PROFESSIONAL DEVELOPMENT
SEMINAR SERIES

GPS-130 UNDERSTANDING GENERATOR RELIABILITY

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 reliability 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 the key factors necessary to ensure the highest degree of reliability in emergency power system design. It explores strategies for value engineering projects through utilization of the best available technologies and innovations without sacrificing overall power system reliability. Guidelines will be provided for the selection of the system best suited to meet a project's cost, reliability and performance criteria. The course will also present measures for determination of reliability and provide tools to establish reliability criteria for overall engine-generator power systems.

TIME:

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

LEARNING OBJECTIVES:

Upon completion of this module, participants will be able to identify and describe the key factors affecting generator reliability. Specifically they will be able to:

- List and describe the physical, organizational, and human elements of the "Reliability Chain"
- Describe how MTBF (Mean Time Between Failures) is used and calculated
- Describe the selection criteria and/or "rules-of-thumb" for critical generator and supporting systems including: engines, alternators, fuel systems, fuel types, on-generator and off-engine cooling systems, temperature, air flow, starting systems, batteries, and indoor/outdoor factors
- List and describe the components of a typical control system
- Describe the various weaknesses affecting control system reliability
- Describe the current practices and technology advancements that have corrected control system weaknesses
- List the advantages of an integrated parallel generator operation over a single generator system

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

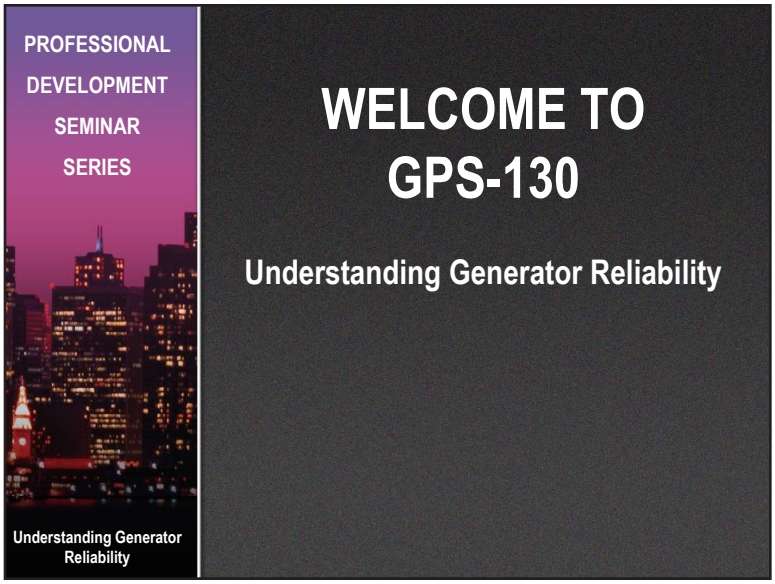
TIME	LESSON	DESCRIPTION
5 minutes	Introductions	Participants and trainer should become briefly acquainted. The trainer welcomes participants and conducts an opening icebreaker activity.
35 minutes	Lesson 1 Analyzing Reliability	Key factors impacting generator reliability will be discussed. The "Reliability Chain", a key concept in understanding the physical, organizational, and human elements affecting reliability is introduced. MTBF is explained along with how it is used and calculated.
35 minutes	Lesson 2 Generator and Supporting Systems	The significant generator components and systems most susceptible to reliability issues are identified and discussed. These will include: engines, alternators, fuel systems, fuel types, on-generator and off-engine cooling systems, temperature, air flow, starting systems, batteries and indoor/outdoor factors. Selection criteria and "rules-of-thumb" will be discussed.
10 minutes	Lesson 3 Control Systems and Multiple Generator Solutions	Control systems will be described along with the current advanced practices that have greatly improved their reliability. Integrated parallel generator operation will be discussed and show how redundancy along with the integration of certain components increases reliability.
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.

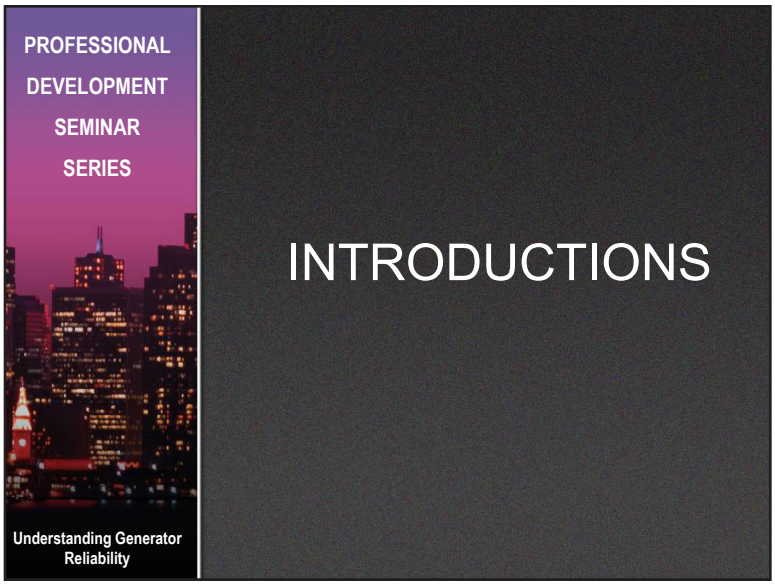
INTRODUCTION

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 reliability.





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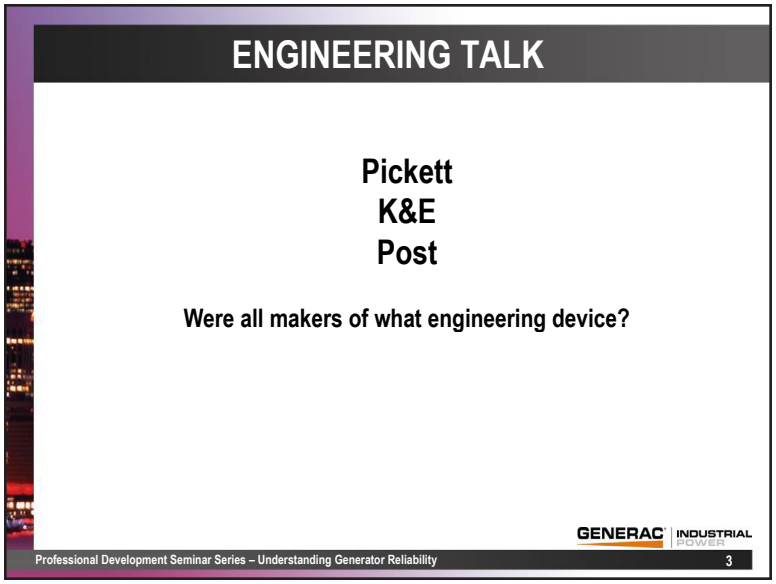
ENGINEERING TALK
Pickett
K&E
Post
Were all makers of what engineering device?
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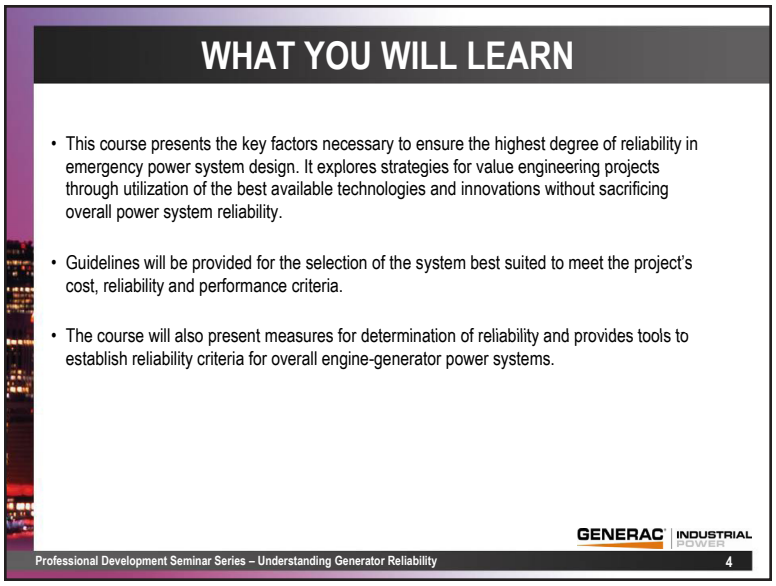
WHAT YOU WILL LEARN
• This course presents the key factors necessary to ensure the highest degree of reliability in emergency power system design. It explores strategies for value engineering projects through utilization of the best available technologies and innovations without sacrificing overall power system reliability.
• Guidelines will be provided for the selection of the system best suited to meet the project's cost, reliability and performance criteria.
• The course will also present measures for determination of reliability and provides tools to establish reliability criteria for overall engine-generator power systems.
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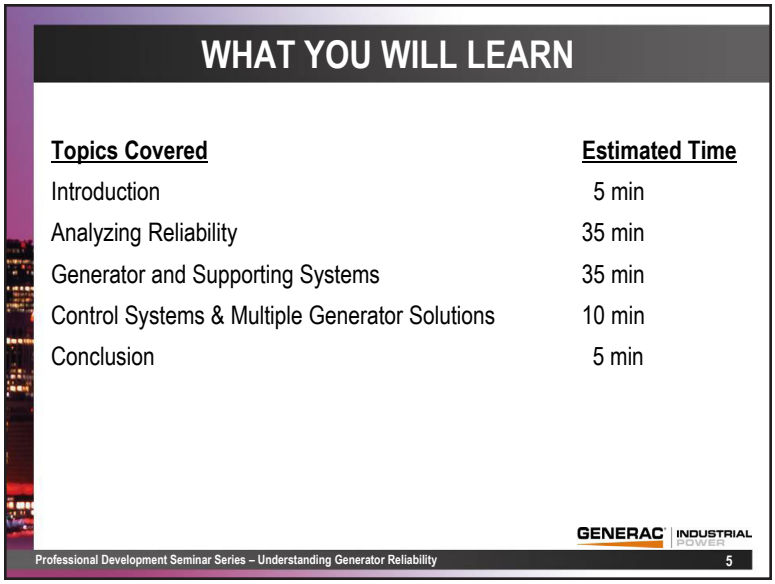
WHAT YOU WILL LEARN
Topics Covered
Estimated Time
Introduction
5 min
Analyzing Reliability
35 min
Generator and Supporting Systems
35 min
Control Systems & Multiple Generator Solutions
10 min
Conclusion
5 min
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NOTES

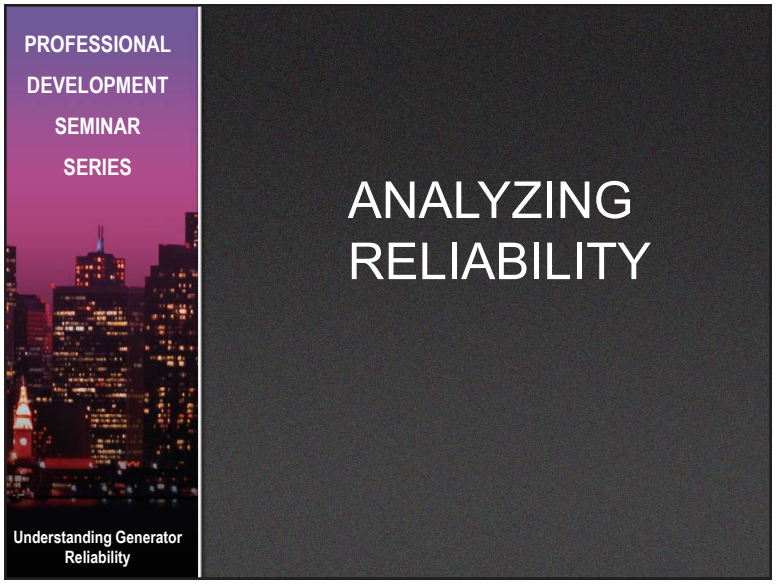
1. Analyzing Reliability

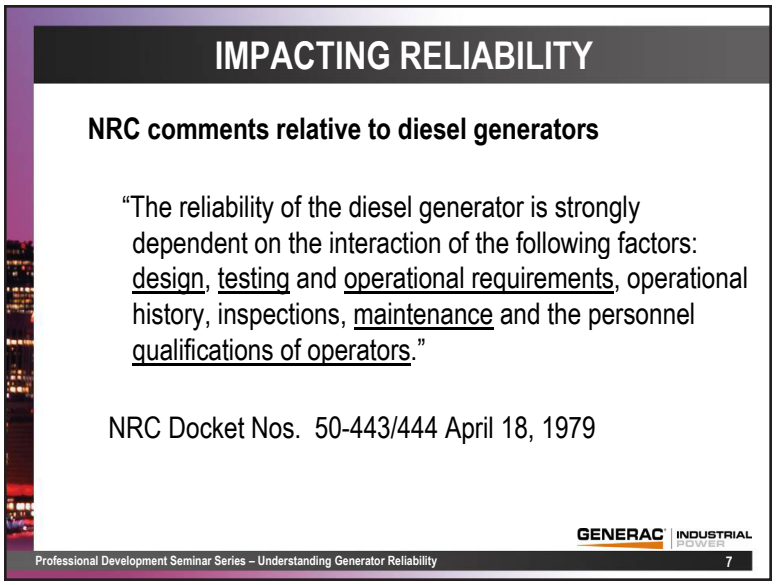
TIME: 35 minutes

OBJECTIVES:

