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

		Temperature rise ºC Class of Insulation System			
Part of Machine	**Method of Measurement**	**A**	**B**	**F**	**H**
Armature windings					
1. All kVA ratings	Resistance	60	80	105	125
2. 1563 kVA and less	Embedded detector	70	90	115	140
3. Over 1563 kVA					
- 7000 V and less	Embedded detector	65	85	110	135
- Over 7000 V	Embedded detector	60	80	105	125
Field winding	Resistance	65	80	105	125

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

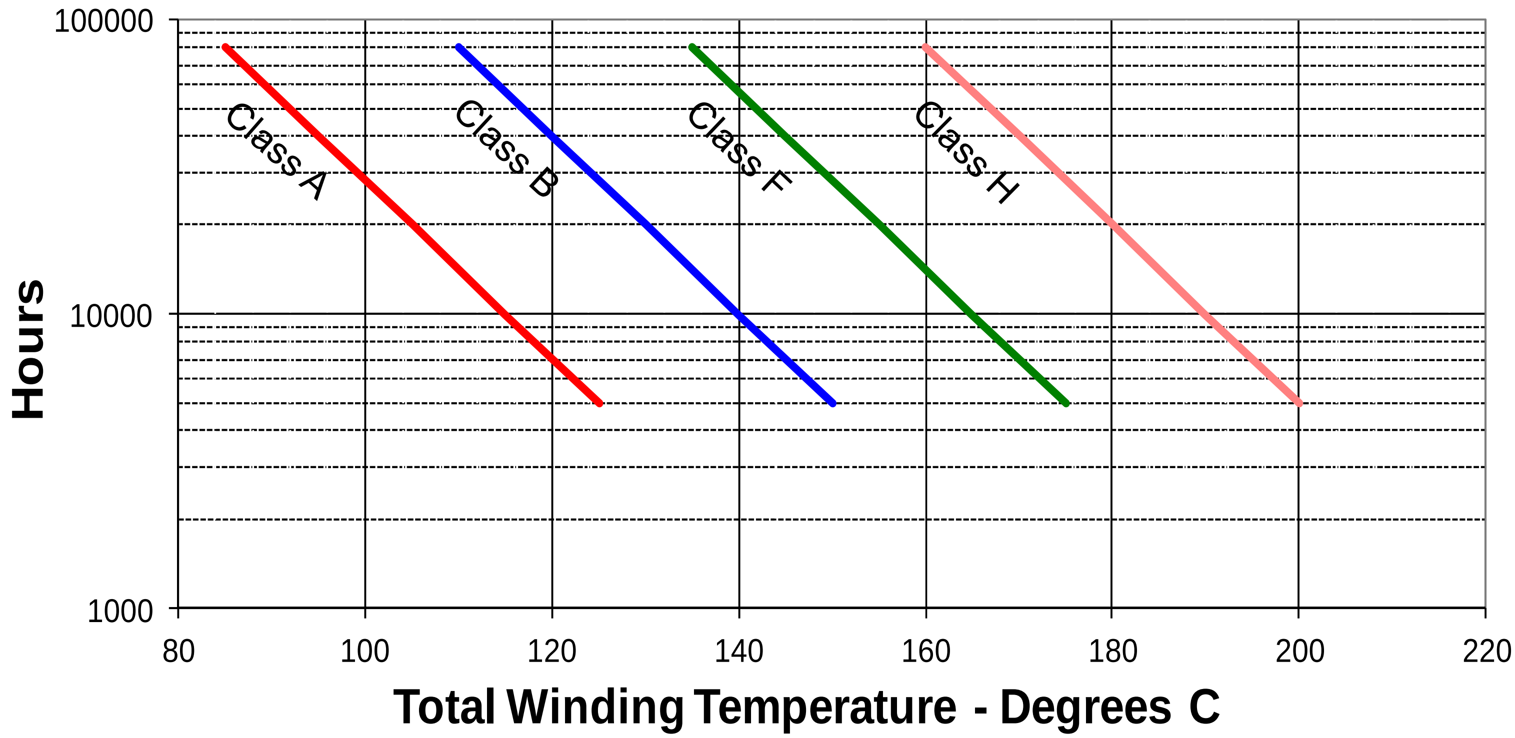
- **IEC60034-1** Table 7
  - For air cooled machines
  - Based on 40°C maximum ambient temperature
  - Limits drop directly with any increase in maximum ambient temperature
  - *(Many variations in IEC – applicable machine parts listed below)*

