Emissions and Generator Sizing

Presented by Generac Industrial Power

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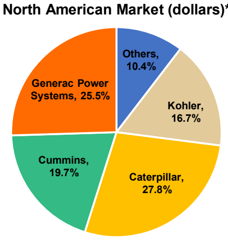
Generac Updates

- **Public Company (NYSE: GNRC):** Transparency
- **Experienced:** 60+ years in market
- **Strong U.S. Manufacturing:** >2,000,000 ft² (6 Plants in Wisconsin, 1 in South Carolina)
- **Engineering Driven:** ~9,500 employees , including 1,000 engineers
- **Aggressive R&D investment in both technology and facilities**
- **Focused:** Power generation > 95%

North American Market (dollars)*



*Numbers Pulled from Frost & Sullivan 2018 Report

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Generac Industrial & Mobile Product Offering

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Local Support – West Coast Energy Systems

From Coast to Coast

Energy Systems has resources throughout the **West Coast and New England** to ensure timely response to your emergency and preventive maintenance needs

ENERGY SYSTEMS

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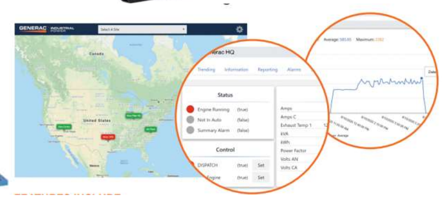
Generac Updates

- Hydrogen Fuel Cell Generator
- Sourcewell sourcing
- Blue Pillar - Remote Connectivity and Monitoring
- FT4 UL2200 500kW diesel gen
- BESS product
- Spec writer
- BESS Performance Spec
- $20M R&D investment
- $65M Manufacturing Facility – Beaver Dam, WI



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We Have Technical Expertise

Environmental Permitting

- Environmental consultant on staff
- Full service turnkey permitting of projects
- Proactive regulatory awareness

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Emission Requirements: EPA vs California

PROFESSIONAL DEVELOPMENT SEMINAR SERIES

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Diesel vs Natural Gas Exhaust Systems

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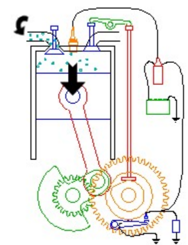
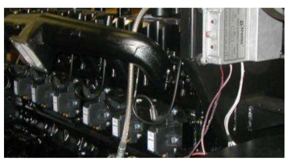
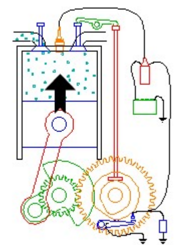
Operational differences NG vs. Diesel

- **Intake stroke**
  - NG: Air & fuel premixed via carburation (enters via intake valve)
  - Diesel: Fuel injected later (air only on intake)



- **Compression**
  - NG: Air & fuel pre-mixed is compressed & ignited with spark plug
  - Diesel: Heat of compression ignites injected diesel
  - Diesel: Higher compression ratios (more efficient)





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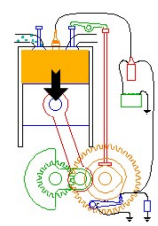
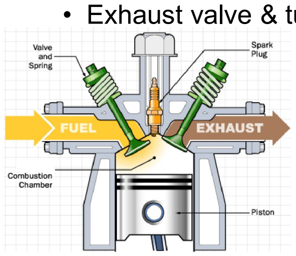
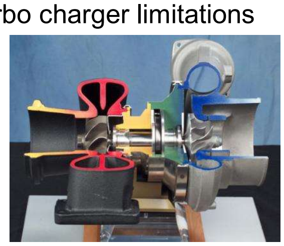
Operational differences NG vs. Diesel

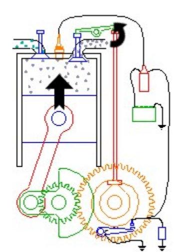
- **Power stroke**
  - Diesel: Engines are more power dense (higher efficiency)
  - NG: Engines typically 30% larger for same output



- **Exhaust stroke**
  - Diesel: Engines operate at 900 – 1000F exhaust
  - NG: Engines (rich-burn) typically have 1300 – 1400F exhaust
    - This higher temperature limits power density
    - Exhaust valve & turbo charger limitations







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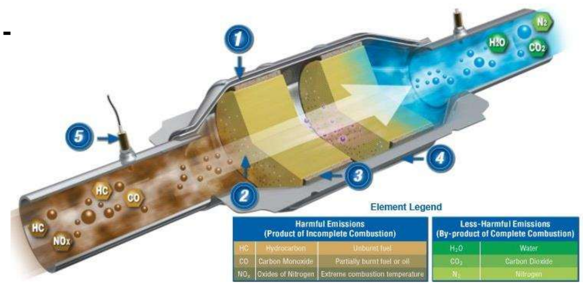
Aftertreatment Equipment – Natural Gas

- **Oxidizing Catalyst** **(precious metal)**
  - Requires fuel lean condition ($\lambda > 1.0$)
  - Lowers CO and HC emissions, Doesn't effect NO_X
- **Reducing Catalyst** **(precious metal)**
  - Requires fuel rich condition ($\lambda < 1.0$)
  - Lowers NO_X, Doesn't effect CO and HC emissions
- **Oxidizing & Reducing Catalyst** **(precious metal -**
  - Requires stoichiometric ($\lambda = 1.0$)
  - Lowers NO_X, CO, HC emissions
- **Life Cycle Cost - Compliant vs. certified**
  - Compliant - Periodic testing
  - Compliant – User responsible
  - Certified – OEM responsibile



