a single circuit board
- Explain "Predictive Maintenance" as it applies to control systems





NOTES

Voltage Regulator

- **Regulator hardware**
  - Integrated
  - Stand alone (digital or analog)
- **Typical analog regulator**
  - Regulation: 1.0%
  - Single phase, peak sensing
- **Typical digital regulator**
  - Regulation: 0.25%
  - Three phase, RMS sensing
  - Engine unloading algorithms

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Control Panels

- **What does a control panel do?**

Historical Control

  - Controls (starting and stopping)
  - Monitors and displays (meters, gauges, display screens)
  - Warns (temp, press, level, …)
  - Protects engine

Today's Digital Controls

  - Protects alternator
  - Advanced functionality
  - Communicates remotely
  - Integrated control
    - Voltage regulation, speed governing
    - Air-fuel-ratio control, Ignition, battery charging
    - Synchronizing, load balancing, protection

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NOTES

Control Panels

Early panels limited to NFPA 110 defined functions

Traditional Analog Control Panel

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NFPA 110 Alarm & Warning Requirements

Table 5.6.5.2 Safety Indications and Shutdowns

	Level 1			Level 2		
Indicator Function (at Battery Voltage)	**CV**	**S**	**RA**	**CV**	**S**	**RA**
(a) Overcrank	X	X	X	X	X	O
(b) Low water temperature	X	NA	X	X	NA	O
(c) High engine temperature pre-alarm	X	NA	X	O	NA	NA
(d) High engine temperature	X	X	X	X	X	O
(e) Low lube oil pressure pre-alarm	X	NA	X	O	NA	NA
(f) Low lube oil pressure	X	X	X	X	X	O
(g) Overspeed	X	X	X	X	X	O
(h) Low fuel main tank	X	NA	X	O	NA	O
(i) Low coolant level	X	O	X	X	O	X
(j) EPS supplying load	X	NA	NA	O	NA	NA
(k) Control switch not in automatic position	X	NA	X	O	NA	NA
(l) High battery voltage	X	NA	NA	O	NA	NA
(m) Low cranking voltage	X	NA	X	O	NA	O
(n) Low voltage in battery	X	NA	NA	O	NA	NA
(o) Battery charger ac failure	X	NA	NA	O	NA	NA
(p) Lamp test	X	NA	NA	X	NA	NA
(q) Contacts for local and remote common alarm	X	NA	X	X	NA	X
(r) Audible alarm silencing switch	NA	NA	X	NA	NA	O
(s) Low starting air pressure	X	NA	NA	O	NA	NA
(t) Low starting hydraulic pressure	X	NA	NA	O	NA	NA
(u) Air shutdown damper when used	X	X	X	X	X	O
(v) Remote emergency stop	NA	X	NA	NA	X	NA

CV: Control panel-mounted visual. S: Shutdown of EPS indication. RA: Remote audible. X: Required. O: Optional. NA: Not applicable.

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NOTES

Control Panels

- **Market migration**
  - Analog to digital
  - Standardized (NFPA 110 Level 1)
  - Display types
  - Advanced features

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Targeting Key Features

- **Reliability: Hardened systems**
- **Flexibility: Site and application customizable**
- **Diagnostics: Minimize repair time**
- **Usability: Easy to use and interface**

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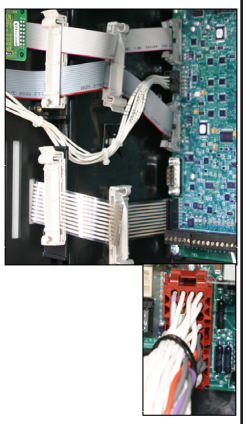
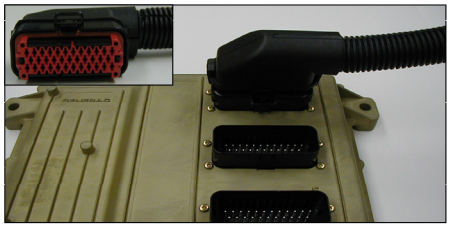
Sealed Plug Connections

- **Traditional open connections**
  - Corrosion over time corrupts sensor signals
  - Many ring terminal connections
- **Sealed plug connects protection against**
  - Corrosion and environmental degradation of control circuits
  - Age deterioration and moisture related failures
  - Supports fast end-user repairs with on-site spare parts





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Hardened Feedback Signals

- **Traditional sensor signals**
  - Resistive sensors with voltage based feedback
  - Sensitive to:
    - Connection corrosion
    - Electrical noise (EMI and RFI)
- **Next level of performance (4-20 ma sensors)**
  - Greatly improved noise immunity
  - Tolerant of connection corrosion
  - Unaffected by long sensor runs
  - Positive indication of sensor failure

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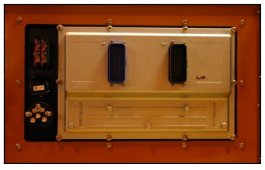
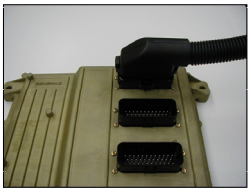
Hardened Boards – Noise Immunity

- **Traditional open boards**
  - Sensitive to:
    - Corrosion
    - EMI, RFI, ESD
    - Potentiometer *"tweakers"*

- **Next level of performance (all digital sealed board)**
  - Electrical and environmental protection





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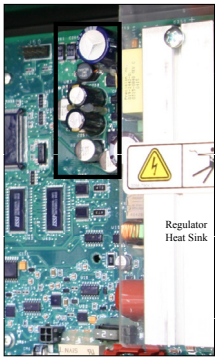
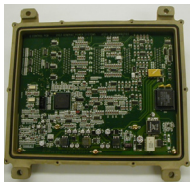
Hardened Boards – Vibration & Thermal

- **Traditional component layout**
  - Sensitive to:
    - Vibration
    - Thermal stress

- **Next level of performance**
  - Surface mount component layout
  - Separate power/thermal elements





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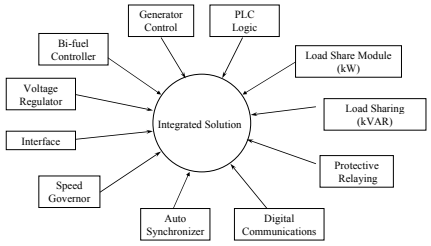
Integration of Control Functions

- **Traditional controller configuration**
  - Separate controller for each function
    - Speed governor, Voltage Regulator, Genset monitoring
    - Synchronizing, Load-sharing, Protective relaying
- **Next level of performance**
  - Integration of all functions into single hardened controller (less to fail)



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Easy to Use Interfaces

- **Traditional controller configuration**
  - Limited display (2 lines)
  - Reliance on fault code numbers

- **Next level of performance**
  - Comprehensive displays (8 lines)
  - Intuitive interfaces (touch screens)
  - Faults (worded descriptions)
  - Diagnostic screens

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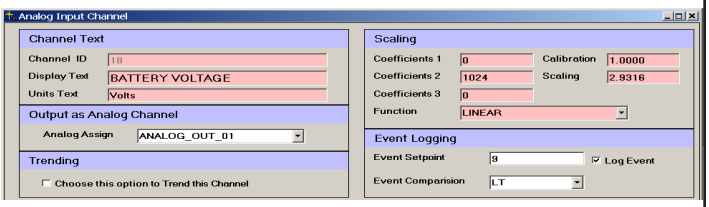
NOTES

Enhanced I/O Control

- **Input "channels":**
  - Curve fit all input parameters
  - Customized events, alarms or warnings
  - Instantaneous and steady state trip points
  - User definable

Benefit

Greater accuracy
Identify potential problem early
Flexibility
Reliability



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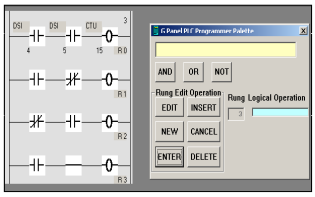
Customizable Spare I/O

- **Traditional controller capabilities**
  - Limited spare I/O
  - Fixed functionality
- **Next level of performance**
  - Significant spare and expandable I/O
  - Configurable and additional functionality
  - Programmable functionality



