Generator Sizing
Details that affect machine size (recap):

- **Output Power**
- **Enclosure Type and Cooling Method**
  - IP2X is standard, higher IP ratings require larger machines due to reduced airflow (filtered) or closed-circuit cooling (TEAAC / CACA).
- **Rotating Speed**
  - Slower speed = larger machine required for same output
- **Winding Pitch**
  - Optimum pitch designs are often smaller than 2/3 pitch
- **Operating Temperature**
  - Lower winding temp limits drive larger machines
Details that affect machine size (recap):

- **Special Requirements (end user or agency specs)**
  - Reactances (voltage dip and/or fault current limits)
  - Efficiency
  - Overload capabilities (long duration overload)
  - Thermal limits during operation

- **Driver Details**
  - 4MW of power behind a recip engine with traditional cooling vs. 4MW of power behind a turbine with inlet chilling will likely be two very different machines.
  - Need details on driver capability vs. ambient temp, preferred cooling method of the alternator, etc.
Details that affect machine size:

• Other Considerations:
  – Ambient conditions > 40°C or < -20°C
  – Altitude >1000M
  – Low power factor (below standard of 0.8)
    • Or is it above the standard 0.8?
  – Excessive load unbalance (>20% delta between phases)
  – High percentage of harmonic loads
  – Motor starting or block loads with voltage dip limits
Sizing approach (basic / typical):

1. Power rating, voltage, enclosure type, temp rise limit
   - Are temp rise limits based on insulation class, or a fixed value per a certain spec? What is the max ambient temp?

2. Driver capability vs. ambient temperature
   - Reciprocating or Turbine driver?

3. Cooling method, temperature of cooling fluid
   - Air vs. H2O cooling, fixed vs. variable fluid temp

4. Performance requirements
   - Efficiency, reactances, agency approvals, other spec details…

5. Does a governing specification require a certain amount of excess capacity or various operating conditions?
Special Enclosures

• Open Drip Proof
  Standard: No de-rate
  Filtered / DIDO: Approx 5% de-rate

• Totally Enclosed Water-to-Air Cooled (TEWAC / CACW)
  Water temperature and flow rate dependent
  Could match ODP size – could be larger…

• Totally Enclosed Air-to-Air Cooled (TEAAC / CACA)
  Cooler efficiency
  60% to 70% of ODP rating

• Weather Protected Type-2 (WPII)
  95% of ODP rating
**Determination of Temp Rise Limits**

- **NEMA MG-1**: Table 32-3
  - For air cooled machines
  - Based on 40°C maximum ambient temperature
  - Limits drop directly with any increase in maximum ambient temperature

<table>
<thead>
<tr>
<th>Part of Machine</th>
<th>Method of Measurement</th>
<th>Temperature rise ºC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Class of Insulation System</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Armature windings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. All kVA ratings</td>
<td>Resistance</td>
<td>60</td>
</tr>
<tr>
<td>2. 1563 kVA and less</td>
<td>Embedded detector</td>
<td>70</td>
</tr>
<tr>
<td>3. Over 1563 kVA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 7000 V and less</td>
<td>Embedded detector</td>
<td>65</td>
</tr>
<tr>
<td>- Over 7000 V</td>
<td>Embedded detector</td>
<td>60</td>
</tr>
<tr>
<td>Field winding</td>
<td>Resistance</td>
<td>65</td>
</tr>
</tbody>
</table>
NEMA MG.1: Exceptions to Temp Rise

- Generators may be rated on a stand-by basis (see 32.35). Temperature rise not to exceed Table 32-3 by more than 25º C.
- For ambient temperature higher than 40º C, the temperature rise shall be reduced by the degrees that the ambient exceeds 40º C.
- For totally enclosed water-air cooled machines, the cooling air temperature is that of the air leaving the coolers.
  - On machines designed for cooling water from 5º to 30º C – the temperature of the air leaving the coolers shall not exceed 40º C.
  - For higher water temperatures – the temperature of the air leaving the coolers can exceed 40º C if the rise is limited to less than Table 32-3 by the degrees that the air leaving the coolers exceeds 40º C.
# Determination of Temp Rise Limits

- **IEC60034-1** Table 7
  - For air cooled machines
  - Based on 40°C maximum ambient temperature
  - Limits drop directly with any increase in maximum ambient temperature
  - *(Many variations in IEC – applicable machine parts listed below)*

<table>
<thead>
<tr>
<th></th>
<th>Class B</th>
<th>Class F</th>
<th>Class H</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R (K)</td>
<td>ETD (K)</td>
<td>R (K)</td>
</tr>
<tr>
<td>AC Windings &gt;5 MVA</td>
<td>80</td>
<td>85*</td>
<td>105</td>
</tr>
<tr>
<td>AC Windings 0.2-5.0 MVA</td>
<td>80</td>
<td>90*</td>
<td>105</td>
</tr>
<tr>
<td>Field Windings</td>
<td>80</td>
<td>-</td>
<td>105</td>
</tr>
</tbody>
</table>

* For machines >12kV, maximum allowed temp rise by RTD reduces by 1° for each 1kV above 12kV up to and including 24kV per Table 9, item 4.
Insulation Temp vs. Life

- Per IEEE 117 and 101
- Determined by testing samples at elevated temperatures, cyclic stresses (including vibration) and high humidity.
- $10^{\circ}C$ rule: 2X life for every $10^{\circ}C$ the temp is lowered (based on 20,000 hour intercept as the thermal index).
Altitude: Generator De-rate

- Generators specifically designed for high altitude may have a larger fan to partially compensate for reduced heat capacity of air, or could be oversized to run cooler under these conditions.