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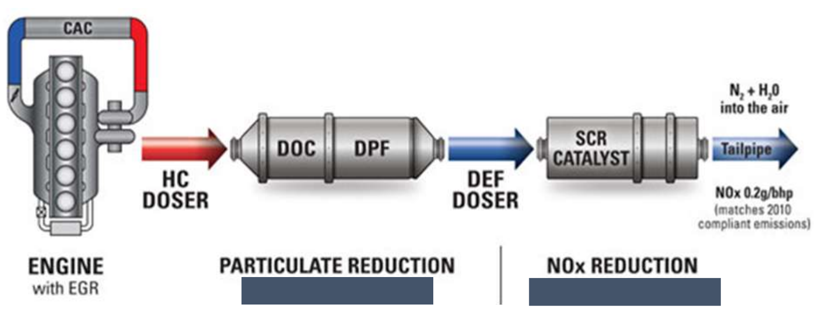
Aftertreatment Equipment – Natural Gas

- **Electronic injection & Exhaust Gas Recirculation (EGR)**
  - Typical on 150 – 500 kW engines (tier 3)
- **Diesel Particulate Filters (DPF),**
  - Entering some standby markets (CA near sensitive receptors, NYC)
- **Selective Catalytic Reduction (SCR)**
  - All non-standby applications (tier 4 final)



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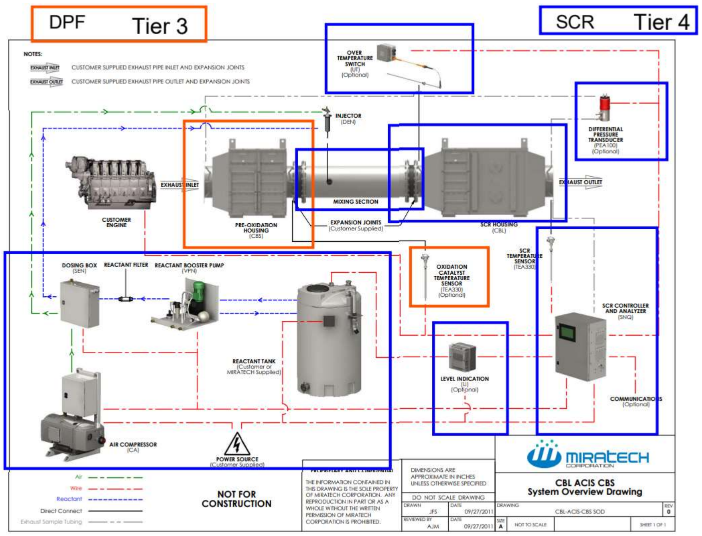
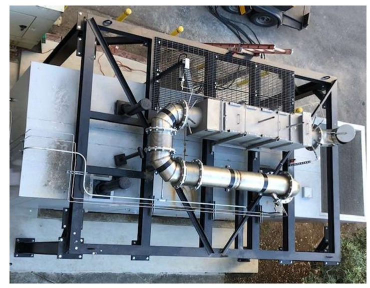
Aftertreatment Equipment - Diesel





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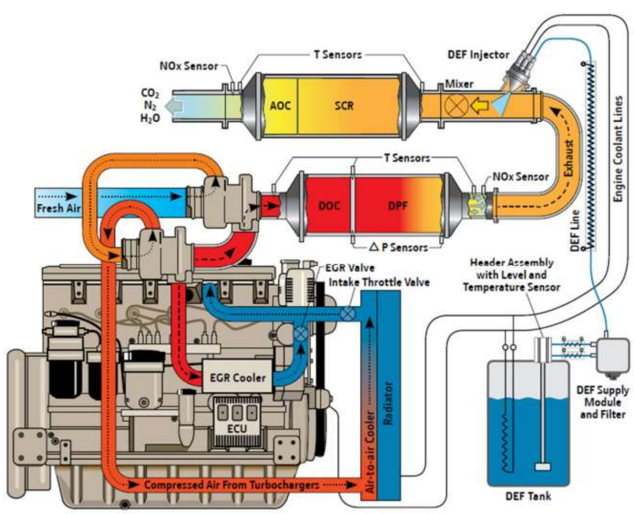
Equipment

Final Tier 4 Product Value



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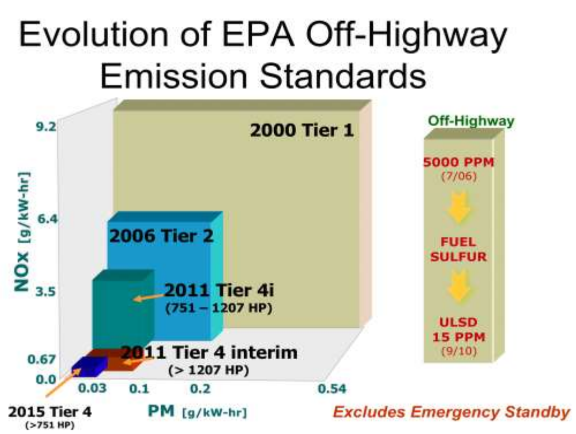
EPA Emissions Rules for non-highway applications