	Class B		**Class F**		**Class H**	
	R (K)	ETD (K)	R (K)	ETD (K)	R (K)	ETD (K)
AC Windings >5 MVA	80	85*	105	110*	125	130*
AC Windings 0.2-5.0 MVA	80	90*	105	115*	125	135*
Field Windings	80	-	105	-	125	-

** 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

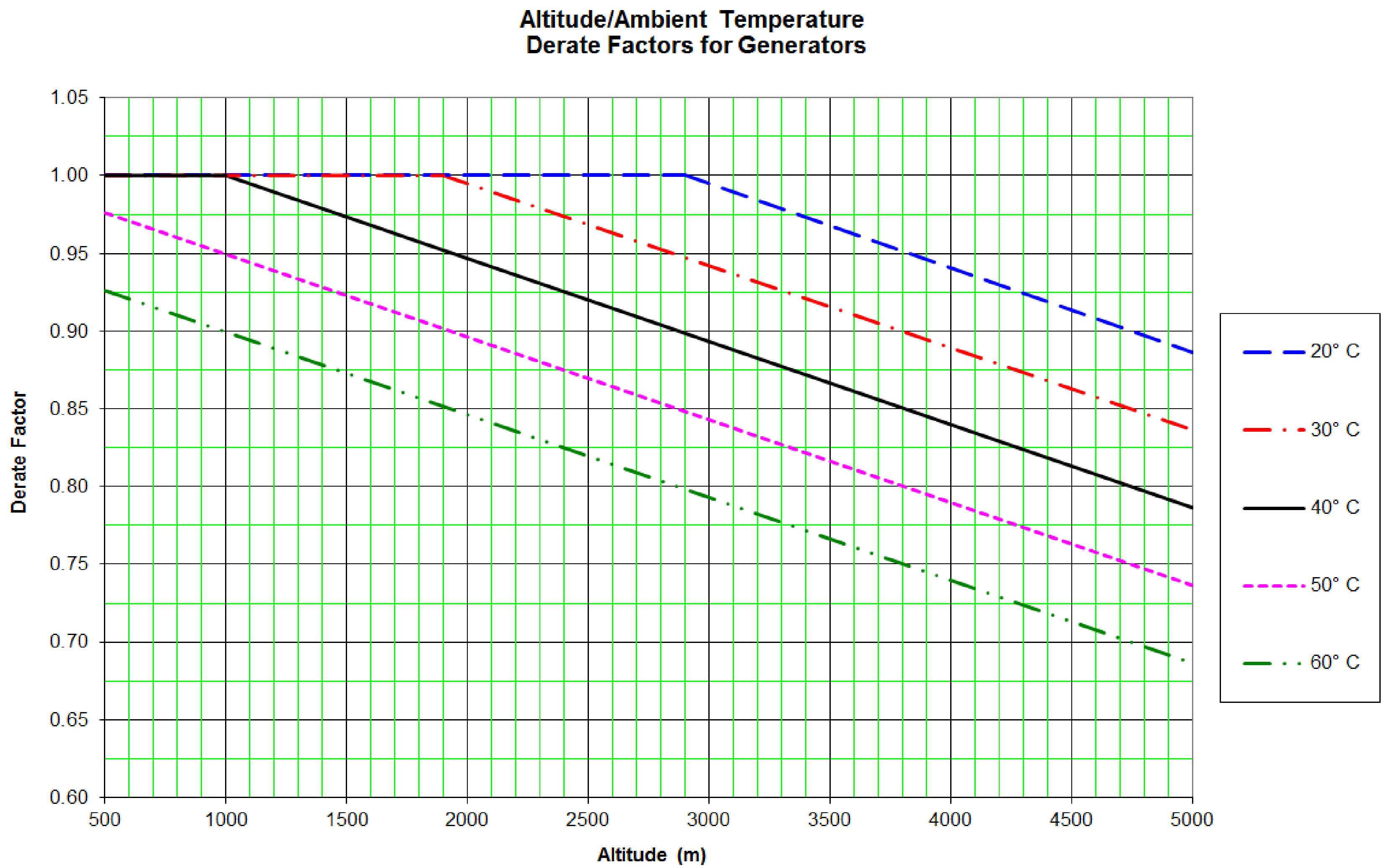
- Per IEEE 117 and 101
- Determined by testing samples at elevated temperatures, cyclic stresses (including vibration) and high humidity.
- 10º C rule: 2X life for every 10º C the temp is lowered (based on 20,000 hour intercept as the thermal index).