- Reduced ambient temperature at high altitude may partially compensate.
Depends on allowable temperature rise and other factors; actual value may vary.
kW and kVA loads vs % lagging PF

% lagging power factor

Load in % of rated kVA

Typical generator

kVA

kW
Reactive Capability Curve

Limited by rotor heating

Limited by stator heating

Limited by control stability

Limited by dynamic stability

Power (kW)

Inductive Load

Capacitive Load

(Power Factor)

0.4

0.6

0.7

0.8

0.9

Leading -- Reactive Load kVAR -- Lagging

-3000

-2000

0

1000

2000

3000

-3000
Continuous Unbalanced Loading

- Minimum current / rated current
- Maximum current / rated current

Allowable unbalance
Excessive unbalance

Based approximately on a 10% equivalent negative sequence current
Unbalanced Load

- Stator current limited to rated current so single-phase L-L rating of stator is 58% (1/3) of three-phase rating.
- Rotor heating due to negative-sequence current may further limit single-phase rating.
- 100% unbalanced load (single-phase L-L load) requires about 50% oversizing, depending on rotor construction (robust fully-connected copper cage preferred).
- Increased distortion may result.
- Efficiency will drop as rotor losses increase.
Harmonic Loads

• To meet temperature rise:
  – Type of load:
    • Linear
    • Non-linear:
      – Type of load (e.g. six-pulse diode rectifier) or percentage of rated current for each harmonic
      – Filtering and impedance

• To meet voltage distortion requirements:
  – Need measured harmonic currents and frequencies.
  – Is an estimate only since actual result depends on system factors other than generator impedance.
Harmonic Loads (cont.)

Assumes “typical” six-pulse harmonic spectrum and that harmonics have the same effect as negative-sequence current. Modified to account for no derating with up to 10% 12E.

For machine with robust cage fully connected.
Motor Starting: Examples

- NEMA MG1 32.18.5.3 Motor starting equation

\[
\text{\% Dip} = 100 \times \frac{X'd}{X'D + \frac{\text{Base kVA}}{\text{Starting kVA}}} \quad \text{Where X'd is in per unit of the KVA base}
\]

Example: 2000 kW @ 0.8 PF with X’D = 18.2% starts a 750 HP code F motor – What is the approximate voltage dip?

- Base kVA = 2000 kW / 0.8 PF = 2500
- Starting kVA = 750 HP × 5.6 kVA / HP = 4200
- % dip = 100 x (0.182) / (0.182 + (2500 / 4200)) = 23.4%

- Note: To reduce the dip, reduced voltage starters can be used. Engine transient response will add to this dip, but the engine response is usually much slower than the generator. This assumes a very low starting power factor.
Generator Size vs. Required V Dip (%)

Note:
Better results can be obtained if the generator is specifically designed for low voltage transient. This is for illustrative purposes only.
Design Comparison Keys

• Performance of a machine can be specified in a variety of ways and the details are important.

• Don’t filter the specifications; pass them on to us. Important information may not catch your eye.

• Clear communication is critical in making an informed design selection.

• If there is any doubt, get clarification from customer as well as supplier to keep everyone on the same page.
Why So Many Questions?

• “All I need is a quote for a generator..... Why do you keep coming back with more questions?”

• “Why do you need all of these answers up front?”

• “Why can’t we work out these details later after the order is placed?”
Quoting Example 1 (hypothetical)

• Customer requests 2 MW, 1800 RPM generator with an IP23 enclosure, 105° C/40° C.

• Machine is sized, order is placed, and then a full specification is sent with the order.

• Spec calls for class F insulation (105° C/40° C) with a class B rise (80° C/40° C).

• Result: Stack length grows to meet new temp rise requirement, adds cost, may delay schedule slightly.
Quoting Example 2 (hypothetical)

• Customer requests 2 MW, 1800 RPM generator with an IP23 enclosure, 105° C/40° C.

• Machine is sized, order is placed, but then a full specification is sent with the order.

• Spec calls for API, ABS, IP56 enclosure and a guaranteed minimum X”d of 15%.

• Result: Machine frame changes, all mechanical and electrical data changes, 2+ days of special testing needs added, price of new design plus special testing is at least 2.5x more than the original quote. Significant project delays may occur.