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

- List and describe the key factors impacting the generator reliability chain
- Explain the terms MTBF and reliability percentage
- Describe serial system reliability
- List three ways to minimize the impact of serial components
- Describe Parallel System reliability





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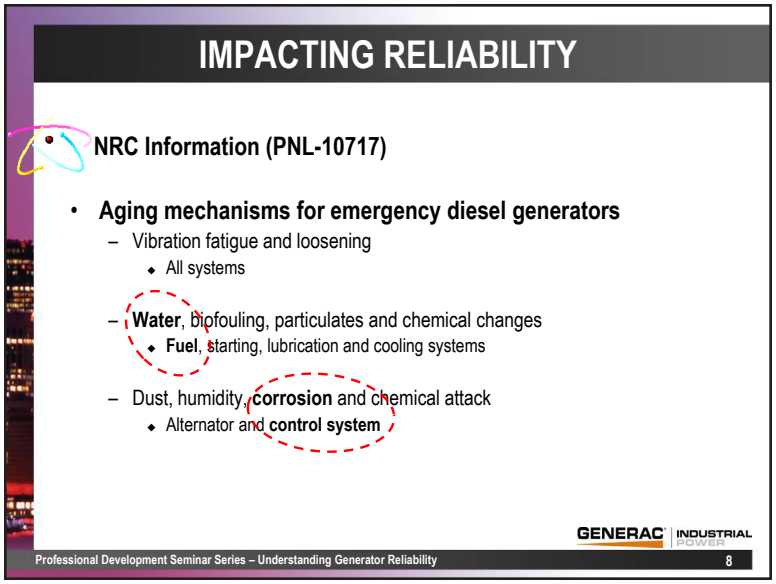
IMPACTING RELIABILITY
NRC Information (PNL-10717)
• Aging mechanisms for emergency diesel generators
– Vibration fatigue and loosening
◆ All systems
– Water, biofouling, particulates and chemical changes
◆ Fuel, starting, lubrication and cooling systems
– Dust, humidity, corrosion and chemical attack
◆ Alternator and control system
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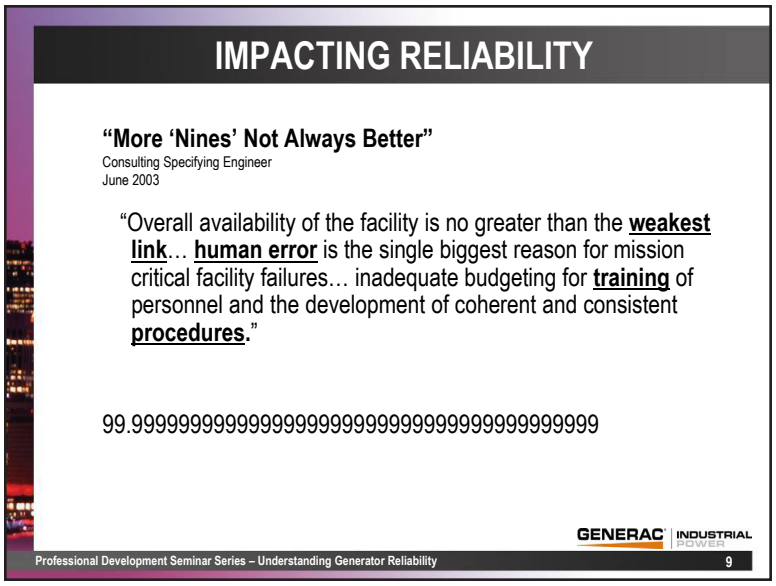
IMPACTING RELIABILITY
"More 'Nines' Not Always Better"
Consulting Specifying Engineer
June 2003
"Overall availability of the facility is no greater than the weakest link... human error is the single biggest reason for mission critical facility failures... inadequate budgeting for training of personnel and the development of coherent and consistent procedures."
99.9999999999999999999999999999999999999999
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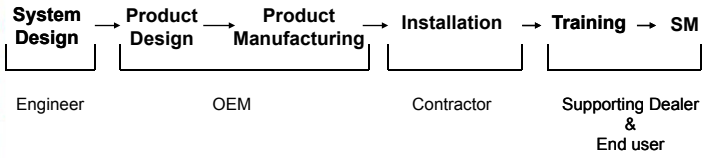
NOTES

IMPACTING RELIABILITY

- Chain is only as strong as its weakest link
- Reliability chain



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IMPACTING RELIABILITY

- **Consulting engineer's role**
  - Designing system
    - Topology (power flow & switching)
    - Sizing (matching generator capacity to load)
    - Supporting systems design (fuel, air flow, exhaust)
    - Locating equipment
    - Good awareness of all available technologies
- **Contractor's role**
  - Installation per system design & code

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IMPACTING RELIABILITY

- **Selecting the OEM**
  - Product
    - Quality of the product
    - Breadth of product line (single source of responsibility)
    - Service & parts support
  - Organizational capabilities
    - Engineering expertise
    - Years of experience
    - Core competency
    - Organizational resources
    - Organizational assets

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IMPACTING RELIABILITY

- **Supporting dealer's role**
  - Power generation expertise
  - Equipment startup
  - End user training
  - Service repairs
  - Scheduled maintenance programs
- **End user's role**
  - Understand basic operation
  - Manage load growth
  - Maintain system operation status
    - Weekly no load testing
    - Monthly load testing
    - Schedule scheduled maintenance

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RELIABILITY TERMS

- **MTBF - Mean Time Between Failures**
  - Equals service hours/failures
  - Estimated during product design
  - Calculated for mature products (field data)
  - Meant for use with high volume, repairable products

- **Definition of a failure**
  - Anytime the generator system is unable to startup and carry a load (excluding scheduled maintenance)

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WHAT MTBF REALLY MEANS

(Running the Numbers)

- **A supplier shows a picture of a generator system**
  - Literature indicates 200,000 hrs MTBF based on 20,000 units
  - The scope of the 200,000 hrs MTBF is not defined

8,760 hours in a year
200,000 / 8,760 = 22.83 years

- **Can I expect a genset to last nearly 23 years without a failure?**
- **Will the control system last 23 years without a failure?**
- **What generates large MTBF numbers?**

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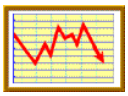
WHAT MTBF REALLY MEANS

(Running the Numbers)

- **MTBF number may have a limited scope (i.e., just the micro)**
- **MTBF may be a design calculation**

or

- **MTBF may also be calculated early in a product life cycle**
  - An example
    - MTBF = Service hours/failures
    - Manufacturer produces 10,000 units
    - 100 unit failures in the first year
    - MTBF = 10,000 x 8760 / 100
      = 876,000 hours
    - At the end of year two, all the units fail once due to design flaw
    - Updated MTBF = 17,520 hours



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COMPARING MTBFs

Electronics

Workstation	=	2,000 to 5,000 hrs
HVAC Controller	=	19,000 to 22,000 hrs
Ethernet	=	35,000 to 50,000 hrs
IEEE Bus	=	50,000 to 100,000 hrs

Mechanical Systems

Diesel Engine Generator (includes exercising)	=	7,000 to 14,000 hrs
Boiler	=	8,000 to 31,000 hrs
Compressor	=	34,000 to 66,000 hrs

Source
Reliability Analysis Center, Rome NY

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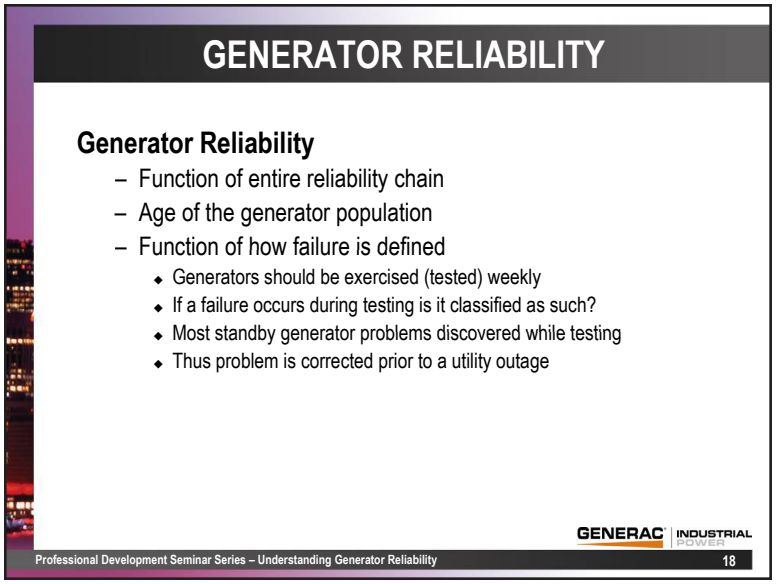
GENERATOR RELIABILITY
Generator Reliability
– Function of entire reliability chain
– Age of the generator population
– Function of how failure is defined
◆ Generators should be exercised (tested) weekly
◆ If a failure occurs during testing is it classified as such?
◆ Most standby generator problems discovered while testing
◆ Thus problem is corrected prior to a utility outage
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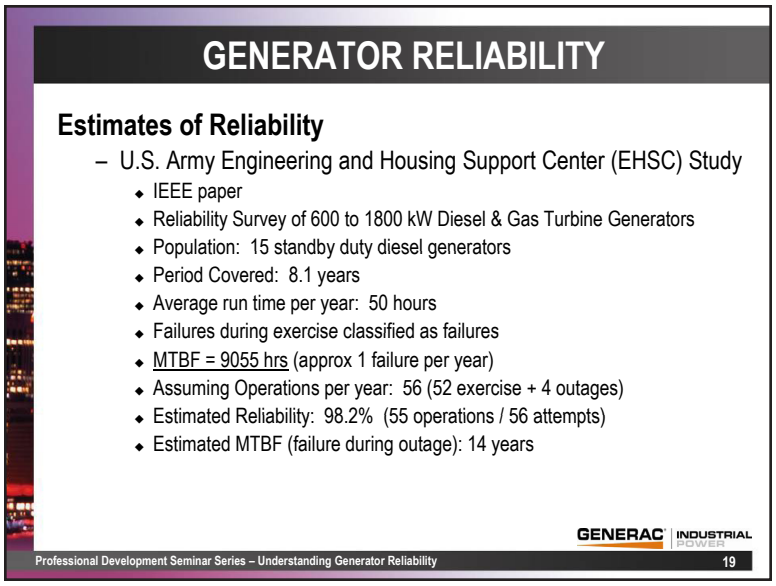
GENERATOR RELIABILITY
Estimates of Reliability
– U.S. Army Engineering and Housing Support Center (EHSC) Study
◆ IEEE paper
◆ Reliability Survey of 600 to 1800 kW Diesel & Gas Turbine Generators
◆ Population: 15 standby duty diesel generators
◆ Period Covered: 8.1 years
◆ Average run time per year: 50 hours
◆ Failures during exercise classified as failures
◆ MTBF = 9055 hrs (approx 1 failure per year)
◆ Assuming Operations per year: 56 (52 exercise + 4 outages)
◆ Estimated Reliability: 98.2% (55 operations / 56 attempts)
◆ Estimated MTBF (failure during outage): 14 years
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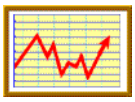
GENERATOR RELIABILITY



- **Increasing MTBF**
- **A failure every 14 years is not acceptable**
  - MTBF values should be **2 to 5** times typical field values
  - How?
    - Improved OEM designs
    - Factory complete system
    - Good installation practices
    - Strong Scheduled Maintenance program
    - Good end user awareness

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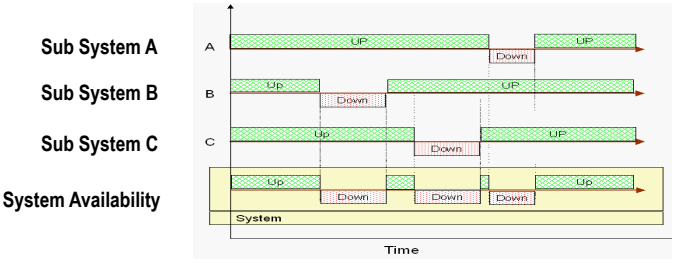
SERIAL SYSTEM RELIABILITY

System Availability

- Function of reliability of supporting systems
- Function of reliability of all mission critical components



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NOTES

SERIAL SYSTEM RELIABILITY

How to minimize the impact of serial components

- Integration
  - Control functions
  - Fuel system
  - Exhaust system
  - Cooling system
  - Starting system
- Factory complete solutions

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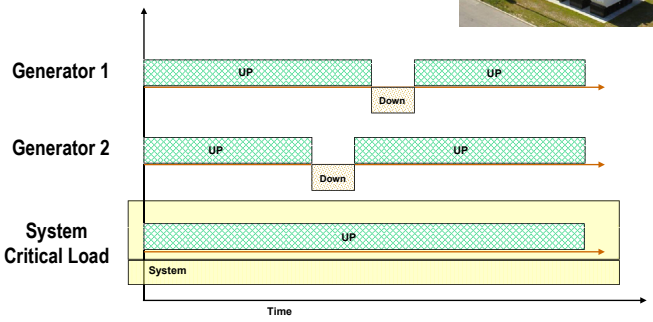
PARALLEL SYSTEM RELIABILITY