Altitude: Generator De-rate

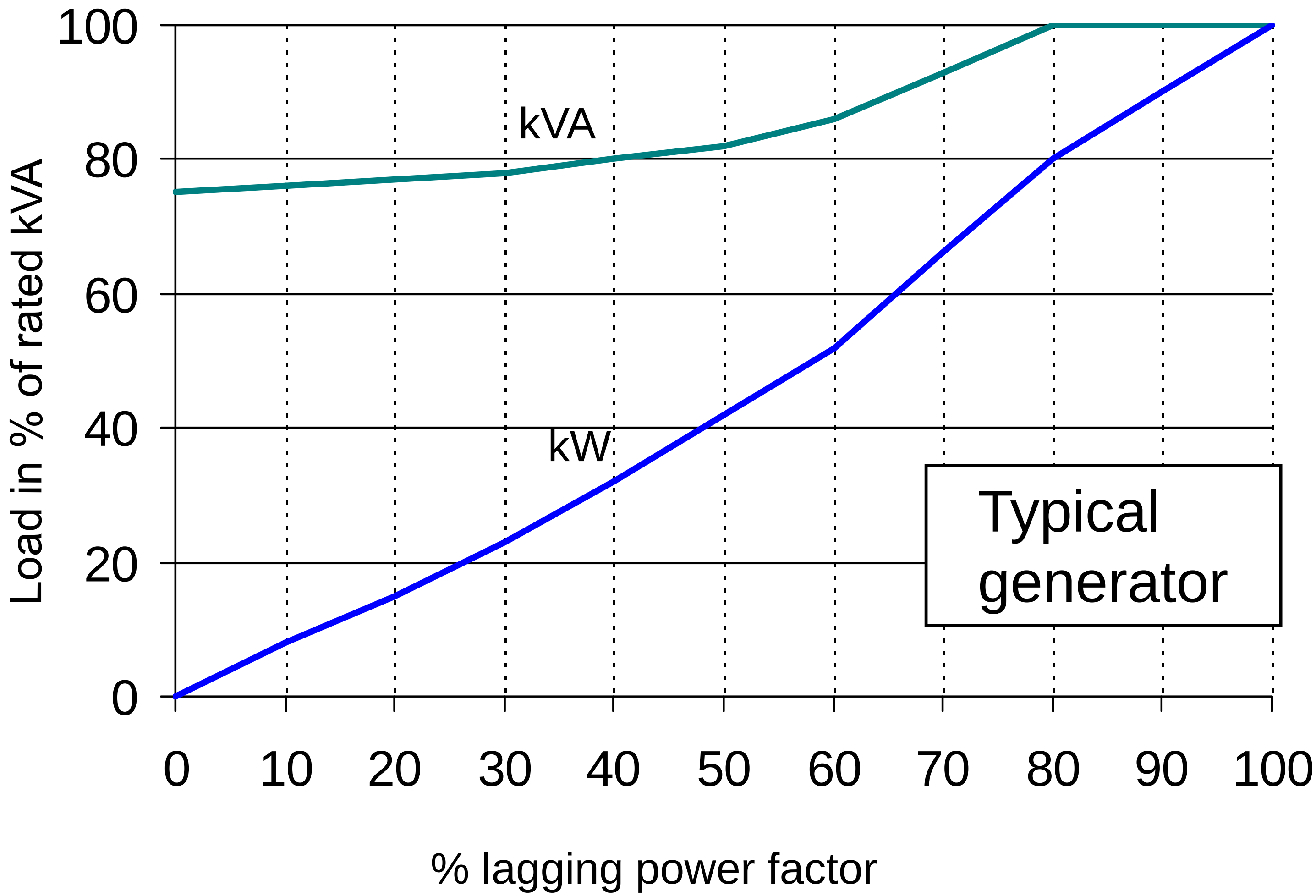
- Generators specifically designed for high altitude may have a larger fan to partially compensate for reduced heat capacity of air, or could be oversized to run cooler under these conditions.
- Reduced ambient temperature at high altitude may partially compensate.