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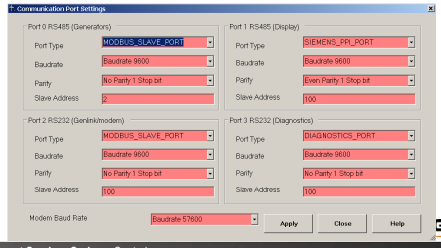
Communication & Interfacing

- **Traditional communication capability**
  - Limited communications and specialized communication protocol
- **Next level of performance**
  - Spare communication ports and universally supported protocol (Modbus)
  - Support for modem or Ethernet connectivity
  - Canbus (SAE J1939) support for integration of engine management systems



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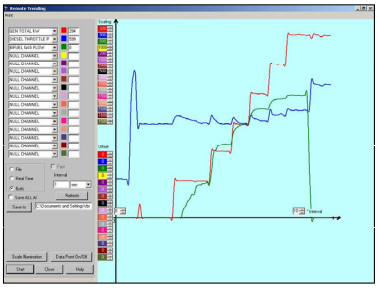
Data Logging & Trending

- **Traditional data log**
  - Combined events and alarm logs
  - Limited to no trending capabilities



- **Next level of performance**
  - Time stamped (real time clock) event and alarm logs with key operating conditions
  - Full data trending capability (built in strip chart recorder)
  - High speed data capture functionality (waveform analysis and advanced diagnostics)

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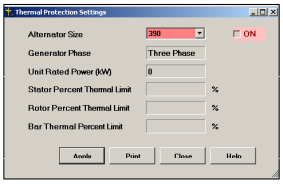
Protection

- **Traditional protection**
  - No support for instantaneous and steady state alarm points
  - Limited to alternator protection algorithms
- **Next level of performance**
  - Support customizable alarm points on every controller input
  - Support instantaneous and steady state alarm points
  - Alternator thermal predictive modeling and protection
    - Moving beyond simple I^2t short circuit

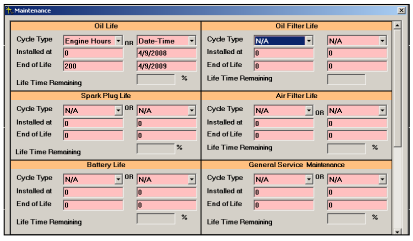


GENERAC INDUSTRIAL POWER

Professional Development Seminar Series – Controls 34

Predictive Maintenance

- **Traditional**
  - No support for predictive maintenance
  - Standby generator reliability is significantly impacted by lack of PM
- **Next level of performance**
  - Predictive maintenance with monitoring, alarming and call-out capabilities

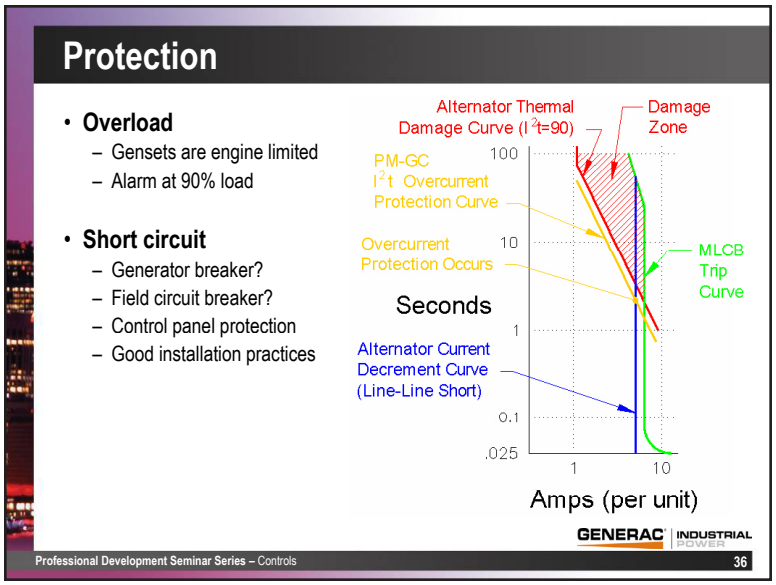


GENERAC INDUSTRIAL POWER

Professional Development Seminar Series – Controls 35

NOTES

2. GENSET CONTROLS



NOTES

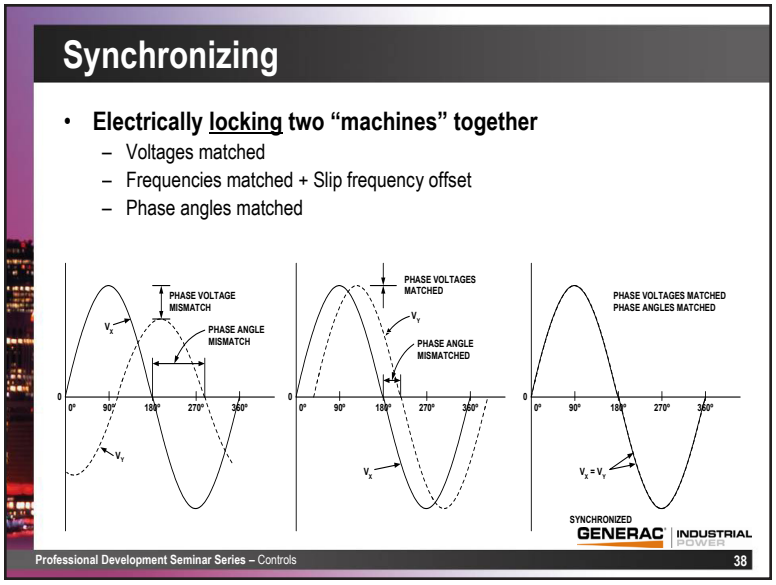
3. PARALLELING CONTROLS

TIME: 35 minutes

OBJECTIVES:

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

- Explain synchronizing as it applies to paralleled generators
- Describe how load sharing is controled when paralleling generators
- Describe the differences between real and reactive power
- Explain protective relaying in paralleled generators

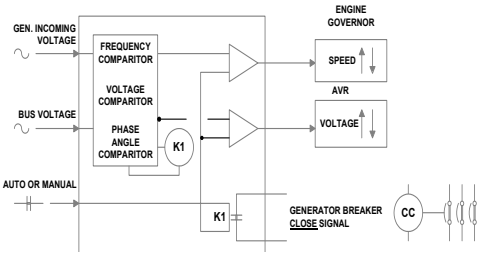


NOTES

3. PARALLELING CONTROLS

Synchronizing

- **Automatic synchronizers provide:**
  - Adjust speed of incoming generator set.
  - Match frequencies & phase angles.
  - Provide breaker close signal
  - Optional voltage matching control.



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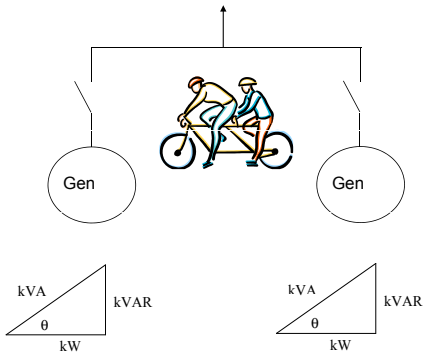
Load Sharing -- Balancing the Triangles