"Emergency" Generator No more than 100 hours	Non-Emergency Generator Everything else
Diesel Tier 4 - less than 80kW Tier 3 - 80kW to 400kW Tier 2 - 500kW and greater	Diesel Tier 4 - All, including any mobile products
Spark-Ignited Certified for emergency use	Spark Ignited Certified for use as non-emergency

Evolution of EPA Standards



California Requirements for Diesel Gens

Stationary, Embergency Standby Diesel Engine BACT Standard by EPA Teir

AIR DISTRICT	MAX ENGINE POWER					
	> 37 kW	37 ≤ kW < 75	75 ≤ kW < 130	130 ≤ kW < 560	560 ≤ kW < 1,340	kW ≤ 1,340
	> 50 hp	50 ≤ hp < 100	100 ≤ hp < 175	175 ≤ hp < 750	750 ≤ hp < 1,000	hp ≤ 1,000
California ARB - ATCM	Exempt	Tier 3	Tier 3	Tier 3	Tier 2	Tier 2
Bay Area AQMD	Exempt	Tier 3	Tier 3	Tier 3	Tier 2	Tier 4
Butte County AQMD	Exempt	Tier 3	Tier 3	Tier 3	Tier 2	Tier 2
Feather River AQMD	Exempt	Tier 3	Tier 3	Tier 3	Tier 2	Tier 2
Monterey Bay ARD	Exempt	Tier 3	Tier 3	Tier 3	Tier 2	Tier 2
Placer County APCD	Exempt	Tier 3	Tier 3	Tier 3	Tier 2	Tier 2
Sacramento Metro AQMD	Exempt	Tier 3	Tier 3	Tier 3	Tier 2	Tier 4
San Diego APCD	Exempt	Tier 3	Tier 3	Tier 3	Tier 2	Tier 2
San Joaquin Valley APCD	Exempt	Tier 4 [2]	Tier 4 [2]	Tier 4 [2]	Tier 4 [2]	Tier 4 [2]
San Luis Obispo County APCD	Exempt	Tier 3	Tier 3	Tier 3	Tier 2	Tier 4
Santa Barbara County APCD	Exempt	Tier 3	Tier 3	Tier 3	Tier 2	Tier 2
South Coast AQMD	Exempt	Tier 3	Tier 3	Tier 3	Tier 2	Tier 2
Tulolumne County	Exempt	Tier 3	Tier 3	Tier 3	Tier 2	Tier 2
Yolo-Solano AQMD	Exempt	Tier 3	Tier 3	Tier 3	Tier 2	Tier 2

[1] CARB ATCM PM emissions standard for all engine ratings is 0.15 g/bhp-hr (0.20 g/kW-hr). All stationary CI engines in CA must comply with this standard to be permittec

[2] SJVAPCD BACT policy requires Tier 4 if readily available. If Tier 4 is not readily available, then then current EPA Tier/CARB ATCM for applicable horsepower rating is acce

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Certified vs Compliant FT4

Tier 4 Certified	Tier 4 Compliant
Cleaner Package. No 3rd party skid or exposed components.	Requires Skid and exposed components from 3rd party
No Emissions Testing required.	Larger footprint
Less Expensive package	Requires Emissions testing on initial startup and Annual testing
24hr Run Time Basetank	Basetanks can be changed to accommodate longer desired run time
Certification Requires "Inducement"	Does not require Inducement

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NEC Sizing

- **Emergency Power Systems (NEC 2017)***
  - NEC 700.4(A) (Emergency System - Capacity)
    - "…adequate capacity and rating for **all loads to be operated simultaneously**"

- **Emergency Power Systems (NEC 2020)***
  - NEC 700.4 (Emergency System - Capacity)
    - "…adequate capacity in accordance with **article 220 or by another approved method**.
  - NEC 517.31 D (Health Care Facilities)
    - "… to meet the maximum **actual demand likely to be produced**…"
      "**NEC 700.4 & NEC 701.4 shall not be applied to hospitals**"
    - Practical sizing based on historical, demand factors, calculations

*Source: National Fire Protection Association (NFPA.org)

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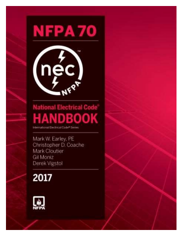
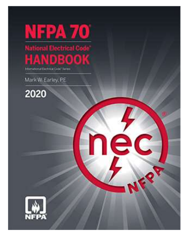
NEC Sizing

- **Standby Power Systems (NEC 2017)***
  - NEC 701.4 (Legally Required System - Capacity)
    - "…adequate capacity and rating for **all loads intended to be operated at one time**"

- **Standby Power Systems (NEC 2020)***
  - NEC 701.4 & 702.4(B)(2) (Legally Required & Optional - Capacity)
    - "…adequate capacity in accordance with **article 220 or by another approved method**.