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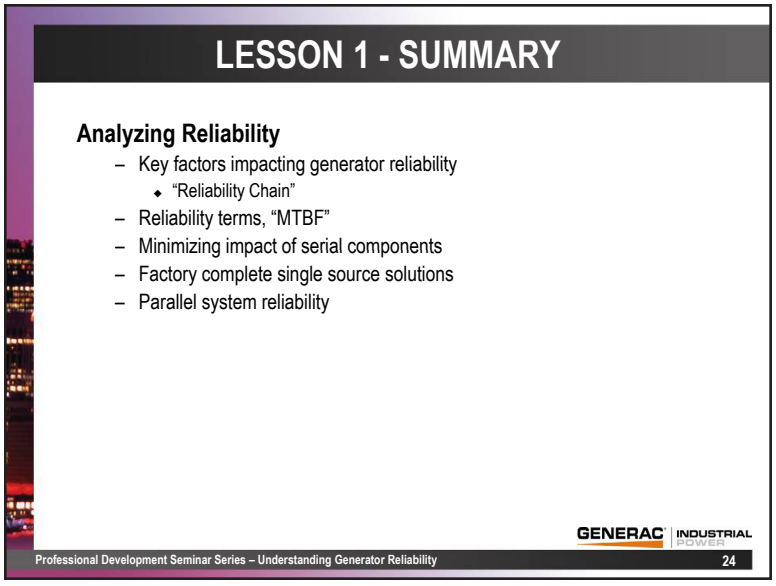
1. Analyzing Reliability



NOTES

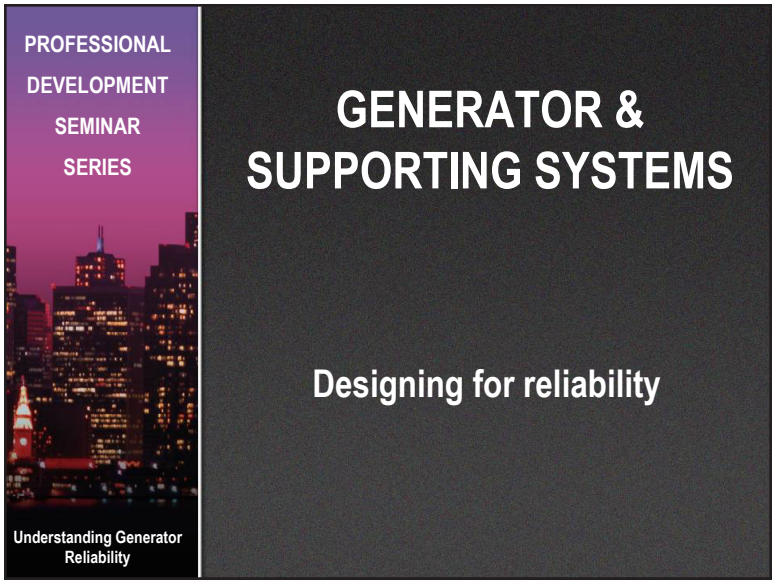
2. Generator & Supporting Systems

TIME: 35 minutes

OBJECTIVES:

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

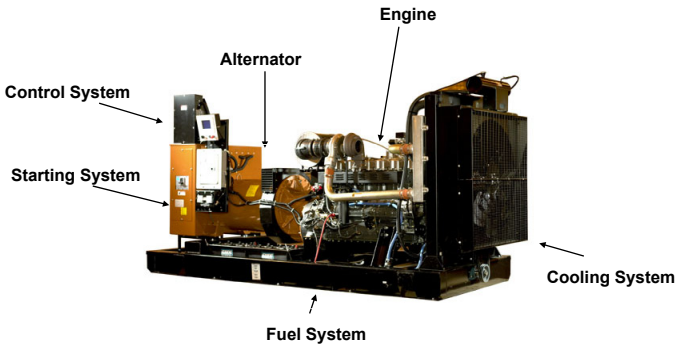
- Describe engine selection
- Describe engine scheduled maintenance and testing factors for maintaining reliability
- Describe alternator criteria affecting reliability
- Describe alternator protection
- List and describe the factors impacting fuel reliability
- Describe on-generator and off-engine cooling systems
- Describe the impact of ambient temperature
- List air flow "rules of thumb" specifically for exhaust discharge (attached radiator) and inlet (attached radiator)
- Describe starting system factors impacting generator reliability
- Describe indoor and outdoor reliability increase and decrease factors



NOTES

2. Generator & Supporting Systems

DESIGNING FOR RELIABILITY



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ENGINE

- **OEMs must invest heavily into the process of**
  - Engine evaluation & selection
    - Evaluate and choose the best engines from the best manufacturers
  - Modification
    - Optimize the engine for standby generation
- **Engine selection determines product viability**
  - Performance ratio, Cost
- **Engine is the most costly component of a genset**

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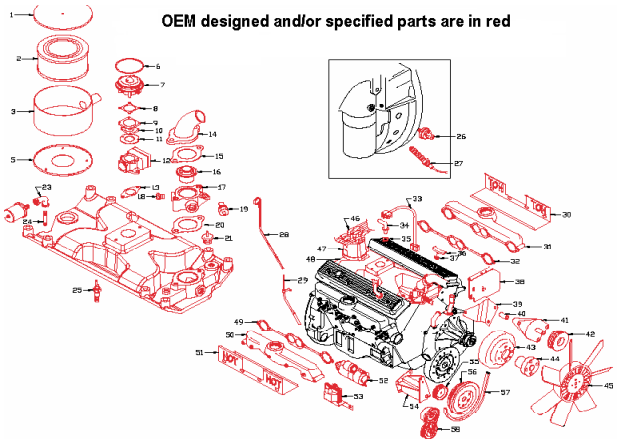
NOTES

ENGINE MODIFICATIONS

OEM designed and/or specified parts are in red



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ENGINE

Reliability

- Is the engine the most critical element?
  - No
  - Genset supporting systems are the most critical elements
- Why?
  - Standby power application engines have limited run hours
  - Engines typically don't fail
- What are the key engine reliability elements? (Reliability chain)
  - OEM experience
  - OEM support
  - Correct application (sizing and ratings)
  - Scheduled maintenance and testing

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NOTES

ENGINE – PM & TESTING

- **Strong maintenance program is a must**
  - Fluids and filters
  - Visual checks
  - Operation checks
  - Certified dealer technicians
- **Testing**
  - Weekly no-load tests
  - Preferred monthly load tests
  - Periodic load test at full load
  - NFPA 110 requirements

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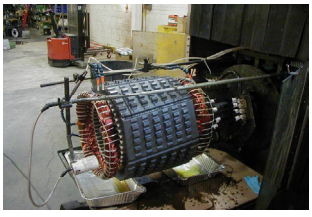
ALTERNATOR CONSTRUCTION

- **Repeatable Manufacturing (Automation)**
- **Standard Industry Features**
  - PMG
  - 2/3 Pitch & Skewed
    - Diagonal slots
    - Removes slot ripple
  - Random Wound
    - Copper wire
    - Machine wound
  - Class H Materials



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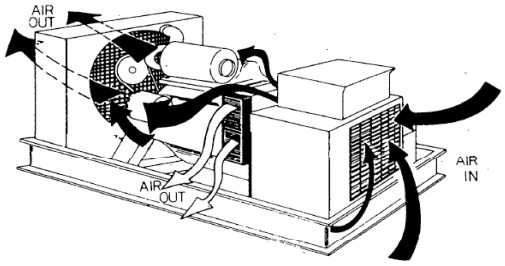
NOTES

ALTERNATOR – LOCATION

Alternator needs cooling air

- Avoid recirculation
- Avoid intake debris



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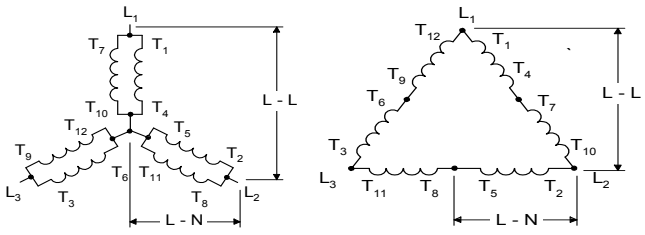
ALTERNATOR -- APPLICATION

Balance loads

- Critical in applications with significant single phase
- Procedures to check load balance
- Overload a specific coil group



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ALTERNATOR -- PROTECTION

- **Generator breaker**
  - Is it closed?
  - Monitoring!!!
- **Shunt tripping**
  - CTTS
  - Fire marshal requirements
  - Avoid if possible

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FUEL SYSTEMS – FUEL TYPE

- **Compression Ignited**
  - Diesel
  - Bi-fuel (Diesel & Natural Gas)
- **Spark Ignited**
  - Natural Gas
  - LP Vapor
  - LP Liquid
  - Dual Fuel (LP & Natural Gas)

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NOTES

FUEL SYSTEMS – FUEL TYPE

- **Why compression ignited (diesel)**
  - Lacking gas infrastructure
  - Lower capital cost (+150 kW)
  - Higher power density
  - Better transient response
  - NFPA 110 requirements for on-site fuel
- **Why spark ignited**
  - Convenience (natural gas)
  - Extended run time (long term outages)
  - Environmental concerns with diesel fuel
  - Environmental concerns with diesel emissions
- **Why Bi-Fuel?**

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FUEL SYSTEMS – BI-FUEL

What is Bi-fuel?

- Simultaneous combustion of two fuels
  - Diesel and natural gas
  - Compression ignition engine
  - Diesel is the igniter (pilot fuel)
  - Up to 75% of the energy comes from the natural gas
  - Extends operation time while minimizing on-site fuel
- Engine can run 100% diesel
- Engine cannot run on 100% natural gas

Diesel vs. Bi-Fuel™ Run Times (600 kW genset at 75% load)

Diesel Tank Capacity	Diesel-Only Run Time	Bi-Fuel™ Run Time
20" tall / 469 gallons	10 hours	33 hours (1.3 days)
30" tall / 936 gallons	20 hours	66 hours (2.7 days)
40" tall / 1349 gallons	29 hours	94 hours (3.9 days)

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FUEL SYSTEMS – NATURAL GAS

Concerns with natural gas

- Supply reliability (utility)
  - Service capability
- Supply reliability (on-site)
  - Pressure drops (inadequate piping)
  - Additional loads (boiler, etc)
  - Security of pressure regulators
  - Securing isolation valves
  - Seismic zones

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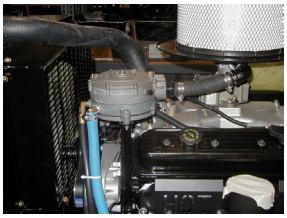
FUEL SYSTEMS -- LP

Concerns with LP

- Electric indication of fuel level
- Vapor
  - Boil off rates
  - Pressure drops
- Liquid
  - Constraints in bringing into building



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NOTES

FUEL SYSTEMS -- DIESEL

- **Problems with diesel**
  - Moisture
  - Gelling
  - Biomass
  - Fuel instability/varnishing
  - Storage/leakage
  - Fuel transfer system
  - Running out
- **Diesel SM program required**

Fuel Filter/Water Separator

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FUEL SYSTEMS -- DIESEL

- **Running out**
  - How much fuel is enough?
  - How much fuel is too much?
- **Solutions**
  - Monitor and alarm fuel level
  - Large fuel tank with maintenance program
  - Keep full programs
  - Fuel contingency planning
    - Does fuel vendor have backup power?
    - Roads accessible?
  - Bi-fuel generator

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NOTES

FUEL SYSTEMS -- DIESEL

Sub base fuel tanks

- Recommend whenever possible
- Simplest system (least to fail)

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FUEL SYSTEMS -- DIESEL

Day tank with main storage tank

- Fail-safe design, Fail-safe design, Fail-safe design (redundancy preventing fuel spills)
- Main tank lower elevation
  - Day tank pump
  - Gravity return
  - Engine return to main tank
- Main tank higher elevation
  - Isolation solenoid (bypass capability, NFPA110 5.6.3.2.1)
  - Return pump (sized larger than inlet flow)
  - Fuel cooler may be needed

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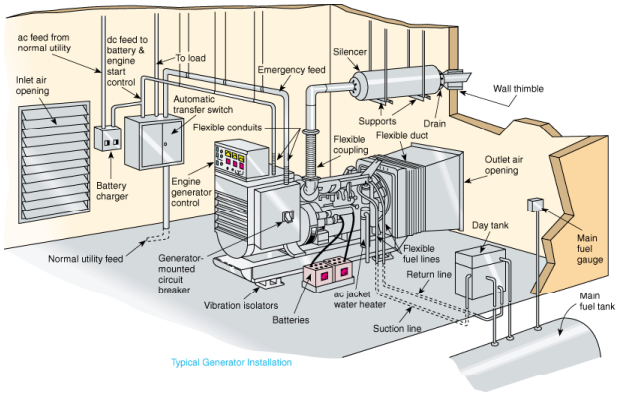
NOTES

FUEL SYSTEMS -- DIESEL



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FUEL SYSTEMS -- DIESEL

- **Failure modes in fuel transfer schemes**
  - Isolation valves closed (monitor electrically or secure)
  - Solenoid failures (solenoid status & bypass)
  - Transfer pump failure (lead lag pumps)
  - Transfer pump breaker open (monitor electrically or secure)
  - Fuel level switch failure (redundant contacts)
  - Hot fuel (fuel cooler)
  - Generator losing prime (check valve)
- **Fuel Flow Control** (NFPA 37 6.5.4)
  - Overflow, high level alarm, automatic shutoff
- **Fuel Systems** (NFPA 110 7.9)

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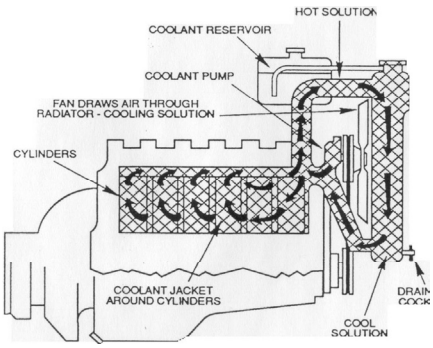
NOTES

COOLING SYSTEM

- **On generators**
  - Closed system
  - Most reliable
- **Off engine**
  - Remote radiator(s)
  - Heat exchangers
  - Circulation pumps
  - Cooling fans
  - Least reliable



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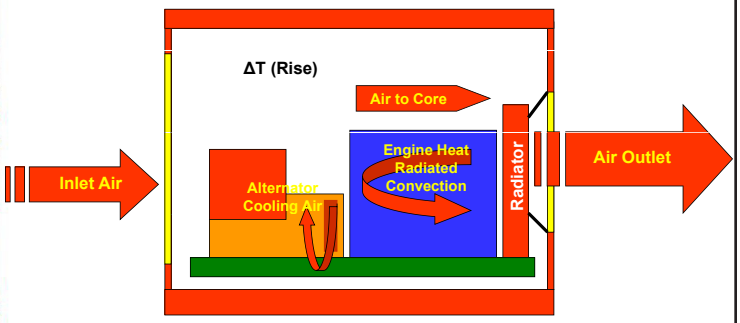
AIR FLOW

Limiting Room Temperature

Ambient???