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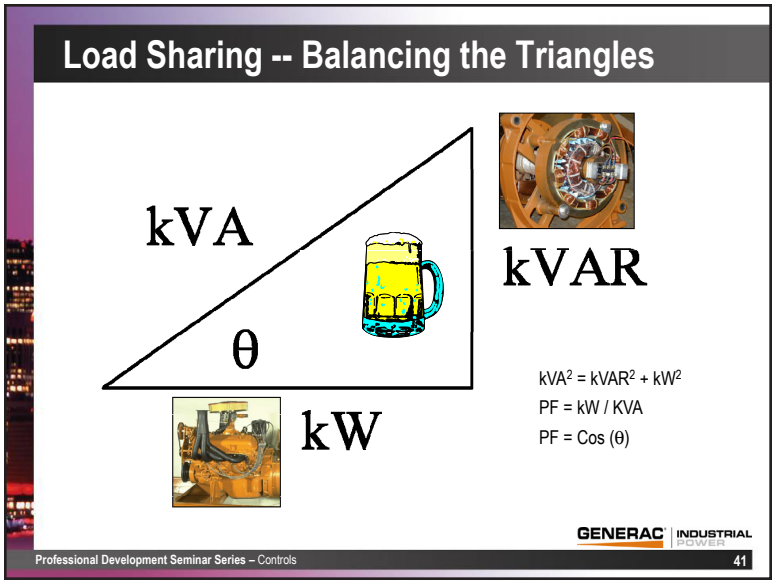
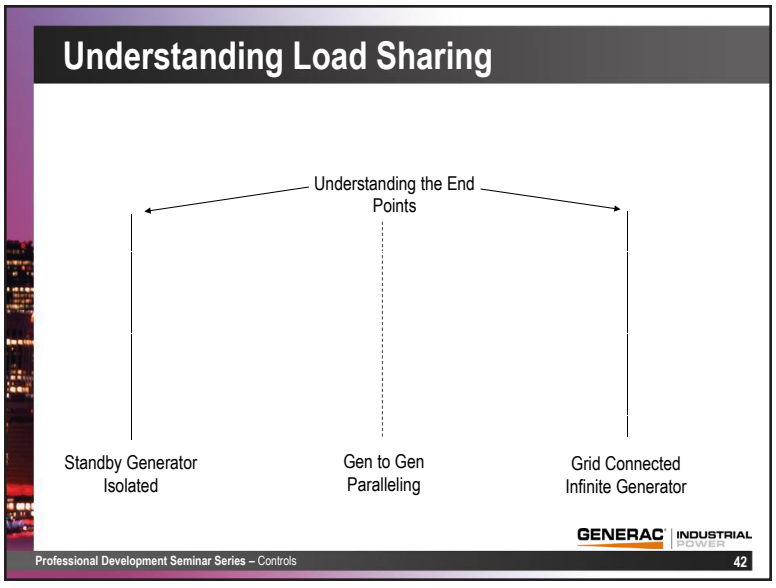
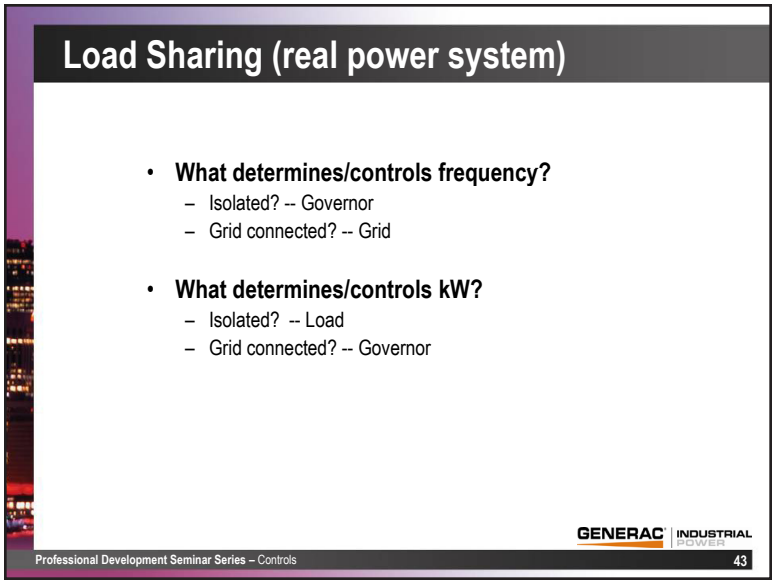
NOTES

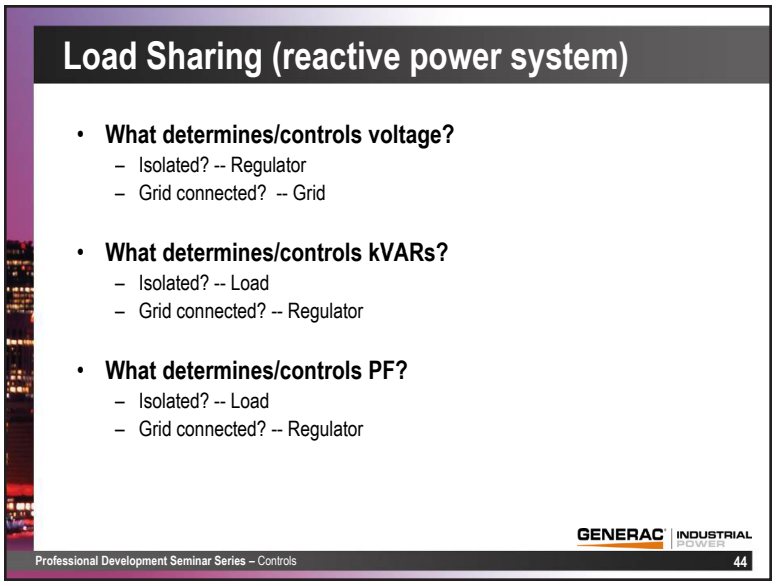
3. PARALLELING CONTROLS





NOTES


Load Sharing (real power system)
• What determines/controls frequency?
– Isolated? -- Governor
– Grid connected? -- Grid
• What determines/controls kW?
– Isolated? -- Load
– Grid connected? -- Governor
GENERAC INDUSTRIAL POWER
Professional Development Seminar Series – Controls
43


Load Sharing (reactive power system)
• What determines/controls voltage?
– Isolated? -- Regulator
– Grid connected? -- Grid
• What determines/controls kVARs?
– Isolated? -- Load
– Grid connected? -- Regulator
• What determines/controls PF?
– Isolated? -- Load
– Grid connected? -- Regulator
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Professional Development Seminar Series – Controls
44

NOTES

Real Versus Reactive

Symmetrical Systems:

Real Power System		Reactive Power System
kW	⇒	kVAR
Frequency	⇒	Voltage
Governor	⇒	Regulator
Engine fuel	⇒	Alternator excitation

Note the answers and questions from previous slides.

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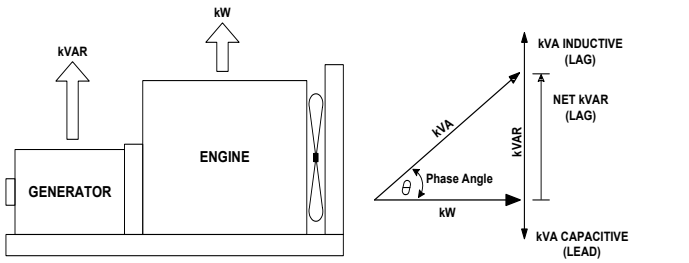
Professional Development Seminar Series – Controls 45

Load Sharing (Two things to control & two ways of doing it)

- **Load Sharing (Matching)**
  - Real Power (kW)
    - Isochronous load sharing or speed droop
  - Reactive Power (kVAR)
    - Reactive cross current or voltage droop



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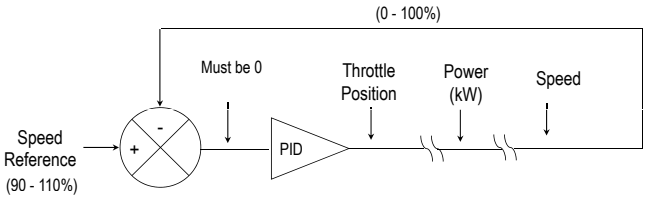
Professional Development Seminar Series – Controls 46

NOTES

Load Sharing (Isochronous operation)

- **Isochronous governors**
  - What happens if two are connected together??