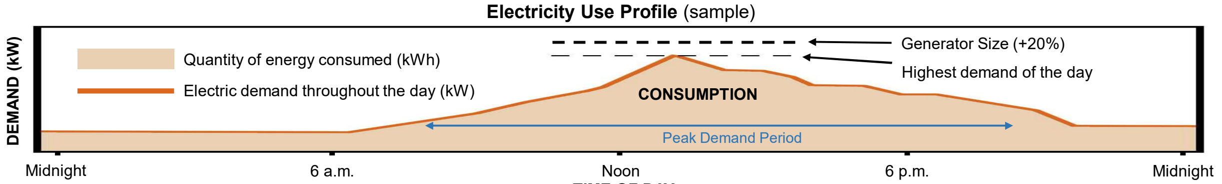


*Source: National Fire Protection Association (NFPA.org)

NEC Sizing

- **Article 220 (Feeder & Service load Calculations`**
  - Part III
    - Sum of the loads on the branch circuits
    - Applicable code allowed demand factors
    - Non-coincidental load allowance
  - Part IV
    - Existing installations can use actual maximum demand
      - Utility peak demand info across one year
      - Measurement data: 30 days
    - Generator sized for 80% loading (demand x 1.25)

Electricity Use Profile (sample)

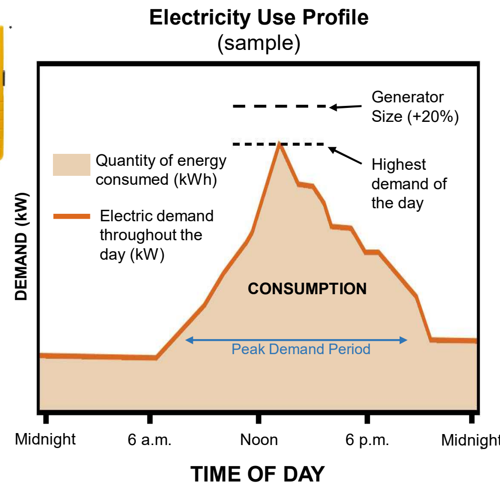


*Source: eaton.com

Measurement Data

- **Existing Facilities Should Utilize Historical & Measurement Data**

- **Billing History**
  - Demand charges (capture peak kW)
    - Captures seasonality & business cycles
    - Peak power over 15 minute average
      - Does not include motor start transients



- **Power Analyzer**
  - Snapshot / short history (measures transient spikes)
  - NEC wants 30 days (15 min averages)
  - Capture power quality
    - Harmonic content
    - Power factor

*Source: FLUKE Corporation

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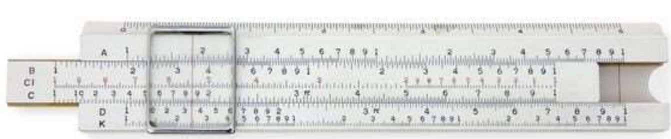
Other Approved Methods

- **“Other Approved Methods”**
  - Open to AHJ interpretation
  - AHJ & plan review have to be comfortable with the sizing process
  - Engineering judgement & PE stamp carry weight
    - New construction circuit loading may be under defined
    - Historical design rules for needed (kW/ft^3)
    - Factors for uncertainty & load growth



*Source: Computerhistory.org

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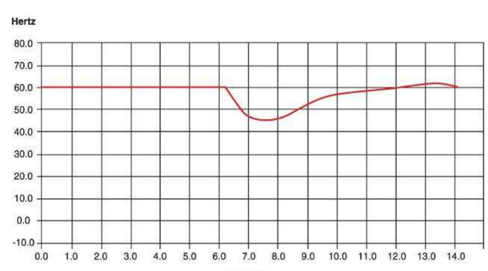
Matching Load Characteristics to the Generators

- **Sizing Larger Applications (many mixed load types)**
  - No single load is all that important
    - Add up total kW
    - Identify the largest transient load (typically an across the line starting motor)
    - Verify that harmonics aren't an issue (covered in Generator Sizing (Part 2))
- **Isolating Loads & Smaller Applications (covered in Generator Sizing (Part 2))**
  - Characteristics of the load is important
    - Accurate modeling of the load characteristics is important
    - Transients (starting kVA & starting kW)
    - Harmonics
  - Characteristics of the Genset are important
    - Voltage stiffness
    - Volts / Hertz response (large natural gas units – softer frequency)
    - Alternator reactance
    - Peak kW capability



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Generator Sizing Programs

- **What Generator Sizing Programs Do Well**
  - Analyze a few discrete loads
  - Analyze a transient load with given pre-load (like a motor start)
  - Harmonics analysis (Generac Power Design Pro unique)
  - Mechanical design (gas piping, exhaust piping, layout)
  - www.powerdesignpro.com

- **Can Generator Sizing Programs Accurately Size Buildings?**
  - No, why:
    - Entering a complete load list assumes all loads are energized
      - Load diversity factors aren't modeled
    - Entering too many loads in a single load step creates a "false" condition
      - Most loads sequence naturally with limited concurrent starting

*Source: electricmotorsforless.com
**Source: illinoiscss.org

Natural Load Sequencing

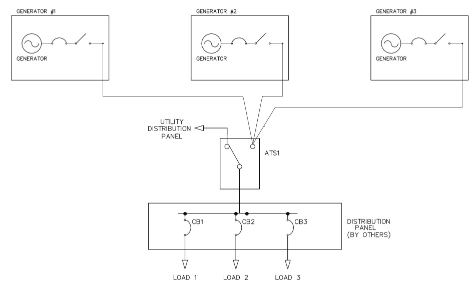
- **Concurrent or Non-concurrent Load Sequencing Assumptions**
  - When power fails all the loads power-off
  - When ATS transfers load is minimum (typically connected lighting)
  - Most loads naturally sequence back-on
    - Chillers & compressors must bled off head pressure
    - UPS have a timer for utility good
    - Machines must be restarted
    - Simple control relay can prevent concurrent starting