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NOTES

AIR FLOW

Rules of Thumb

- Exhaust discharge (attached radiator)
  - Short straight run (match radiator opening)
  - Typically limited to 0.5 to 1 inch water column back pressure
- Inlet (attached radiator)
  - Area 1.5 to 2.0 times radiator opening (no air handler)

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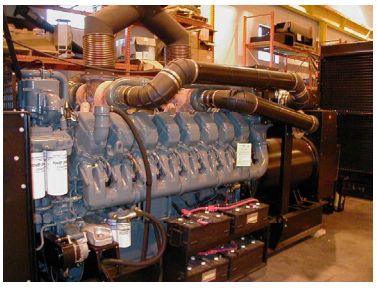
STARTING SYSTEM

Significant impact on generator reliability

- System includes
  - Batteries
  - Battery charger
  - Charging alternator
  - Battery monitoring
  - Starter
  - Starter solenoids



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NOTES

STARTING SYSTEM – BATTERY TYPES

- **Lead acid**
  - Market norm also auto industry preferred
  - Cost-effective and excellent cranking amps
  - Known to end user!!!
    - Fast replacements
    - Jumping and boost charging
    - Maintaining
- **NiCad**
  - Costly
  - Fussy battery – charge algorithms, etc.
  - Marketed as
    - Long life, good in cold and no sudden death

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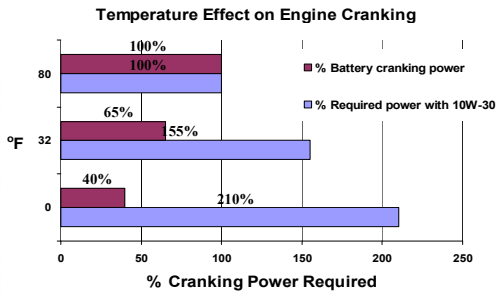
STARTING SYSTEM – BATTERY HEATERS

Cold Cranking Amps (CCA)

- Amps a battery can support for 30 seconds at 0°F



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NOTES

LOCATION – INDOOR VS. OUTDOOR

Indoor

- Reliability increases
  - More controlled environment
  - Warmer & less corrosion
  - Visually inspected more
- Reliability decreases
  - Complex supporting systems
  - System installation compromises/oversights
  - Fire (both are vulnerable if located together)
  - Human factor

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LOCATION – INDOOR VS. OUTDOOR

Outdoor

- Reliability increases
  - OEM complete system
  - Fuel piping issues
  - Exhaust piping issues
  - Air flow issues
  - Limited accessibility (human factor)
  - Isolation in case of fire
- Reliability decreases
  - Less controlled environment
  - Corrosion & cold

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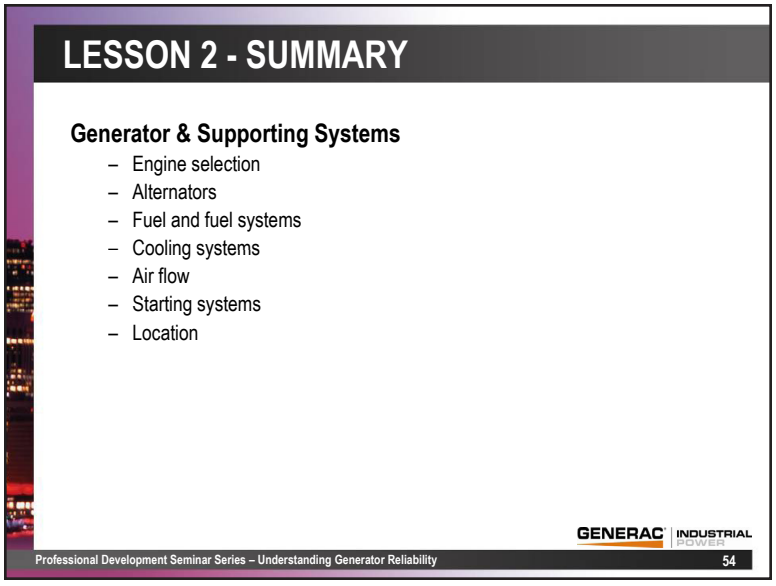
NOTES


LESSON 2 - SUMMARY
Generator & Supporting Systems
– Engine selection
– Alternators
– Fuel and fuel systems
– Cooling systems
– Air flow
– Starting systems
– Location
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NOTES

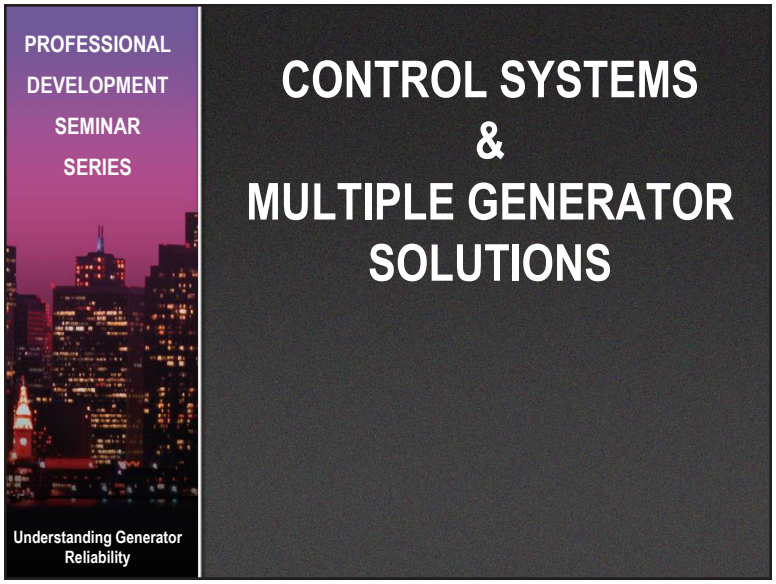
3. Control Systems & Multiple Generator Solutions

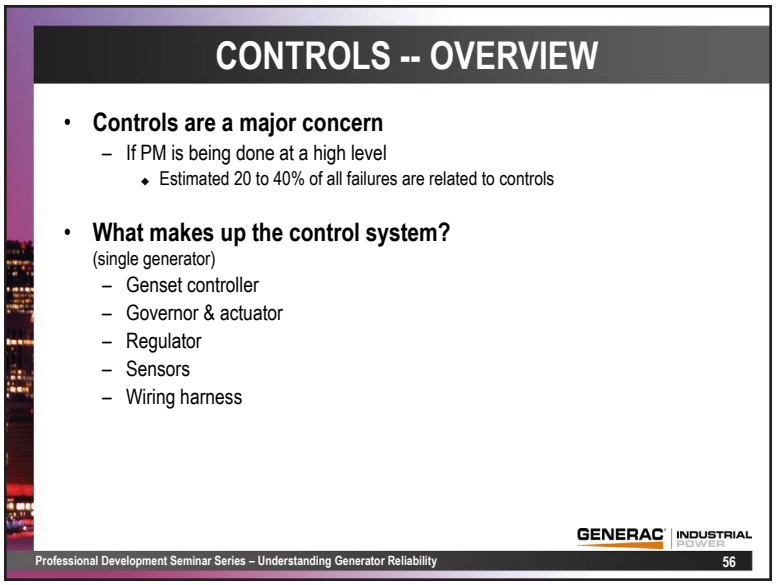
TIME: 10 minutes

OBJECTIVES:

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

- List the components of a typical control system (single generator)
- Identify control system weaknesses that have had serious impacts on reliability
- Describe current advancements that have increased reliability of control systems
- List advantages of paralleled over single generator systems
- List the components of a multi-function digital controller





NOTES

CONTROLS

System Weakness / Solutions

Control system weakness	Solutions
– Corrosion	– Sealed boards and connectors
– Sensor accuracy & failures	– 4 - 20 ma sensors
– Circuit board failures	– Surface mount & seals
– Limited protective functions	– Protective alarms for input parameters
– Reliance on serial reliability of multiple controllers ◆ Genset controller ◆ Governor ◆ Regulator	– Integrated into controller
– Human interaction failures	– All digital with password access
– External system control & monitoring ◆ Limited spare I/O ◆ Limited custom control logic capability	– More I/O & custom logic – Phone lines or Ethernet to unit

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MULTIPLE GENERATOR SOLUTIONS

- **Accepted market reliability for single unit**
  - 98 to 99% (multiple third party references)
- **Integrated paralleling adds redundancy**
  - Typical load factors
  - Minimal load shedding / management
  - Results in redundancy without increasing generator capacity
    - N+1 reliability (99.96 to 99.99%)
    - N+2 reliability (99.9992 to 99.9999%)

VS.

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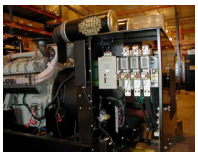
NOTES

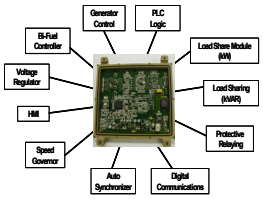
PARALLELING COMPLEXITY SOLVED

Integrate the paralleling into the generator

– Controls
- One per generator
- All digital
- Digital communications for interconnection



– Paralleling switch mounted on the generator
- Optimized & reliable switching



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LESSON 3 - SUMMARY

- **Control Systems**
  - Weaknesses
  - Advancements
- **Multiple Generator Solutions**
  - Paralleled over single generator
  - Multi-function digital controller

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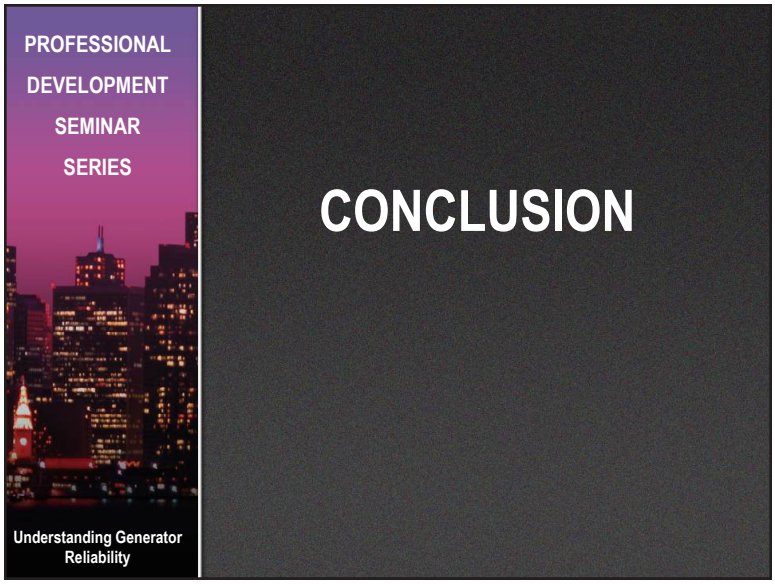
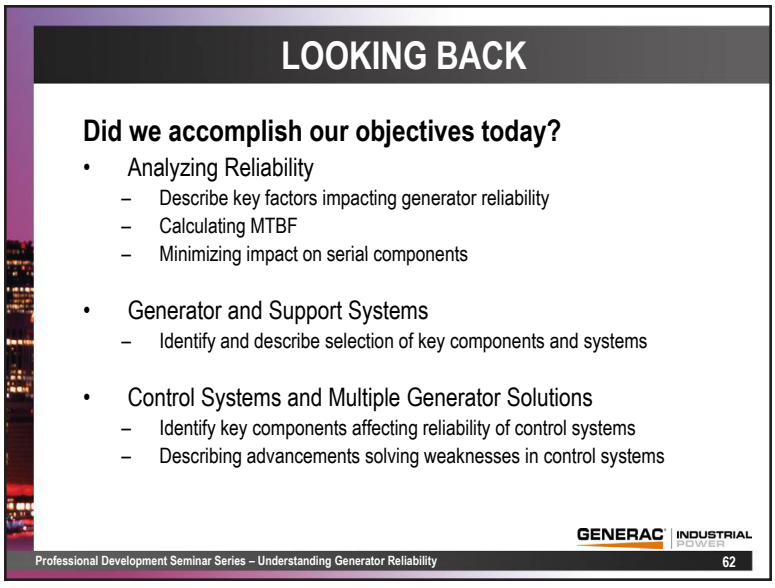
CONCLUSION