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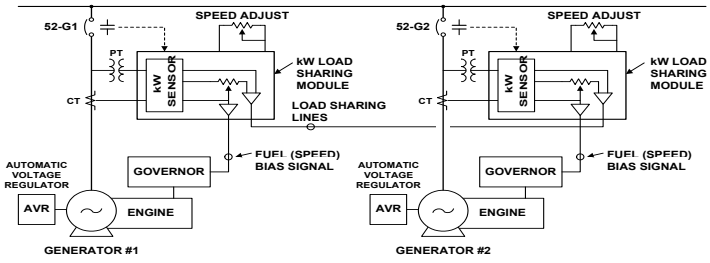
Professional Development Seminar Series – Controls 47

Load Sharing (Isochronous load sharing)

- **Balances real power**
- **Maintains speed at 60 hertz**
- **Historical industry norm – fundamentally is inherently unstable**



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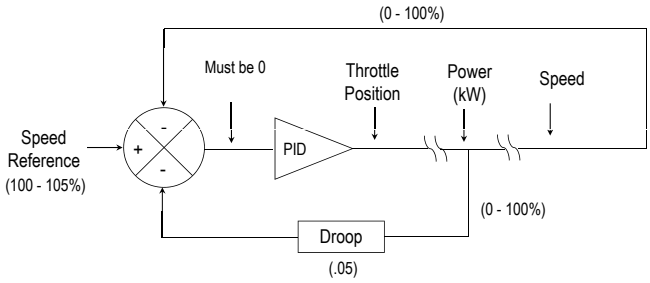
Professional Development Seminar Series – Controls 48

NOTES

Load Sharing (Understanding droop)



Speed = - Droop (kw) + Speed Ref

Note:
y = - m(x) + b
Droop is the slope
Speed Ref is the intercept

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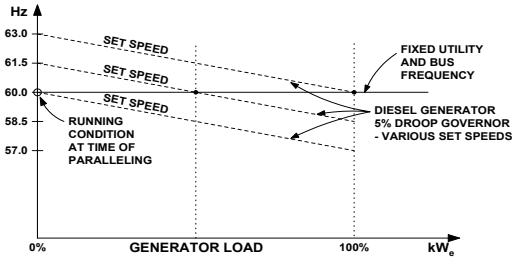
Professional Development Seminar Series – Controls 49

Load Sharing (Understanding droop)

- **Speed droop graphical representation**
- **Will two speed droop governors share load?**
  - What is the negative consequence?



Speed = - Droop (kw) + Speed Ref

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Professional Development Seminar Series – Controls 50

NOTES

Load Sharing (Understanding droop)

- **Market needs and perceptions**
  - Wants isochronous operation
    - Maintain 60hz at all load points
  - Views droop as "out-dated technology"
- **How does the power grid operate?**
  - Isochronous load sharing or speed droop?
    - Why?
    - What benefits are gained?

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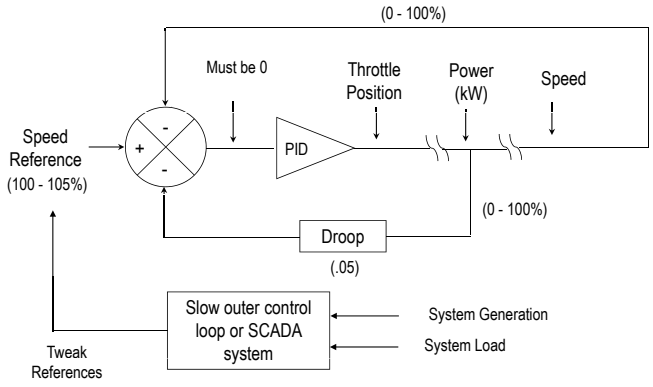
Professional Development Seminar Series – Controls 51

Load Sharing (How the grid works)

Speed = - Droop (kw) + Speed Ref



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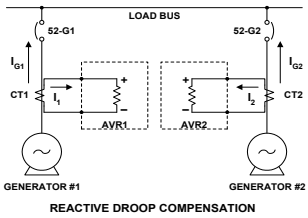
Professional Development Seminar Series – Controls 52

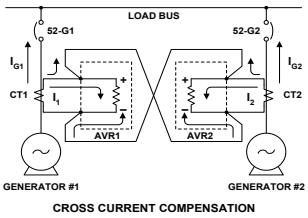
NOTES

Load Sharing (Reactive load balancing)

- **Load sharing (reactive)**
  - Reactive droop (varying voltage)
    - Voltage = - droop (kVAR) + voltage reference
  - Reactive cross current (constant voltage)



REACTIVE DROOP COMPENSATION



CROSS CURRENT COMPENSATION

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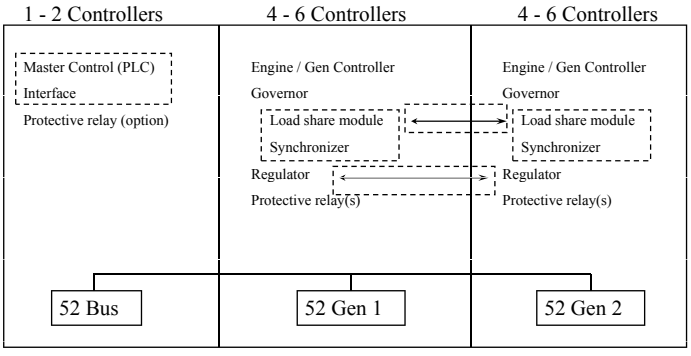
Professional Development Seminar Series – Controls 53

Controller count with traditional paralleling

- **Controller complexity constraints of traditional implementation?**



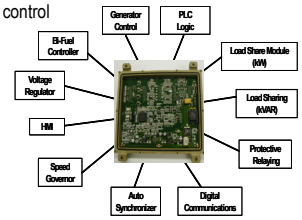
GENERAC INDUSTRIAL POWER

Professional Development Seminar Series – Controls 54

NOTES

Controller count reduction via integration

- **Controller issues are corrected**
  - An integrated, all digital approach
    - Reduces interconnected wiring
    - Proven hardware & software (not one-off designs)
    - Removes calibration issues (self tuning)
    - Enhances load balancing stability (inherently stable algorithms)
    - Improves tolerance to electrical noise (no load share lines)
    - System remains operational without master control
    - Maximizes system reliability



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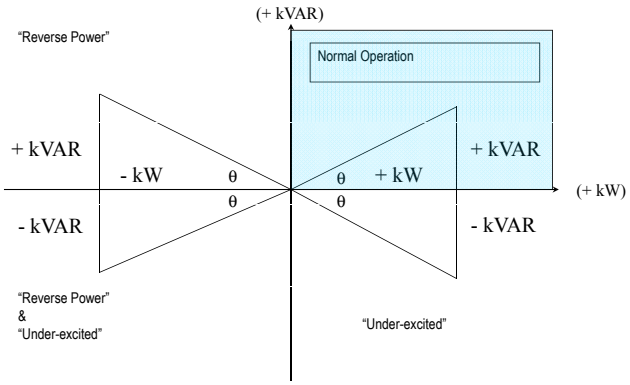
Load Sharing -- Protection



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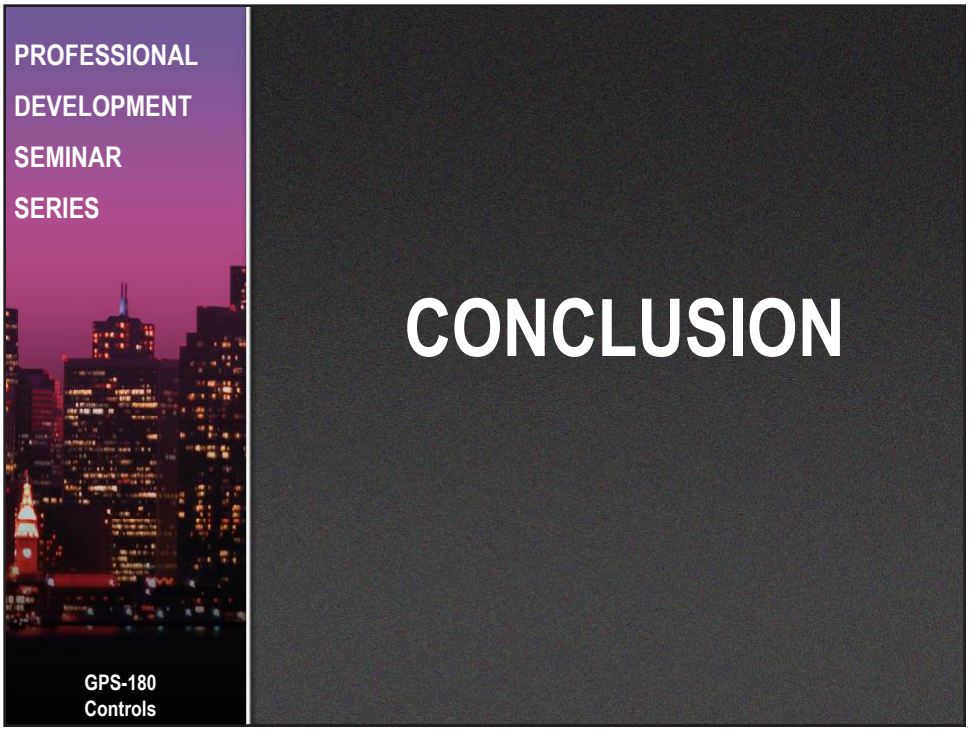
NOTES