- **Generac's Power Design Pro (available online)**
  - Supports both concurrent & non-concurrent
  - Recommend using "Group" – assumes non-concurrent load start with largest last
  - Program also includes "Steps" – for few times when loads must start concurrently

*Source: Trane.com

Load Uncertainty – New Construction

- **New Construction Should Be Sized Using Engineering Judgment**
  - What is the anticipated load level
    - Often services are sized conservatively (actual loads of 50% are not uncommon)
    - Typically, the generator is sized less robust than the service
  - What circuits are going to be connected?
    - Whole building, selected standby loads, emergency system
    - End users often want a large load list initially
    - What loads are essential & what are optional?
  - What types of loads will be connected?
    - Resistive (kW)
    - Motor Loads (transients & voltage dips)
    - Non-Linear (voltage distortion)



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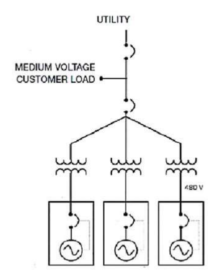
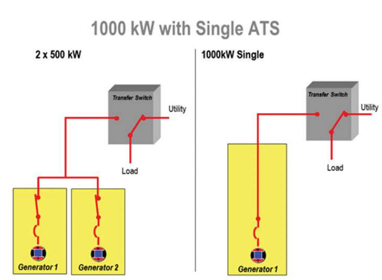
Load Uncertainty – Load Growth

- **What Is The Expected Load Growth?**
  - Does the end user have an aggressive growth plan?
  - How certain is the business model?
  - What is the value of different capital expenditures?
- **Would The Customer Benefit From An Expandable Solution?**
  - Is integrated parallel generation an option?





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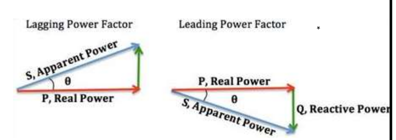
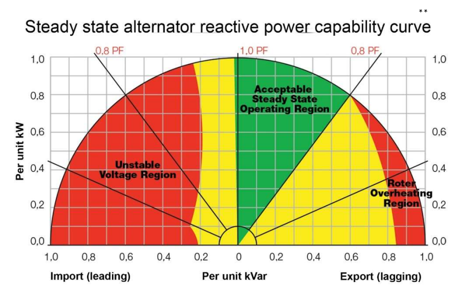
Load Uncertainty – Transient Loads

- **What Are The Largest Load Steps On The Generator?**
  - Starting large motor loads can challenge system sizing
- **What Are The Acceptable Transient Limits?**
  - Generators are not infinite sources
  - Expect voltage & frequency dips
  - Size for total power and transient performance
    - Size based upon largest load step while powering the building
    - For general (non-dedicated) loads, limit the voltage dip to 15%
    - Frequency dip seems to be less of an issue (most loads don't care)