NOTES

TECHNICAL PERSPECTIVE

Designing Generator Systems for Reliability and Long Life

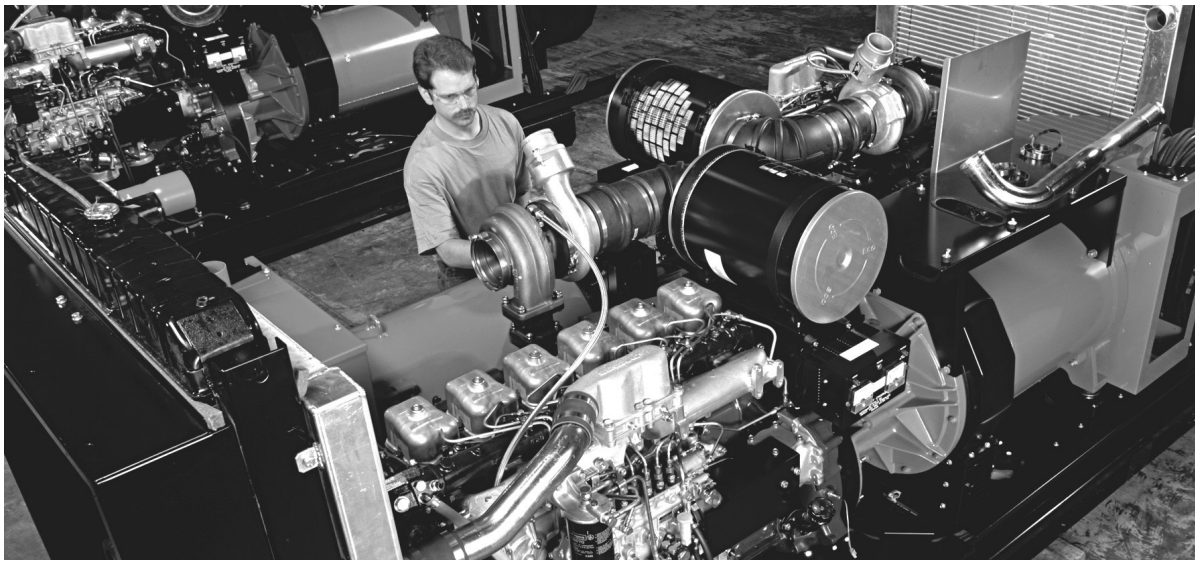
INTRODUCTION

In the world of standby power generation, the truest test of generator design is time. Through years of service, generator sets endure a host of trials including the elements. Because of their relatively low number of run hours, standby gensets typically don't wear out, but they can rust out. That's why attention to environmental concerns and proper design engineering are essential to ensure that backup systems provide decades of reliable service when properly maintained.

Generac Power Systems has set the standard for longevity. We are the specialists of both gaseous and diesel standby generators. Generac remains at the forefront in the industry for a reason. We combine the highest protective features with the most durable materials. We make certain that our individual components and our integrated systems withstand a rigorous and comprehensive testing process. We build quality, durability and reliability into all our products.

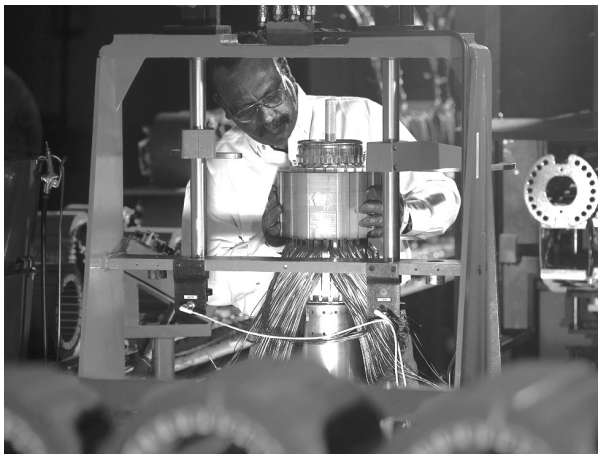
KEY POINTS

- Reliability Through Design
- Proven Examples of Durability and Long Life



TECHNICAL PERSPECTIVE

Designing Generator Systems for Reliability and Long Life



Reliability Through Design

At Generac, product reliability is always a high priority. We stay focused on reliability throughout the design, engineering, testing and manufacturing process.

All Generac products must pass rigorous laboratory performance, reliability and endurance tests before being released to production. Existing equipment is also evaluated on a continuing basis. We also look at engineering design reviews, end user feedback, dealer suggestions and warranty information to focus on quality improvement and refinement of the products.

After installation, Generac stands behind its dealers to provide you with 100% of your parts and service requirements. To maximize the reliability and longevity of your Generac equipment, a regularly scheduled maintenance program is important. Consult with your dealer for a maintenance contract that will help keep your unit operating reliably every year.

Engine Selection:

- Top quality prime movers – Unlike many other manufacturers who are limited to a particular line of engines (their own), Generac evaluates and selects top quality, prime movers from an array of world class manufacturers. These reliable, proven designs are well suited for power generation. Through advanced engineering and the use of Generac-designed components, we optimize performance with an emphasis on durability and long life. Each engine is tested, up to 1000 hours, at its standby rating to ensure performance capabilities.

Engine Cooling System:

- Closed cooling system – To prevent corrosion, cooling systems feature pressure caps with expansion tanks to keep air from entering the system.
- Low coolant shutdown – To guard against the effect of a slow leak, sensors shut down the generator if coolant levels drop below safe margins.
- High coolant temperature shutdown – To prevent overheating of the system, high coolant temperatures will cause the generator to shut down.
- UV resistant hoses – Coolant and oil hoses are made of compounds that resist the degrading effects of ultraviolet light.
- Top quality block heaters – Low watt density electrical block heaters are designed for increased starting reliability and extended life.

Engine – Electrical Interface:

- Corrosion protected terminals – All exposed electrical terminals on the engine are coated for corrosion protection and enclosed within a boot for mechanical protection.
- Dual wire sensors – All engine sensors have been changed from industry standard single wire to dual wire types. This reduces circuit failure due to unreliable ground return circuits.

TECHNICAL PERSPECTIVE

Designing Generator Systems for Reliability and Long Life

Wiring:

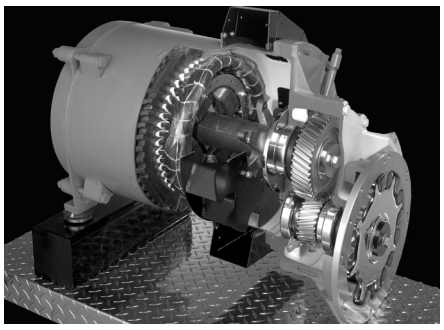
- Fully enclosed wiring system – All wiring is enclosed in flexible plastic conduit to prevent damage to harnesses and connectors.
- Waterproof and airtight connectors – Generac has led the industry in establishing an even higher reliability standard through its standardization of automotive / aircraft type waterproof and airtight electrical cable connectors.

Battery Charger:

- Heavy-duty 12 volt DC battery charging alternators – Generators up to 150 kilowatts of output use brushless 12 volt Generac designed DC battery charging alternators with heavy-duty, oversized bearings.

Gearbox:

- Solid design rationale – The gear drive allows an engine to operate within its optimal speed range and peak power band vs. running at just 1800 revolutions per minute (the required speed to produce electricity at 60 hertz with a 4-pole alternator). This enhances durability and extends engine life because the engine is working under less stress with reduced pressure on its critical components.



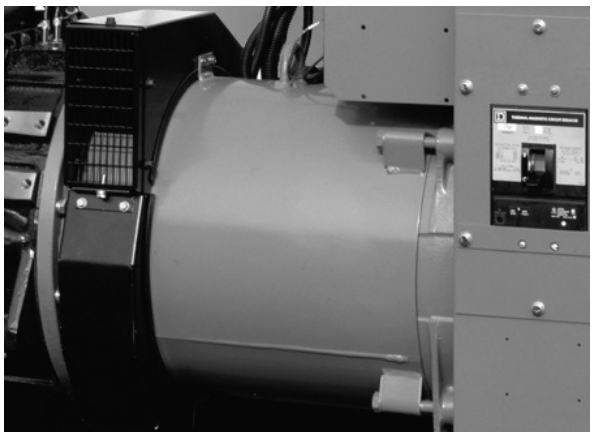
- Durable components – Generac's gearboxes and elastomeric couplings are well proven designs. With thousands of gear driven gensets produced over the past 15 years, this system has demonstrated outstanding durability.

Electronic Control System:

- Coated circuit boards – All printed circuit control boards are conformal-coated or encapsulated to prevent environmental corrosion and mechanical damage.
- Surge protection – Built-in surge suppressors enhance protection from voltage spikes. This increases the reliability of the generator and its controls.
- Magnetic shielding – All units are EMI (electrical magnetic interference) tested and equipped with magnetic shielding to protect the control system from magnetic interference.
- Fuse protection – Control systems have board and system level fuse protection.
- Environmentally sealed – All industrial control printed circuit boards are environmentally sealed in an aluminum case.

Alternator:

- High temperature alternator wiring – All alternators are built with high temperature 190°C NEMA Class H wire and insulation. Maximum operating temperatures do not exceed lower Class F levels per UL 2200. This provides an extra margin of thermal capability for standby applications with single phase and non-linear loads.



TECHNICAL PERSPECTIVE

Designing Generator Systems for Reliability and Long Life

Enclosure:

- Rhino-Coat™ powder painted surfaces – Our textured, powder coat paint process provides consistent coverage and better bonding to seams and exposed edges for maximum resistance to environmental degradation. All sheet metal is cleaned, rinsed and treated with an iron phosphate to provide superior paint adhesion. TGIC powder paint is electrostatically applied and baked at 375°F to chemically adhere the powder coat finish to the metal.
- Corrosion resistant design – Door hinges, latches and striker plates are made of stainless steel. Corrosion resistant JS500 plated steel fasteners are utilized throughout the enclosure.

- Structural integrity – Integrated stiffeners on the interior walls provide overall compartment strength and rigidity. Sheet metal thickness is 14 gauge for Series 2000 enclosures and 12 gauge for large gensets.

UL 2200 Listing:

- Designed and built to high standards – Generac was the first to introduce its complete product line in conformance with UL 2200 safety standards. We continue to manufacture our products to these exacting requirements.
- Self-certification – Because of the many tests and requirements needed for UL Listing, Generac invested in its own research and development facilities to self-certify its equipment for UL compliance. For this procedure, we follow stringent UL guidelines in testing our products to UL's uncompromising standards. All such work is subject to UL's oversight and audit procedures however, it speeds up the Listing process.

Proven Examples of Durability and Long Life

In demanding real-world applications, Generac standby generators have compiled an enviable record of durability and long life. To see examples of well-proven Generac equipment, visit the case study library on the Industrial side of the Generac Power Systems Web site (www.generac.com). In particular, see the two case studies entitled "Little Engine, Big Hours" and "Twenty Years On The Job – And Still Going Strong".

TECHNICAL PERSPECTIVE

Prototype and Production Testing

INTRODUCTION

As one of the world's leading manufacturers of power generation equipment, Generac Power Systems is committed to a comprehensive program of research and development. Part of that R&D initiative is extensive product evaluation. Before a design goes into production, it is subjected to exhaustive prototype testing to evaluate every aspect of construction and performance. When it becomes part of the Generac product line, every unit undergoes a rigorous test before it leaves the factory. This regimen ensures that Generac gensets and transfer switches operate properly and provide years of reliable service.

KEY POINTS

- Generac's Investment in Research and Development Proves its Commitment
- Prototype Testing Ensures Performance and Reliability
- Production Testing Ensures Operability and Satisfaction

Generac's Investment in Research and Development Proves its Commitment

Generac is at the forefront of innovation and product development. We lead the industry in the creation of unique products and technologies. Our commitment extends beyond a product focus as we also invest heavily in leading-edge facilities and expert personnel.

Our ability to quickly design or modify our equipment to meet the rapidly changing marketplace has been a cornerstone to our success. This would not be possible without the skills and talents of our electrical, mechanical and industrial engineering groups. With several design teams working in the United States and overseas, Generac engineering is truly a global endeavor that brings the best minds to every challenge.

TECHNICAL PERSPECTIVE

Prototype and Production Testing

Generac has state-of-the-art research and development laboratories in each of our manufacturing facilities. Designs can be created, tested and evaluated for engine output, exhaust emissions, alternator performance and sound levels. The company's main R&D laboratory — at corporate headquarters in Waukesha, Wisconsin — features numerous computer design stations, a large fabrication workshop, individual test cells and an outdoor testing site. To ensure that our equipment lives up to Generac's reputation for durability, we subject our engines, alternators, controls and transfer switches to the industry's most punishing test routines. Once we're certain that these units are up to the task, we make them a part of our valued product line.