CONCLUSION

NOTES



NOTES

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"*

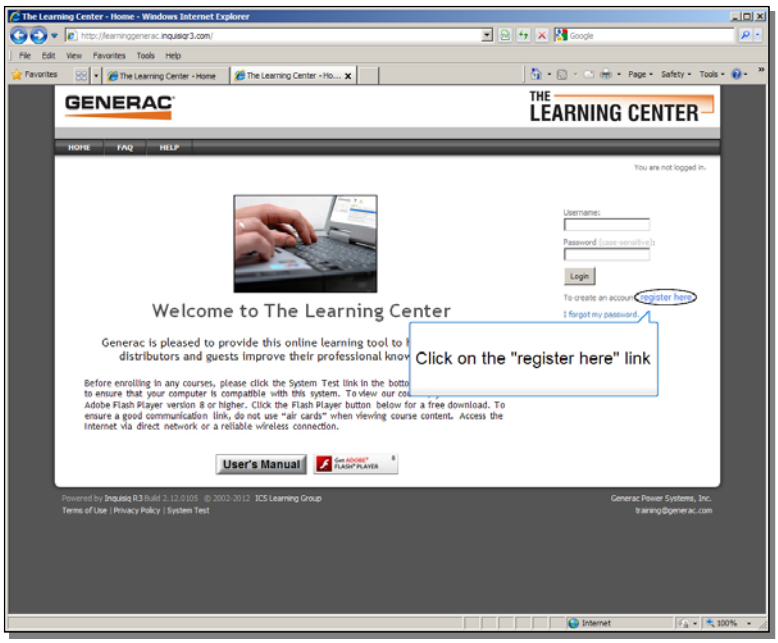
To gain access to *"The Learning Center*", you are required to register and set up a user account. During your account setup you will create a *Username* and *Password*. Your username and password can then be used to log in on subsequent visits.

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

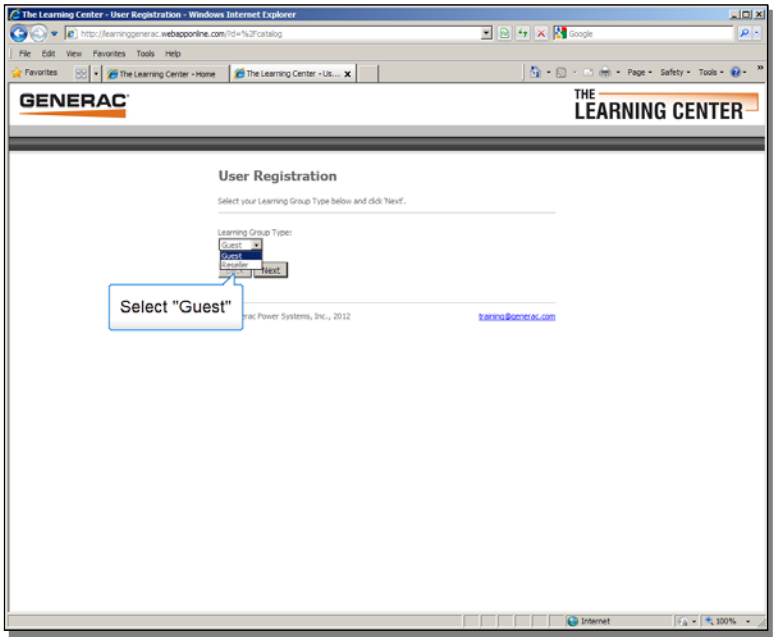
To begin the registration process, open your computer's browser and enter http:// learning.generac.com. This should take you to *"The Learning Center"* home page. This page is displayed at the top of the next page. From this point you can follow illustrated steps.

ONLINE FINAL ASSESSMENT AND CERTIFICATE REGISTRATION AND LOGIN PROCEDURE

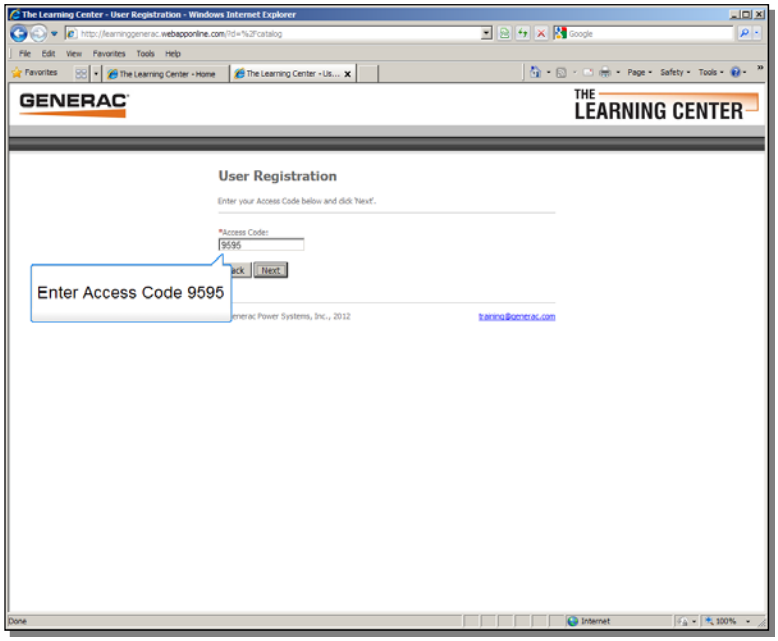
Begin by entering http://learning.generac.com in your computer's browser. The screen below will be displayed. Click on the "register here" link to begin the registration process.



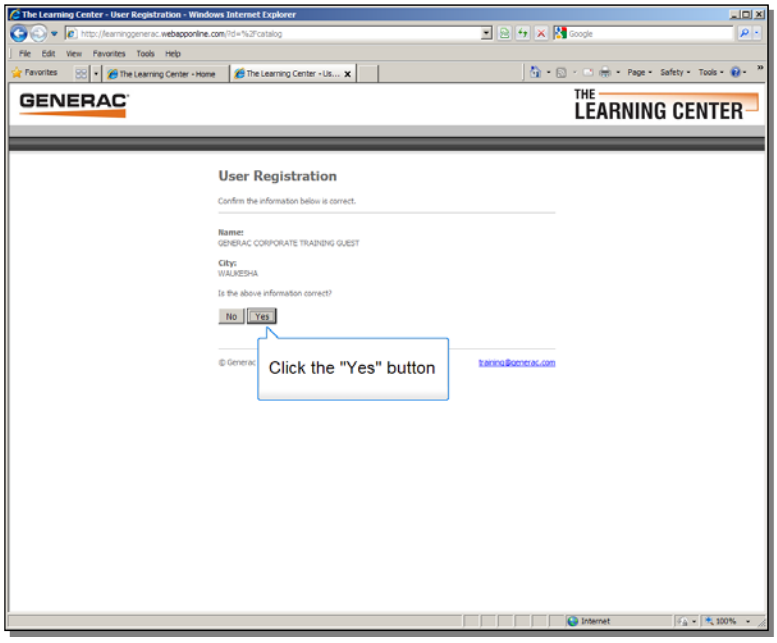
On this screen you will select "Guest" from the drop down box and click the "Next" button.



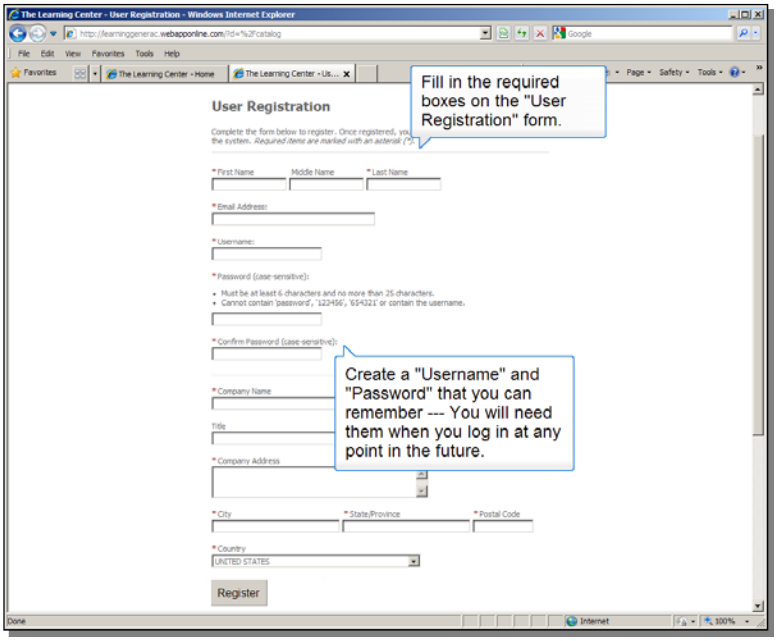
In this next screen enter **Access Code 9595** and click the “Next” button. Please keep this code private.