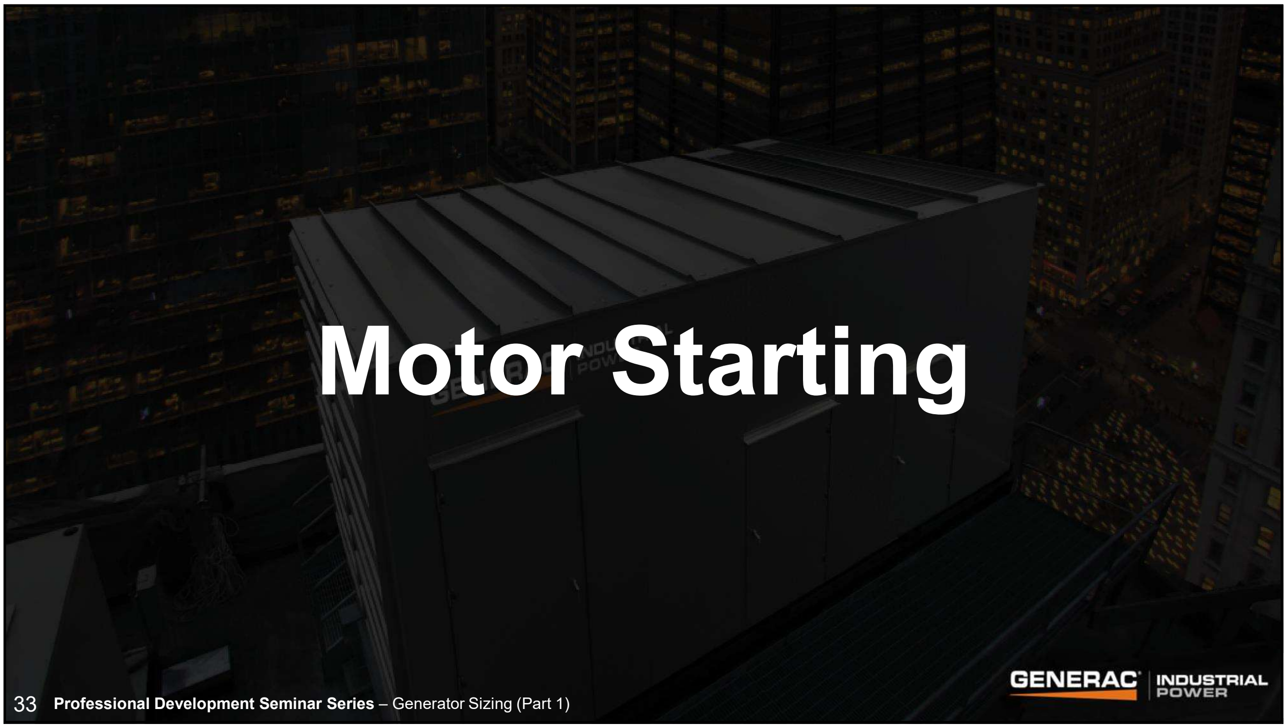
Load Uncertainty – Leading PF

- **Generators Are Rated For .8 PF (Lagging) To 1.0 PF**
- **Leading PF Can Cause Self Excitation Resulting In**
  - Voltage instability
  - Over-voltage shutdowns
- **Sources Of Leading Power Factor**
  - Power factor correction capacitors at the service
  - Lightly loaded (less than 30%) UPS's & VFD's with filtering
    - Capacitor cut-out contactor filter option
- **If Power Factor Is Leading**
  - Remove the leading power factor elements
  - Add offsetting lagging power factor loads





*Source: billfinnell.com
**Source: electricalknowledgecommunity.blogspot.com



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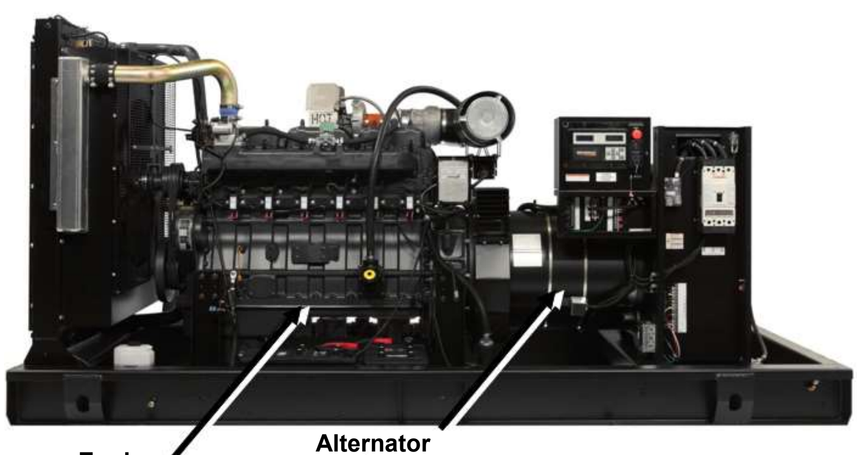
Motor Starting Transients



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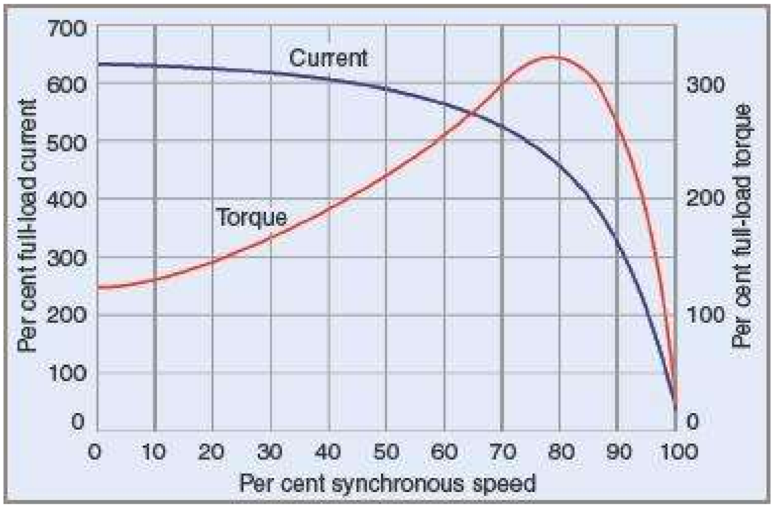
Motor Starting Transients (Starting kVA)



*Graph Source: electricala2z.com

Motor Starting Transients (Starting kVA)

- **What Happens When A Contactor Closes To Start An Electric Motor?**
  - Immediate inrush of current
  - Inrush is referenced as:
    - Locked rotor amps (LRA)
    - Inrush current or motor starting current
  - Converting LRA to skVA
    - skVA easier for using rules

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

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

skVA required to start the motor

Note: "s" indicates the motors starting period

Motor Starting Transients (Starting kVA)