Prototype Testing Ensures Performance and Reliability

Our prototype testing is a lengthy process that includes the performance evaluation of individual components and complete gensets. We test new products to ensure they conform to numerous industry standards, including:

- UL — Underwriters Laboratories Inc.
- EPA — Environmental Protection Agency
- NEMA — National Electrical Manufacturers Association
- CSA — Canadian Standards Association
- CARB — California Air Resources Board
- SCAQMD — South Coast Air Quality Management District (California)

The UL Listing from Underwriters Laboratories has become increasingly important for power generation equipment. Because of this, we dedicate considerable engineering, manufacturing and testing resources to ensure we maintain the following UL Listings.

- UL 2200 — Stationary generator sets
- UL 1008 — Automatic transfer switches
- UL 891 — Paralleling switchgear

Because so many tests are needed to obtain these Listings, **Generac built its own research and development facilities to allow us to self-certify our equipment.** We must follow stringent UL guidelines during testing to ensure we comply with UL's uncompromising standards. All such work is subject to UL's oversight and audit procedures.

Prototype testing includes a full array of evaluation procedures covering a comprehensive range of performance aspects.

Gensets:

- **Maximum Power Level** – The unit is operated at its maximum capacity, which is greater than its listed rating, for a minimum of 5 minutes. The load is adjusted until maximum power is obtained at rated speed. Power is measured via the kilowatt output of the generator.
- **Torsional Analysis** – Engine/alternator combinations are verified to be free from damaging torsional stresses. While initial torsional vibration calculations may be performed during the development stages, all new products undergo prototype fatigue testing to confirm torsional compatibility of the engine/alternator system.
- **Transient Response** – Full load is applied at unity power factor with voltage and frequency recorded using a high-speed recorder. Engine/alternator must have the ability to accept application of the full load in a single step and recover fully to the rated voltage and frequency.
- **Engine Cooling Requirements** – Verification of the engine cooling system is performed by operating the genset with a sound attenuated enclosure at full rated load in a 110°F ambient. The cooling system is monitored to ensure that temperatures stabilize within acceptable levels. Horsepower deration is applied beyond 77°F on select engines.
- **Endurance Test** – The unit is tested to meet or exceed endurance requirements of Mil Spec 705. It is operated at full kVA load for up to 1000 hours at its standby rating without mechanical or electrical failure. At the end of endurance testing, key components are inspected and evaluated to ensure that any wear is within acceptable levels.
- **Mechanical Soundness** – The unit must be structurally sound and not have any resonant vibration in either rotating components or structural parts. Alternator rotor assemblies are dynamically balanced to minimize vibration.

TECHNICAL PERSPECTIVE

Prototype and Production Testing

Alternators:

- **Maximum Motor Starting** – Motor starting or instantaneous voltage curves are developed with an inductive load bank at 0.3 power factor. Individual loads are applied to the alternator and voltage dip is determined from a high-speed strip chart recorder. The load is incrementally increased until the voltage dip exceeds 35%.
- **Structural Soundness** – A three phase symmetrical short is applied and opened 10 times over a 60 second period. The alternator must build up and perform normally without intervention.
- **Temperature Rise** – Alternator temperature rise, at full kVA rating, is determined by the IEEE 115 resistance test. Maximum acceptable rise is 125°C per UL over a 40°C ambient.
- **Harmonic Analysis** – A full harmonic analysis is performed. Maximum acceptable total distortion is 3.5%. Telephone Influence Factor is calculated and must be < 50.
- **Voltage Regulator Test** – The voltage regulator must maintain output voltage within $\pm 1\%$ from no load to full load, and no damage to the alternator can occur if voltage sensing is removed from the regulator. The regulator must be able to withstand a 25% current overload for 30 minutes without damage.
- A variety of additional tests are conducted to evaluate performance:
  - Insulation resistance at 170°C temperature
  - High potential test at 1500 volts for five minutes
  - Shaft current measurement
  - Overspeed test at 140% of synchronous speed
  - Saturation curves are plotted
  - Transient response curves are plotted
  - Subtransient, transient, zero sequence, negative sequence and synchronous reactance values are calculated from test data

Transfer Switches:

- **Overload Tests** – Performed at 600% normal current, 0.4 - 0.5 power factor at rated voltage. Depending on switch ampere rating, up to 50 operations are performed at these conditions.
- **Temperature Rise Check** – Switch must continuously carry 100% load at rated voltage and current without exceeding specified temperature limits.
- **Endurance Test** – Switch is operated at 0.75 - 0.80 power factor and rated voltage. Depending on switch ampere rating, up to 3000 operations at rated current and 3000 operations at 2 times rated current are performed.
- **Withstand and Closing Test** – Performed at a minimum of 20 times rated current, in compliance with UL 1008. Switch must withstand the thermal and electromagnetic effects of this current until the circuit protective device (i.e., circuit breaker) opens up.

Once these prototype tests are completed and the unit is accepted for production, additional testing and evaluation may be conducted, as needed, to ensure that the product performs within its design parameters.

Production Testing Ensures Operability and Satisfaction

In addition to in-process component testing, every completed genset and transfer switch is fully tested before it leaves the factory. The production test consists of the following:

Gensets up to 200 Kilowatts

- The engine/generator is visually inspected before load wires and fuel lines are connected. The inspector verifies that all fasteners are tight, belts are secure, and guards are present and clear of any rotating parts.
- The fuel and load leads are connected, the engine is pre-lubricated, the governor and voltage regulator are disconnected, and the engine is started. After inspecting all rotating parts and listening for any unwanted noise, the engine is shut down, the governor and voltage regulator are reconnected, and the engine is restarted.
- The voltage and frequency are set and the voltage stability is adjusted along with voltage gain settings and the under-frequency cutoff.

TECHNICAL PERSPECTIVE

Prototype and Production Testing

- The generator is run at 25% load for 10 minutes, 50% load for 10 minutes, then 100% load for 10 minutes. The unit is constantly monitored for stability, noise, vibration, fluid leaks, engine temperature, oil pressure, exhaust temperature, engine timing and air/fuel ratio for gaseous engines.
- A test summary report is printed and packaged with the support literature to be shipped with the unit.
- The engine is shut down and examined for oil leaks, coolant leaks, loose fasteners and loose wiring. The genset is given a twenty-five point check that covers everything from data plate information to any special engineering items requested.
- If specified, the enclosure and basetank are fastened to the unit.
- The unit is moved into the final staging area where the paint finish is examined and manuals, decals, covers and shipping skids are applied.
- The unit receives a final inspection by quality control personnel for fit and finish, then it is prepared for shipping.

Gensets 230 To 6000 Kilowatts

Larger gensets undergo the same test procedures outlined above, plus the following:

- Strip charts are created showing the load application and load drop transients at six stages:

0 - 50% load	0 - 75% load	0 - 100% load
50 - 0% load	75 - 0% load	100 - 0% load

- Voltage, current, frequency and fuel consumption are documented on hard copy printouts at load points up to 100% and at two hours of run time.
- When low voltage switchgear (soft load) is provided, it is tested with the engine/generator through the complete operating cycle (Modular Power Systems).
- **All paralleled units are tested individually and as a complete system prior to shipment.**

Transfer Switches

- The undervoltage sensor and inphase monitor are calibrated.
- The switch is tested to verify utility fail operation.
- Fast and Normal Test operation is verified.
- All options are tested for proper function.
- All timer and sensor settings are adjusted to factory specifications.

Additional or customized tests (extended run time, more extensive load testing, etc.) may be ordered to meet the specifications of a particular application.

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"*

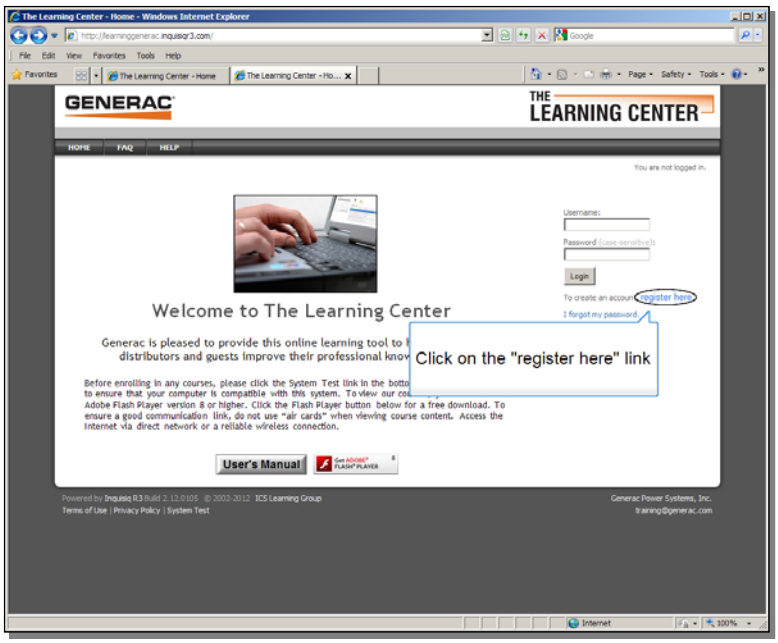
To gain access to *"The Learning Center*", you are required to register and set up a user account. During your account setup you will create a *Username* and *Password*. Your username and password can then be used to log in on subsequent visits.

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

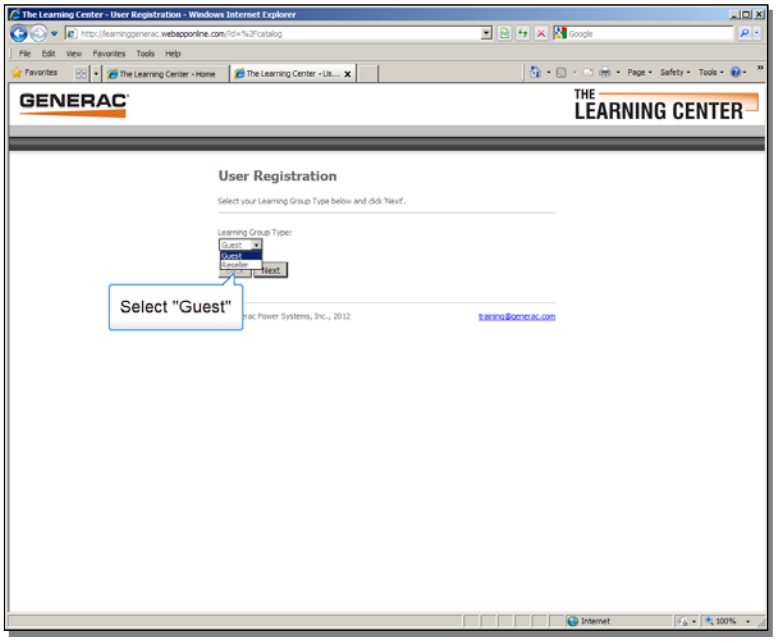
To begin the registration process, open your computer's browser and enter http:// learning.generac.com. This should take you to *"The Learning Center"* home page. This page is displayed at the top of the next page. From this point you can follow illustrated steps.

ONLINE FINAL ASSESSMENT AND CERTIFICATE REGISTRATION AND LOGIN PROCEDURE

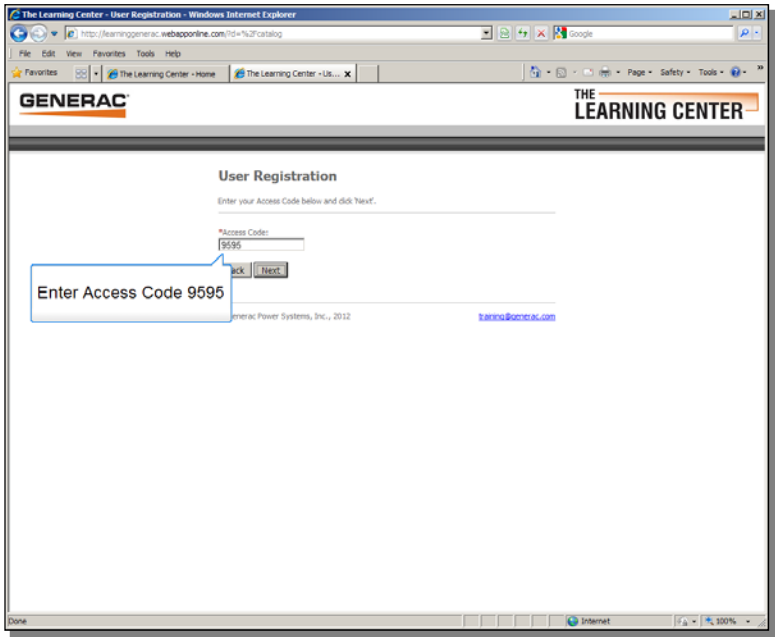
Begin by entering http://learning.generac.com in your computer's browser. The screen below will be displayed. Click on the "register here" link to begin the registration process.