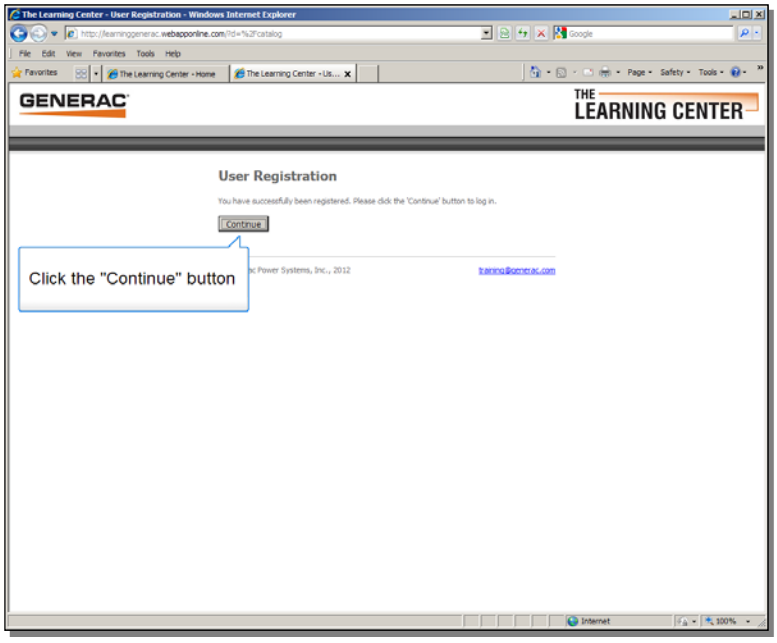
This screen confirms the correct access code entry. Click the “Yes” button to proceed.



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

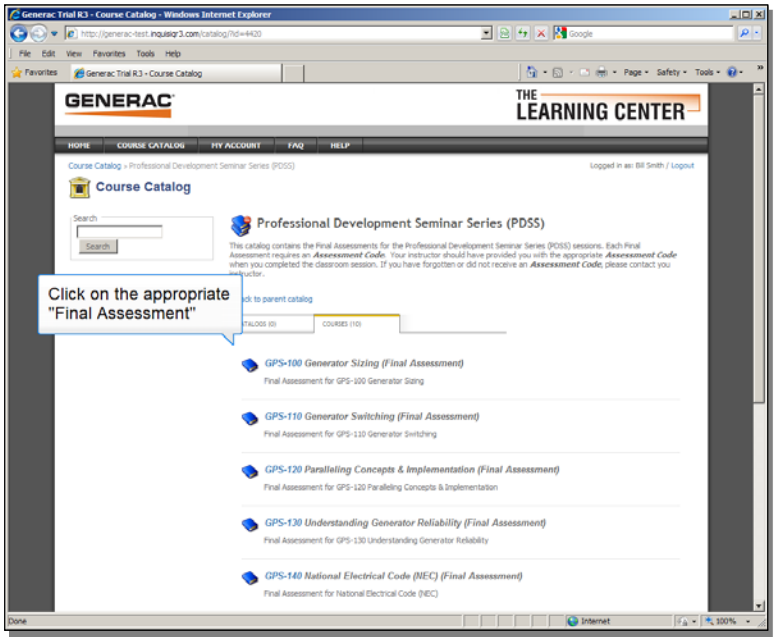


The next screen confirms your registration. Click the “Continue” button to proceed.

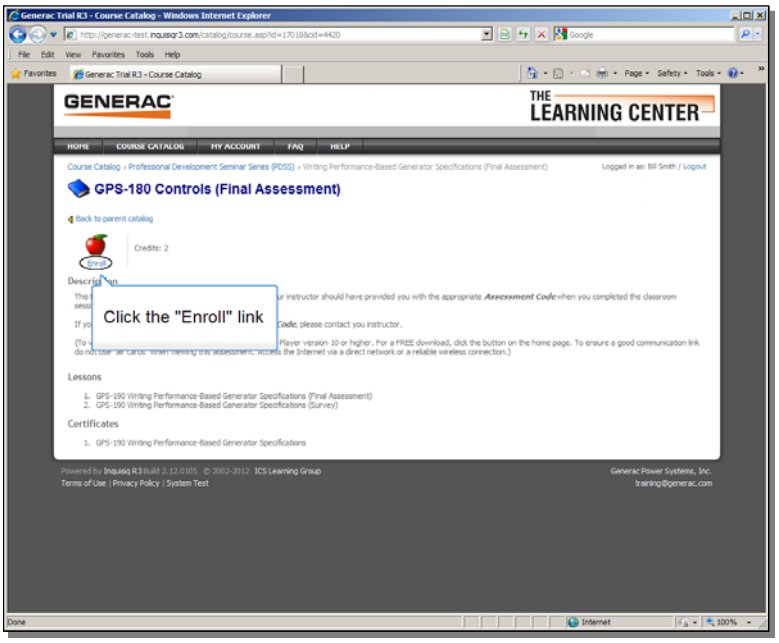


The next screen displays the “Course Catalog.” Click on the “Professional Development Seminar Series” link.

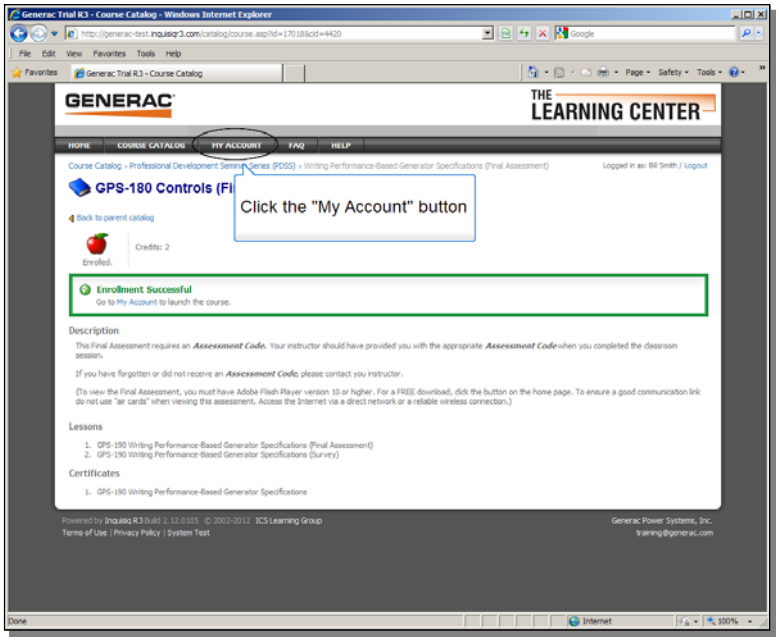
This next screen lists all currently available Final Assessments. Click on the Final Assessment that is tied to the course name and number you completed.