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

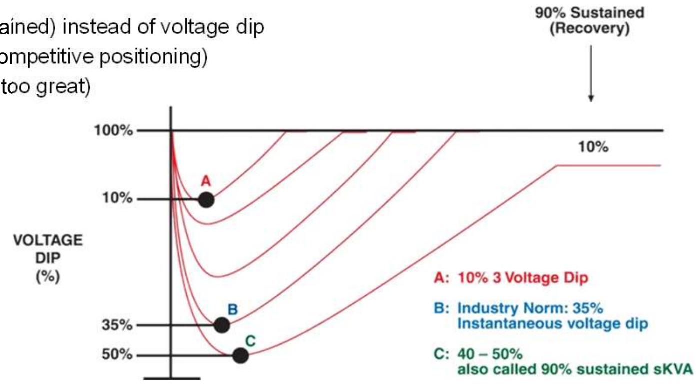
Letter Designation	kVA per hp
A	0 – 3.15
B	3.15 – 3.55
C	3.55 – 4.0
D	4.0 – 4.5
E	4.5 – 5.0
F	5.0 – 5.6
G	***5.6 – 6.3***
H	6.3 – 7.1
J	7.1 – 8.0
K	8.0 – 9.0
L	9.0 – 10.0
M	10.0 – 11.2
N	11.2 – 12.5
P	12.5 – 14.0
R	14.0 – 16.0
S	16.0 – 18.0
T	18.0 – 20.0
U	20.0 – 22.4
V	22.4 and up

Motor Starting Transients (Starting kVA)

- **Expected skVA**
  - Name plate data
    - Typically have a NEMA starting code
    - Don’t confuse design codes (B,C,D) & starting codes (expect code F or higher)
    - LRA (locked rotor amps)
  - IEC vs. NEMA
    - European motors (IEC) typically have higher starting currents
  - High efficiency
    - High efficiency motors have higher starting currents

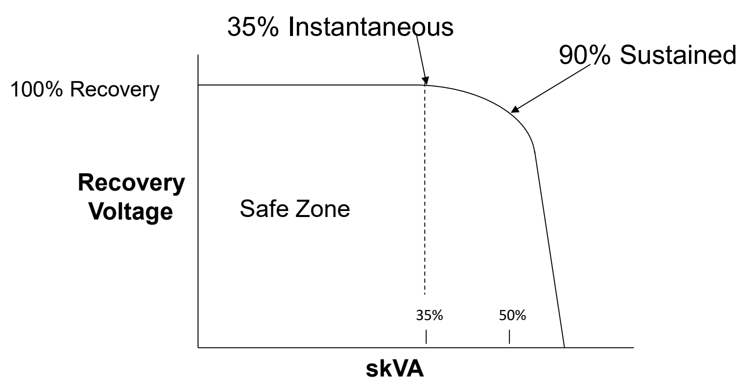
Motor Starting Transients (Alternator Response)

- **Each Line Is The Response For Successively Larger Motors**
  - Line B represents the industry suggested maximum alternator capability limit (35% Vdip) (limit of NEMA motor starter)
  - Line C is used by one OEM
    - Focuses on recovery voltage (90% sustained) instead of voltage dip
    - Generates a very large skVA number (competitive positioning)
    - No application relevance (voltage dip is too great)



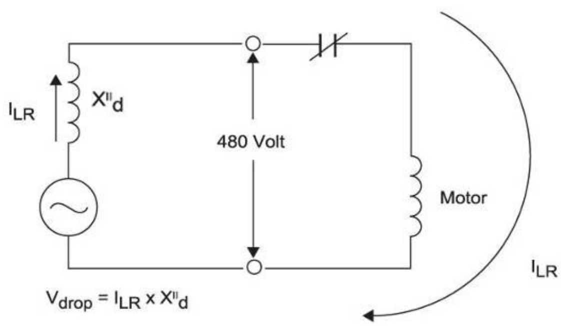
Motor Starting Transients (Alternator Response)

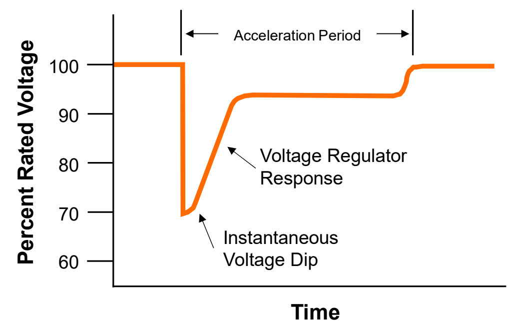
- **Operating Beyond 35% Voltage Dips**
  - Typically results in collapsing the alternator output voltage
  - Often resulting in application issues (motor contactors dropping out)



Motor Starting Transients (Alternator Response)

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





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

Motor Starting Transients (Alternator Response)

- **Improve Motor Starting**
  - Minimize X "$_d$ (generator sub-transient reactance)

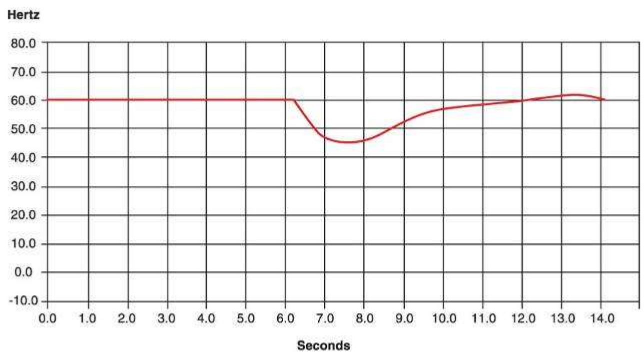
Upsizing the Alternator (improves motor starting)

Example: 50hp x 6.0 skVA/Hp = 300 skVA

Voltage dip	35%	25%	20%	15%	10%
Alternator	130	200	250	300	600

Motor Starting Transients (Engine Response)