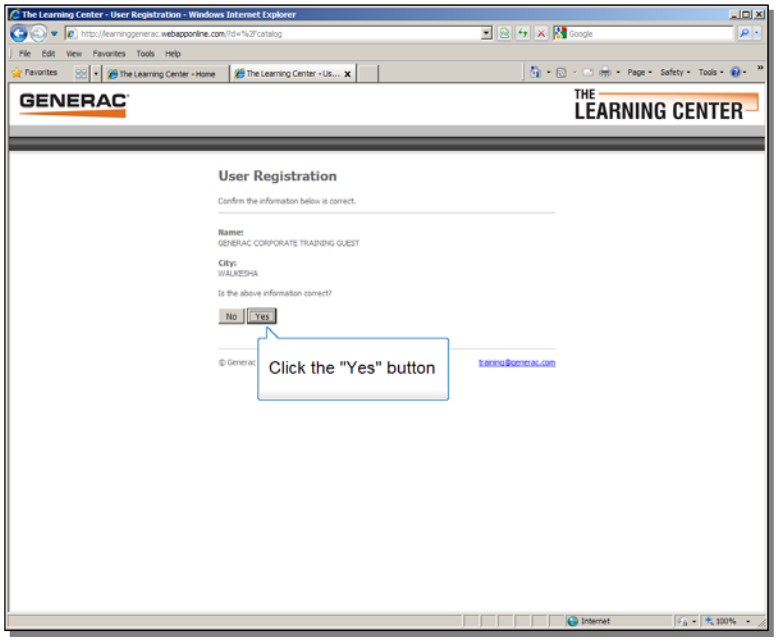
On this screen you will select "Guest" from the drop down box and click the "Next" button.



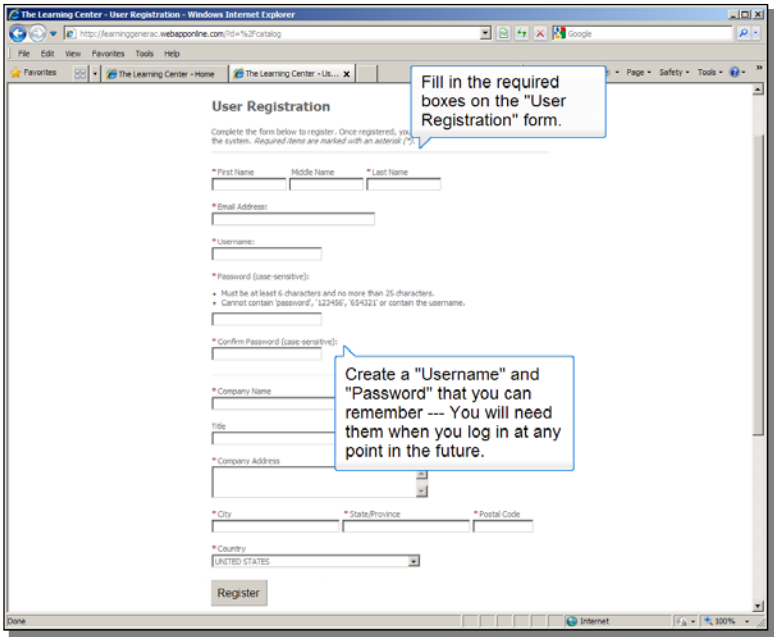
In this next screen enter **Access Code 9595** and click the “Next” button. Please keep this code private.



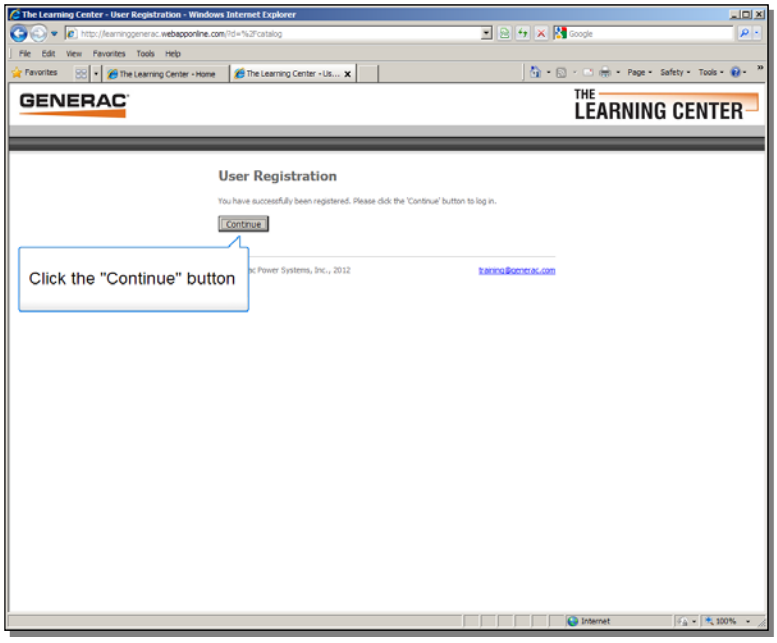
This screen confirms the correct access code entry. Click the “Yes” button to proceed.



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

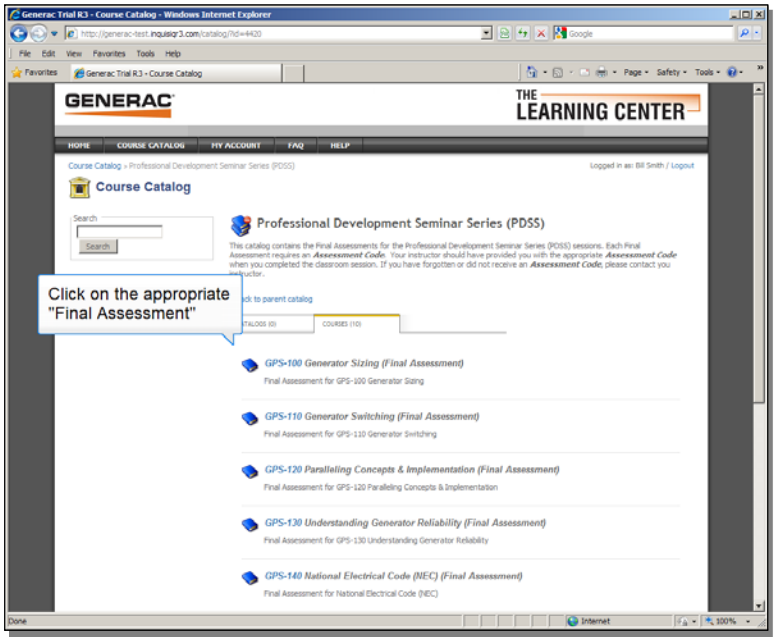


The next screen confirms your registration. Click the “Continue” button to proceed.

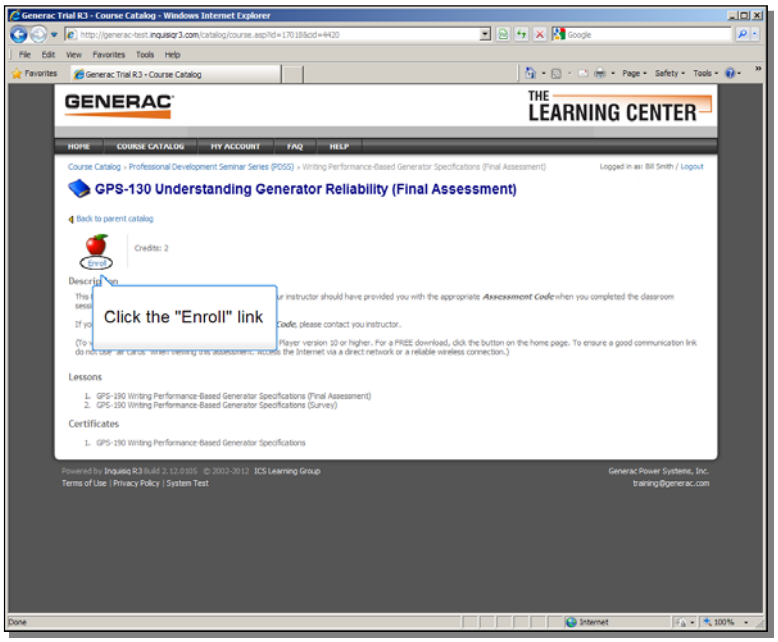


The next screen displays the “Course Catalog.” Click on the “Professional Development Seminar Series” link.

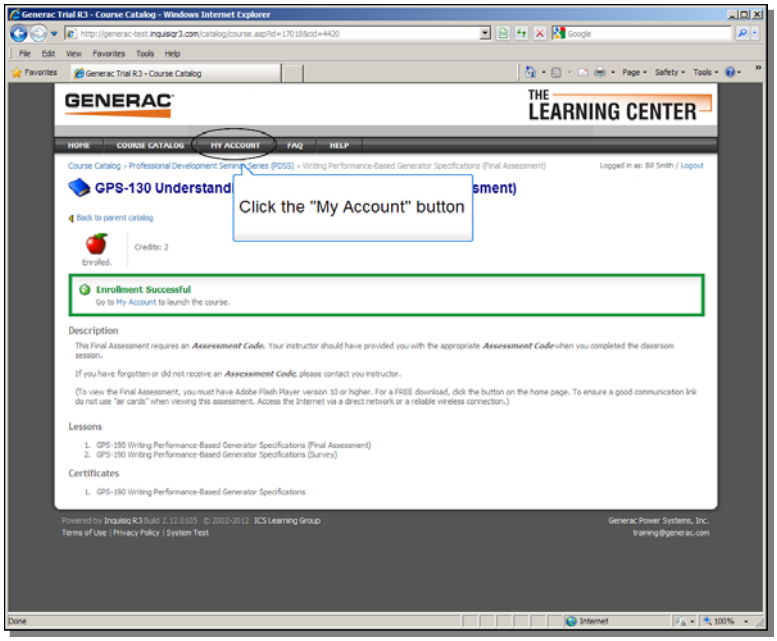
This next screen lists all currently available Final Assessments. Click on the Final Assessment that is tied to the course name and number you completed.



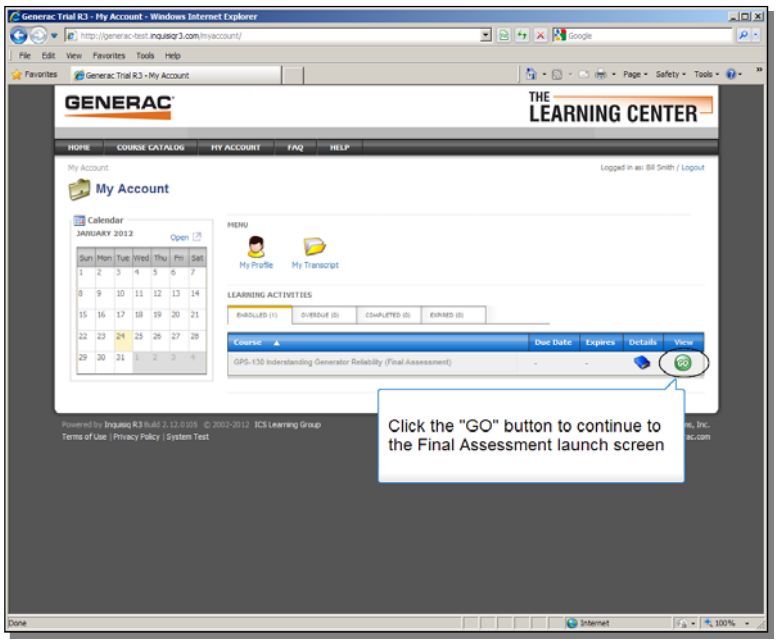
The next screen is the “Enrollment” screen for the Final Assessment that you selected. Click the “Enroll” link to proceed.



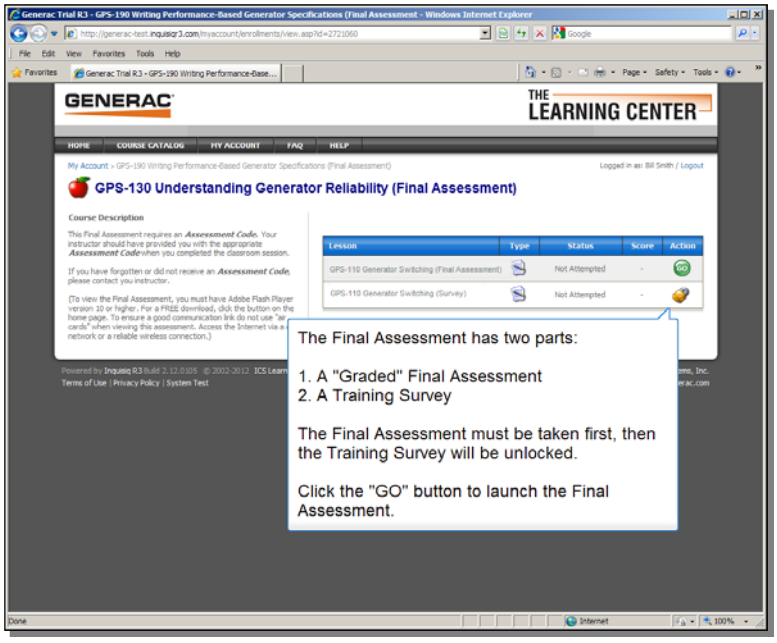
This screen confirms your enrollment. Click the “My Account” button to proceed.