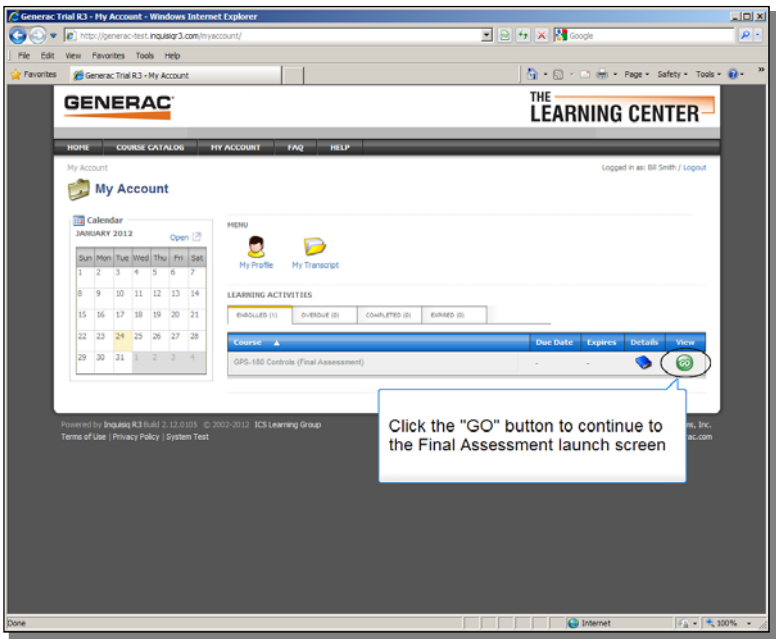
The next screen is the “Enrollment” screen for the Final Assessment that you selected. Click the “Enroll” link to proceed.



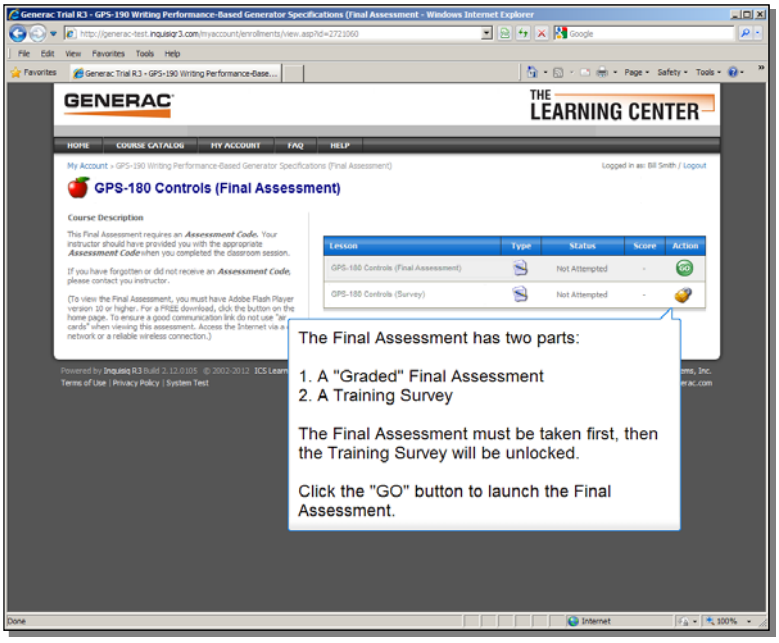
This screen confirms your enrollment. Click the “My Account” button to proceed.



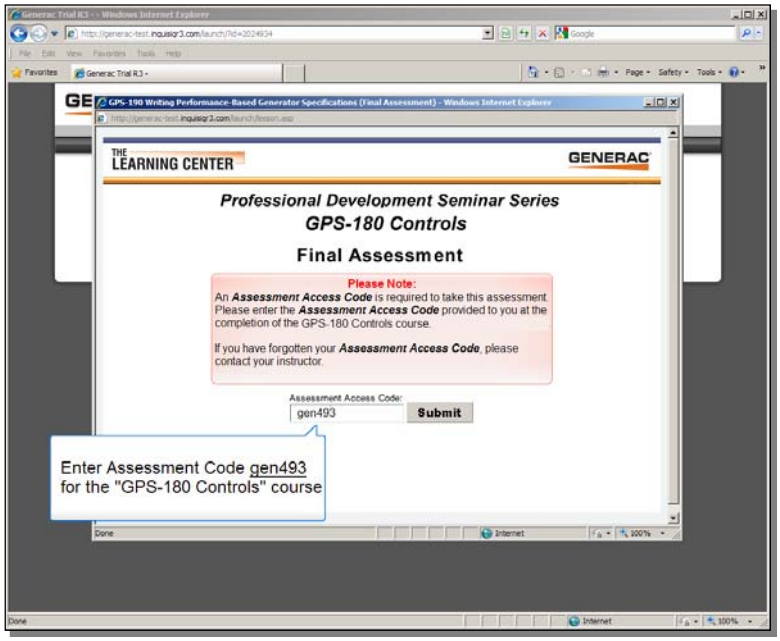
This is your “My Account” screen. Note that the Final Assessment you selected is displayed under the “Enrollment” tab. Click the “GO” button to proceed.



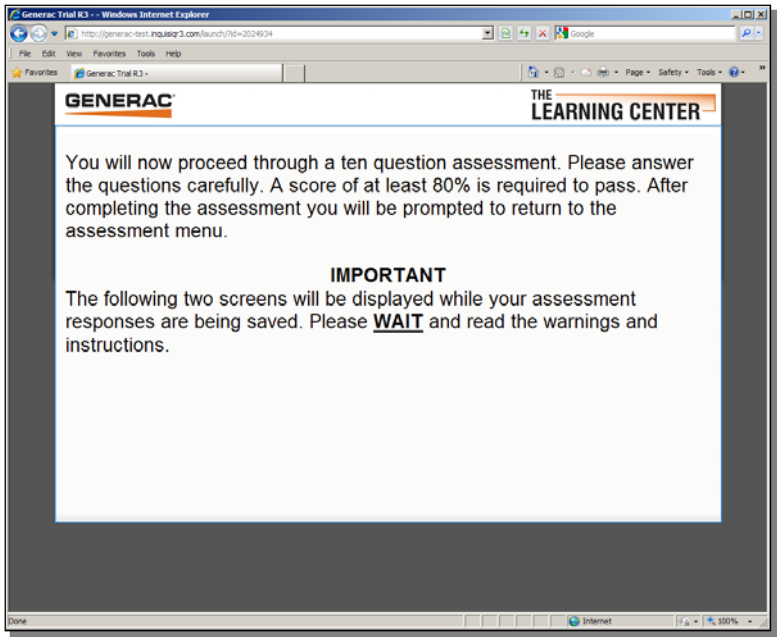
This screen lists the two parts to the Final Assessment. You must take the “Graded” Assessment first, then the Training Survey.



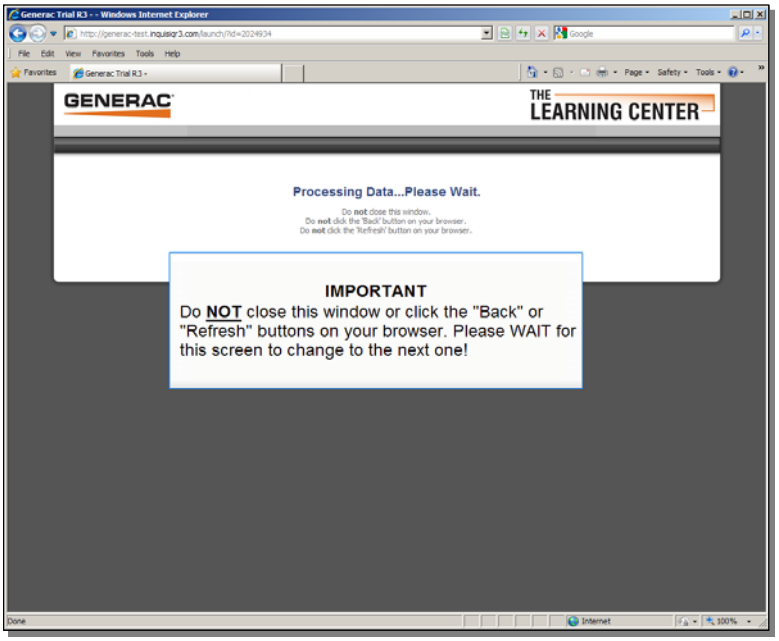
In the next screen an “Assessment Code” is required before you can continue. The code for GPS-180 Controls is **gen493**. Enter the code in the box and click the “Submit” button to continue.