- **How Does The Engine Respond To Motor Starting?**
  - Frequency dips are dependent on engine configuration & voltage regulator unloading
    - Fuel type (diesel vs. natural gas)
    - Engine displacement
    - Engine technology (mechanical vs. electronic injection)



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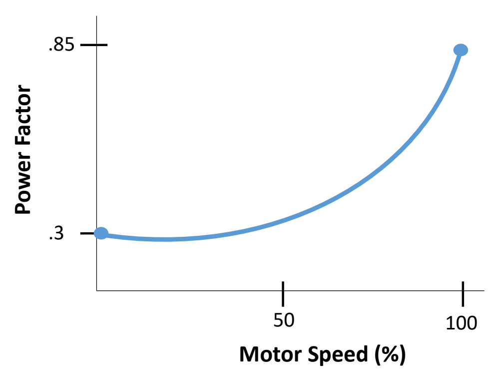
Motor Starting Transients (Engine Response)

- **Why does the engine speed dip during a motor start?**
  - PF = kW/kVA (definition of PF)
  - sPF = skW/skVA (add “s” for starting period)
    - Function of motor size & design
    - Typical sPF range is .25 to .45 (1000 to 5hp)
    - Power factor increases when motor accelerates
  - skW = skVA x sPF (calculate for starting kW)
  - Example of skW (Start kW)
    - 100 hp x 6.0 (skVA/hp) = 600 skVA
    - 600 skVA x .3 sPF = 180 skW



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Motor Starting Transients (Engine Response)

- **Engine Speed (Frequency)**
  - Frequency will dip
  - skW ≅ 2 x motor hp (conservative estimate for across line starting)
- **Engine Performance**
  - 8 to 12 hertz dip @ 100% load step (average diesel performance)
  - 12 to 18 hertz dip @ 100% load step (average gas performance)
  - Frequency dip is managed by the regulator volts-per-hertz function
    - Shedding voltage reduces the load seen at the engine by a square function (Power = V^2/R)
- **Load Acceptance**
  - Most loads are tolerant of frequency dips
  - Line interactive UPS technologies are frequency sensitive

Motor Starting Transients (Rule of Thumb)

- **Rules of Thumbs**
  - Alternator
    - skVA = hp x 6.0
    - rkVA = hp
  - Engine
    - skW = hp x 2
    - rkW = hp x .85

EXCEPTIONS: SPECIALTY MOTORS

Submersible Pumps
skVA = hp x (12 to 14)

Motor Starting Transients (Exercise)

- **Three Motors Are At A Pump Station**
  - 50hp, 100hp, 200hp
- **What sequencing should we assume?**
  - What order gives us the smallest generator?
  - What sequencing typically matches the real world application?
  - Exercise 1 (start sequence 200hp, 100hp, 50hp) – Largest first
  - Exercise 2 (start sequence 50hp, 100hp, 200hp) – Largest last
  - Exercise 3 (start all the motors simultaneously)

Notes the following slides:
"s" indicates starting
"r" indicates running
"p" indicates peak (previous running loads with current starting loads)

Motor Starting Transients (Exercise)

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

Start 200hp x 2 = 400 skW (need 400 kW genset minimum)
Run 200hp x .85 = 170 rkW (preload for next load step)
Start 100hp x 2 = 200 skW + 170 rkW = 370 pkW (400 kW genset is still enough)
Run 300hp total x .85 = 255 rkW (preload for next step)
Start 50hp x 2 = 100 skW + 255 rkW = 355 pkW (400 kW engine)

Recommended Size 400 kW

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

To determine voltage dip, use alternator data sheets

Motor Starting Transients (Exercise)

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

Preload of (100 + 50)hp x .85 = 127 rkW

Start 200hp x 2 = 400 skW + 127 rkW = 527 pkW

Recommended Size 500-600 kW

Motor Starting Transients (Exercise)

Example 3 Start sequence - all three instantaneously

Start (200 + 100 + 50)hp x 2 = 700 skW

Recommended Size 700 kW

Load sequence impacts generator sizing!!

We recommend using "Groups" in Power Design Pro
Assumes natural sequencing with largest load coming on last

Sizing Summary

- **Existing facilities**
  - Use measurement and billing history demand charge information
  - Consider the building load as pre-load & model starting biggest motor
- **New construction**
  - Engineering judgement & design rules
  - Scalable solutions are a valuable tool to deal with uncertainty and load growth needs
- **Leading Power Factor**
  - Turn off power factor correction or add other offsetting lagging loads
- **Motor Starting**
  - skVA is typically Hp x 6 (this is the impact on the alternator – used for calculating voltage dip)
  - skW is typically Hp x 2 (this is the impact on the engine – used for peak loading and frequency dip)
  - Typically assume natural motor sequencing (non-concurrent starting) with largest coming on last
  - Limit whole building applications to 15% voltage dip
  - Limit simple NEMA motor starter applications to 25-35% voltage dip
  - "90% sustained" is a marketing gimmick by one OEM and has no application relevance

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Opportunities to Interact

- **Key Distributor Projects**
  - "Insert key projects"

- **Opportunities to Interact with Generac**
  - Site visits
  - Factory visit (Fly-in Program)
  - Webcasts (live and recorded)
  - Generac Engineering Symposium