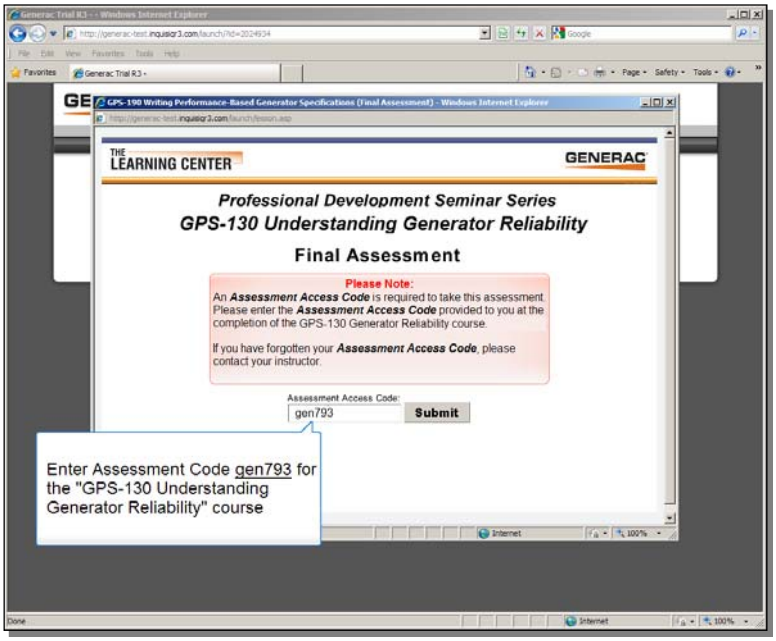
This is your “My Account” screen. Note that the Final Assessment you selected is displayed under the “Enrollment” tab. Click the “GO” button to proceed.



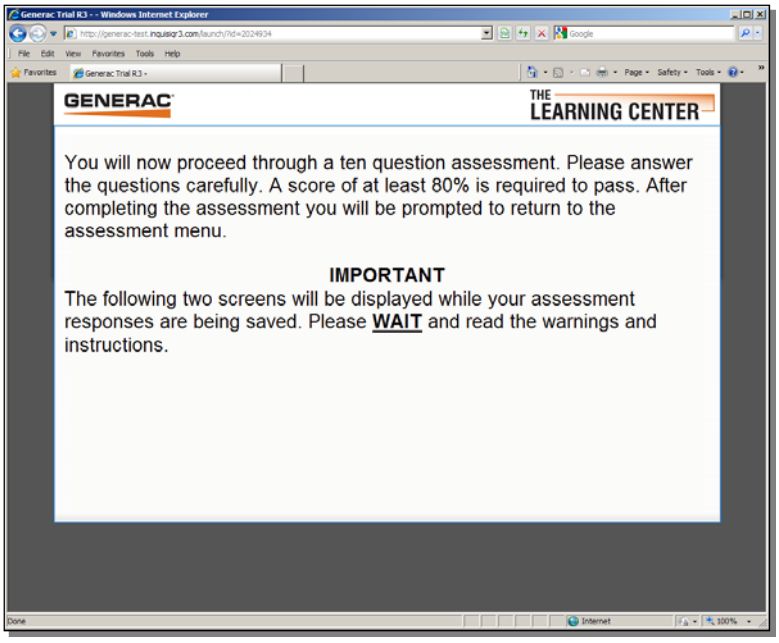
This screen lists the two parts to the Final Assessment. You must take the “Graded” Assessment first, then the Training Survey.



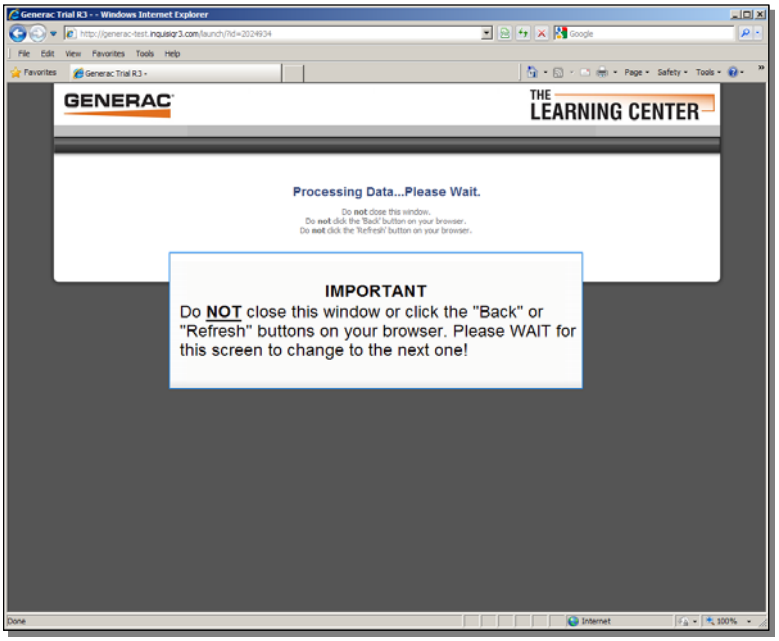
In the next screen an “Assessment Code” is required before you can continue. The code for GPS-130 Understanding Generator Reliability is **gen793**. Enter the code in the box and click the “Submit” button to continue.



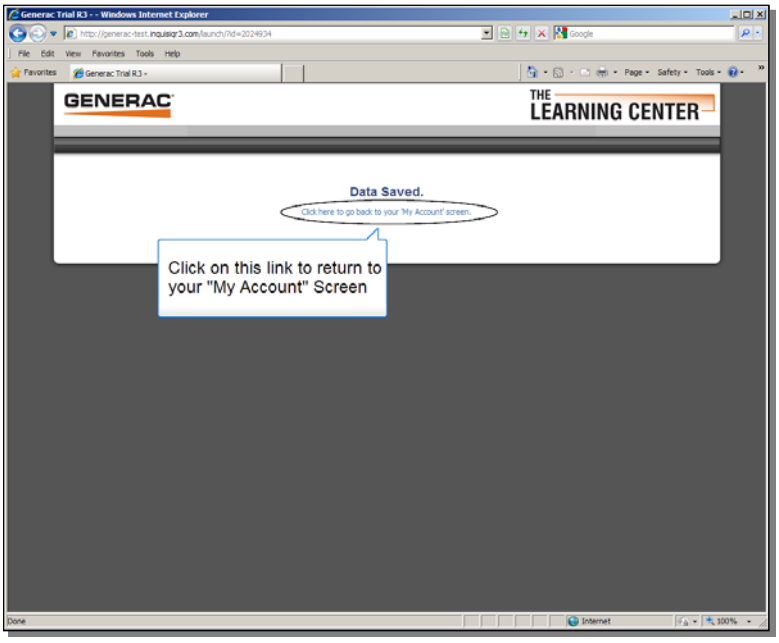
You will now proceed through a ten question assessment. Please read the warnings below.



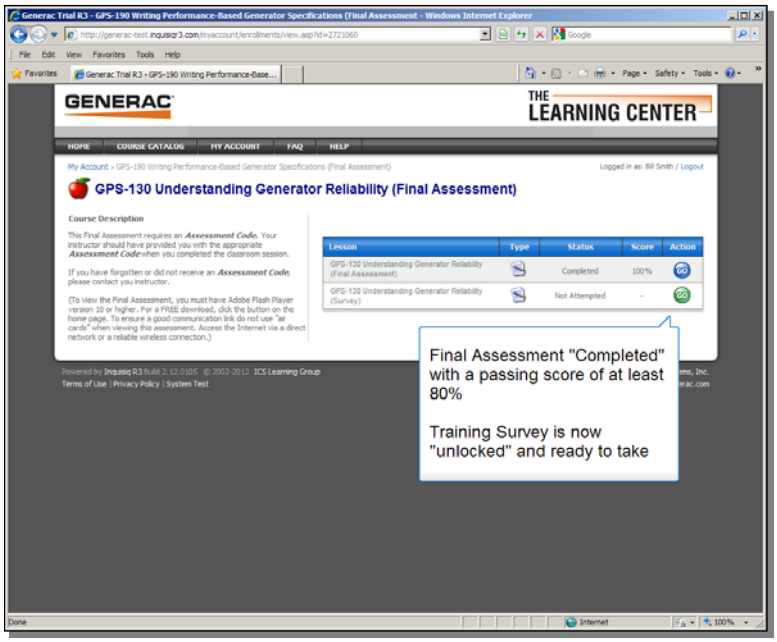
Please follow the instructions on this screen. You must wait for your assessment data to be saved. Do not close this window or click the 'Back' of 'Refresh' buttons on your browser.



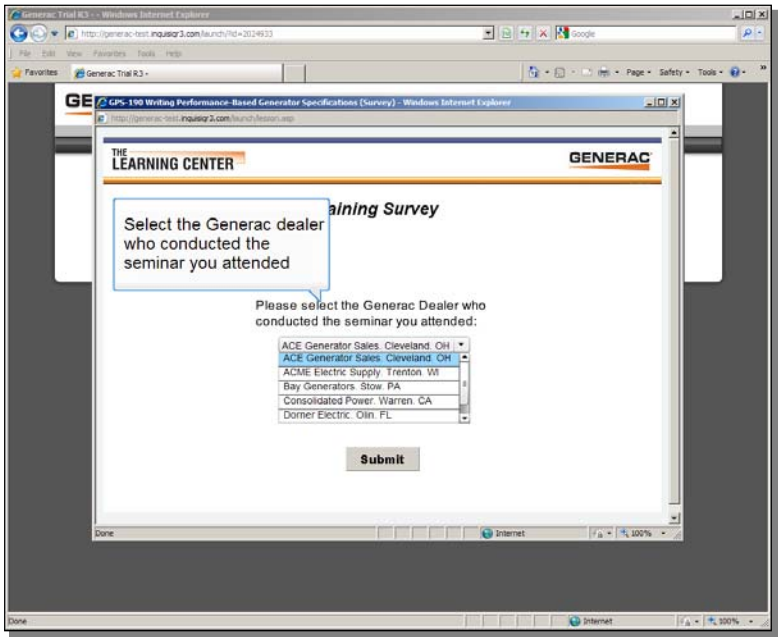
This screen confirms that your data was saved. Click on the link shown here to proceed.



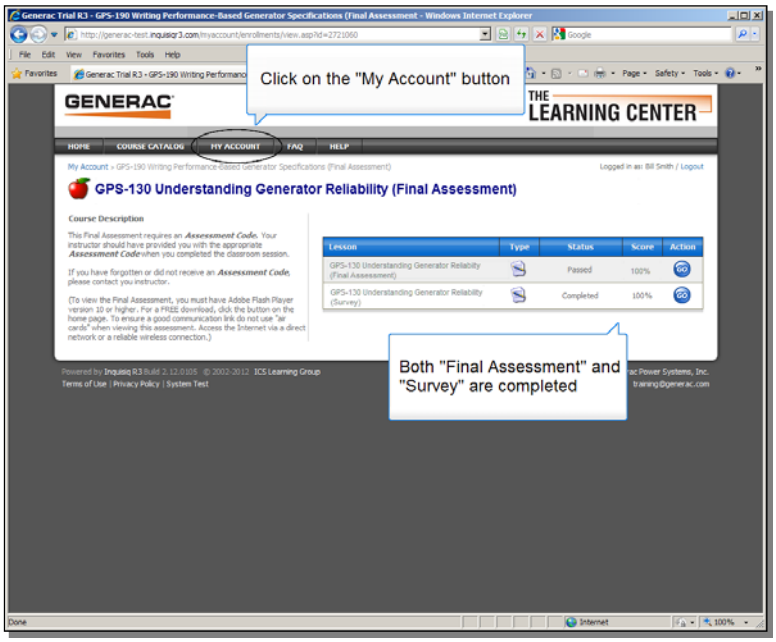
This screen will be displayed after your assessment data is saved. Note that in this example the assessment was passed with a score of 100% and the Survey is unlocked and ready to launch.



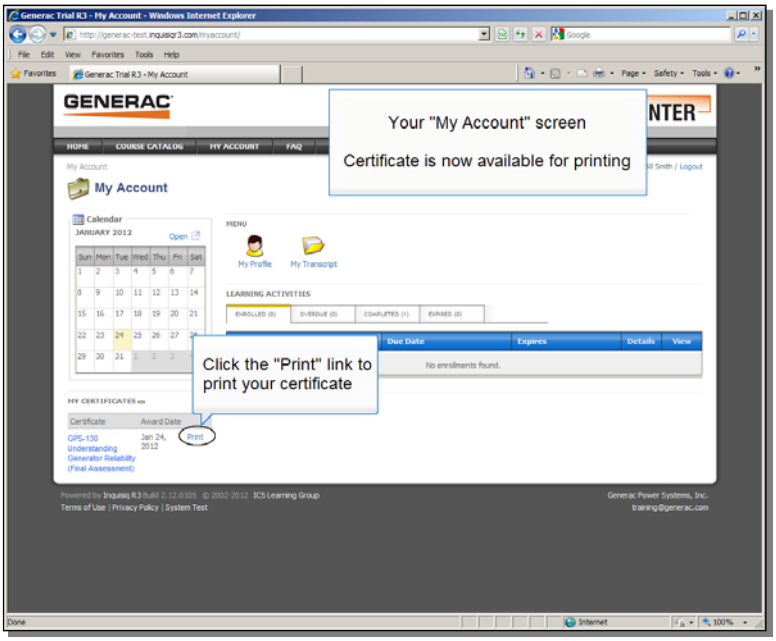
Upon launching the Survey, this screen will be displayed. Select the Generac dealer who conducted the seminar you attended.



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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