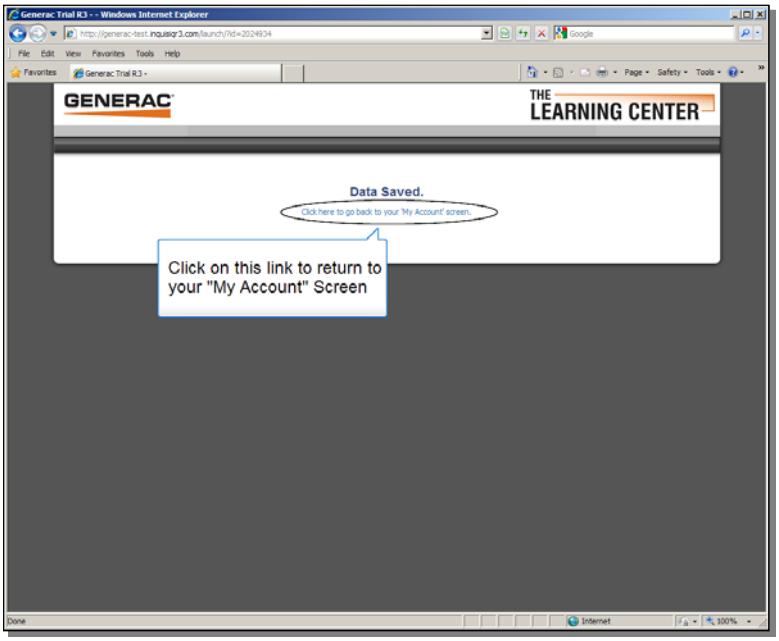
You will now proceed through a ten question assessment. Please read the warnings below.



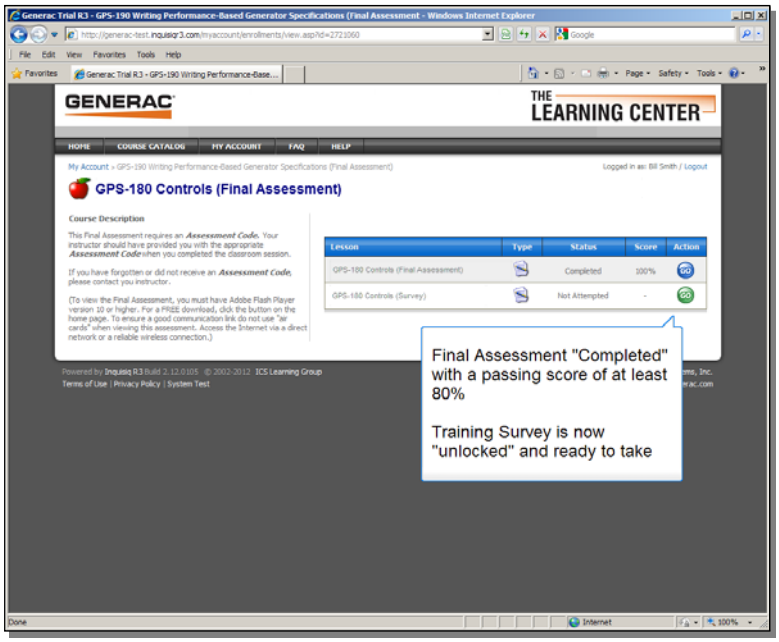
Please follow the instructions on this screen. You must wait for your assessment data to be saved. Do not close this window or click the 'Back' of 'Refresh' buttons on your browser.



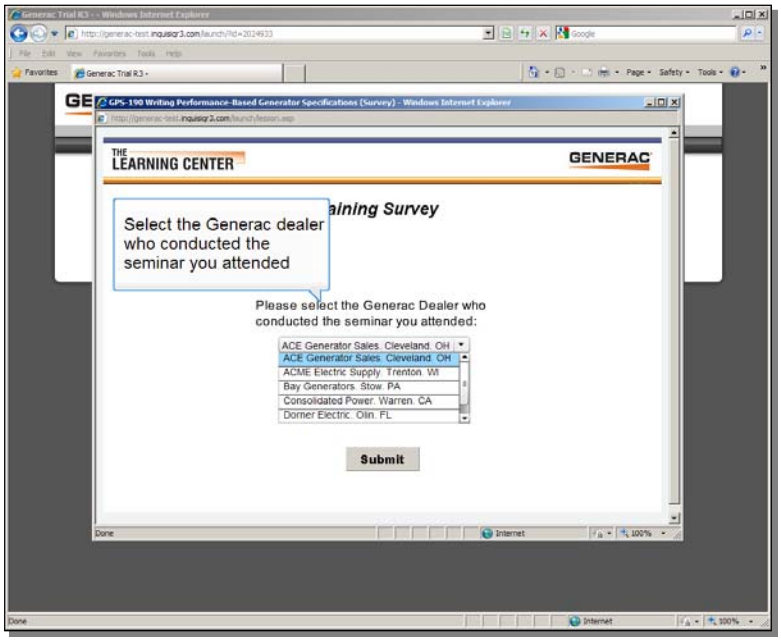
This screen confirms that your data was saved. Click on the link shown here to proceed.



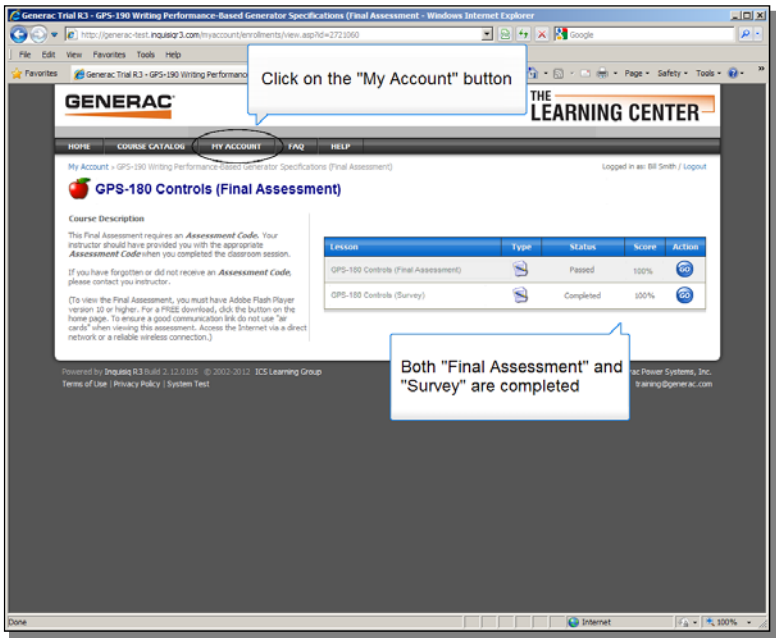
This screen will be displayed after your assessment data is saved. Note that in this example the assessment was passed with a score of 100% and the Survey is unlocked and ready to launch.



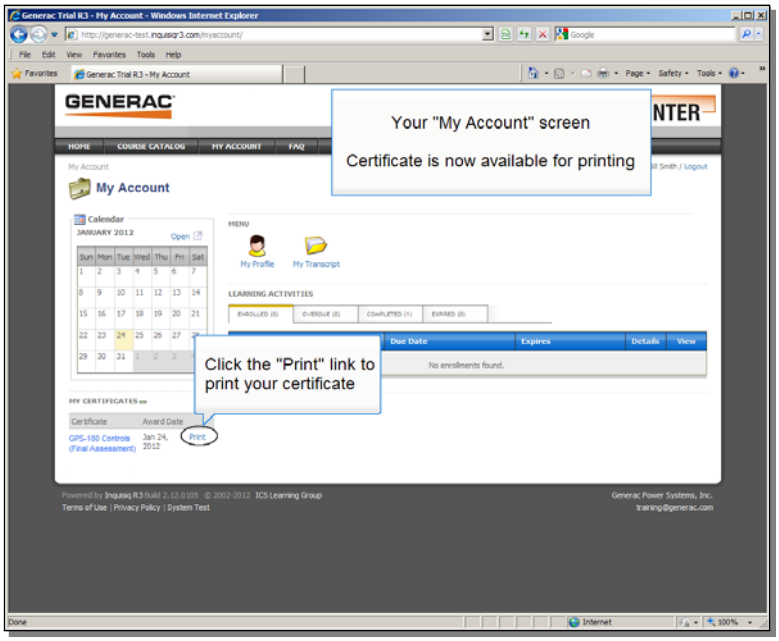
Upon launching the Survey, this screen will be displayed. Select the Generac dealer who conducted the seminar you attended.



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.



NOTES

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