Altitude / Ambient: De-rate Chart

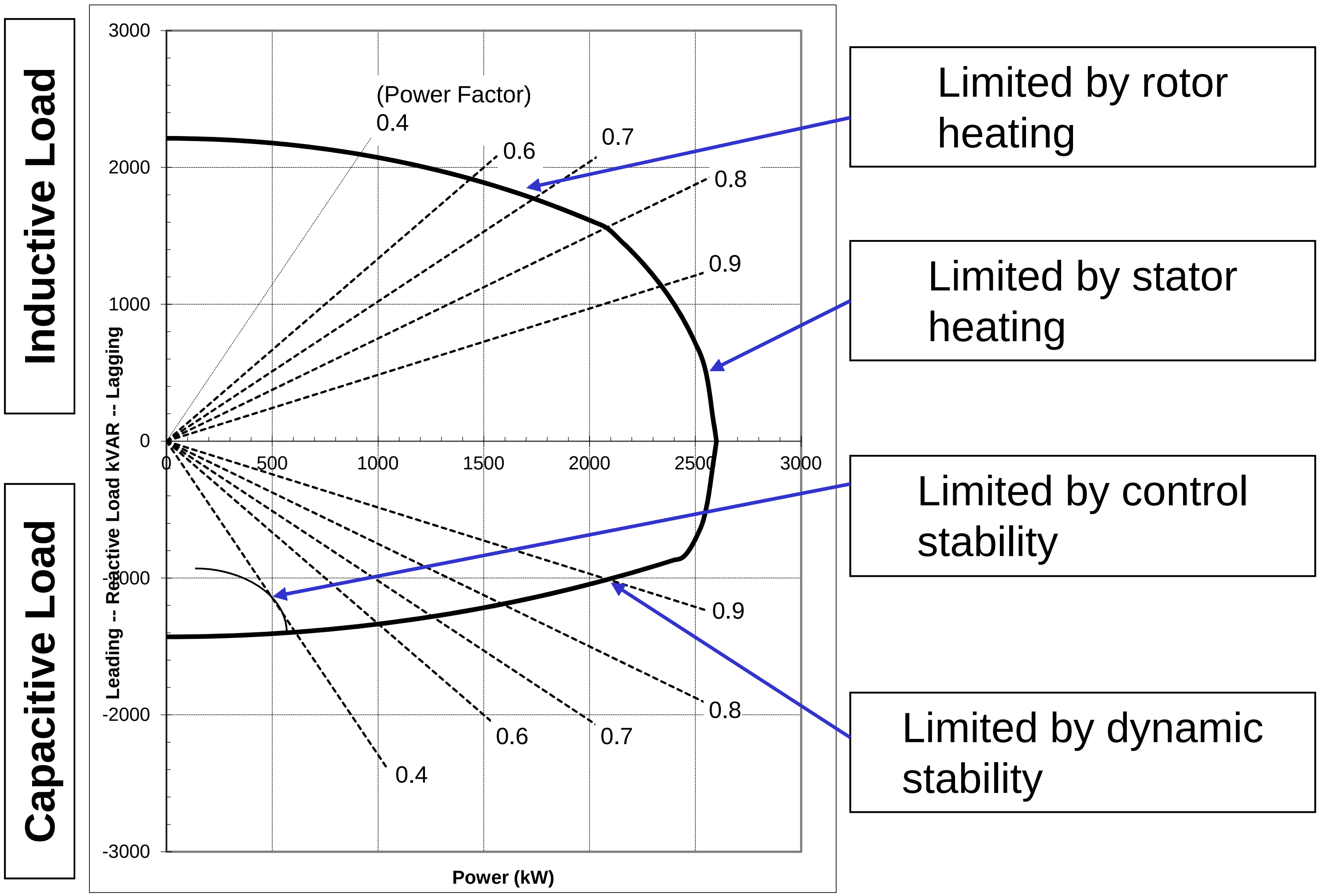


Depends on allowable temperature rise and other factors; actual value may vary.

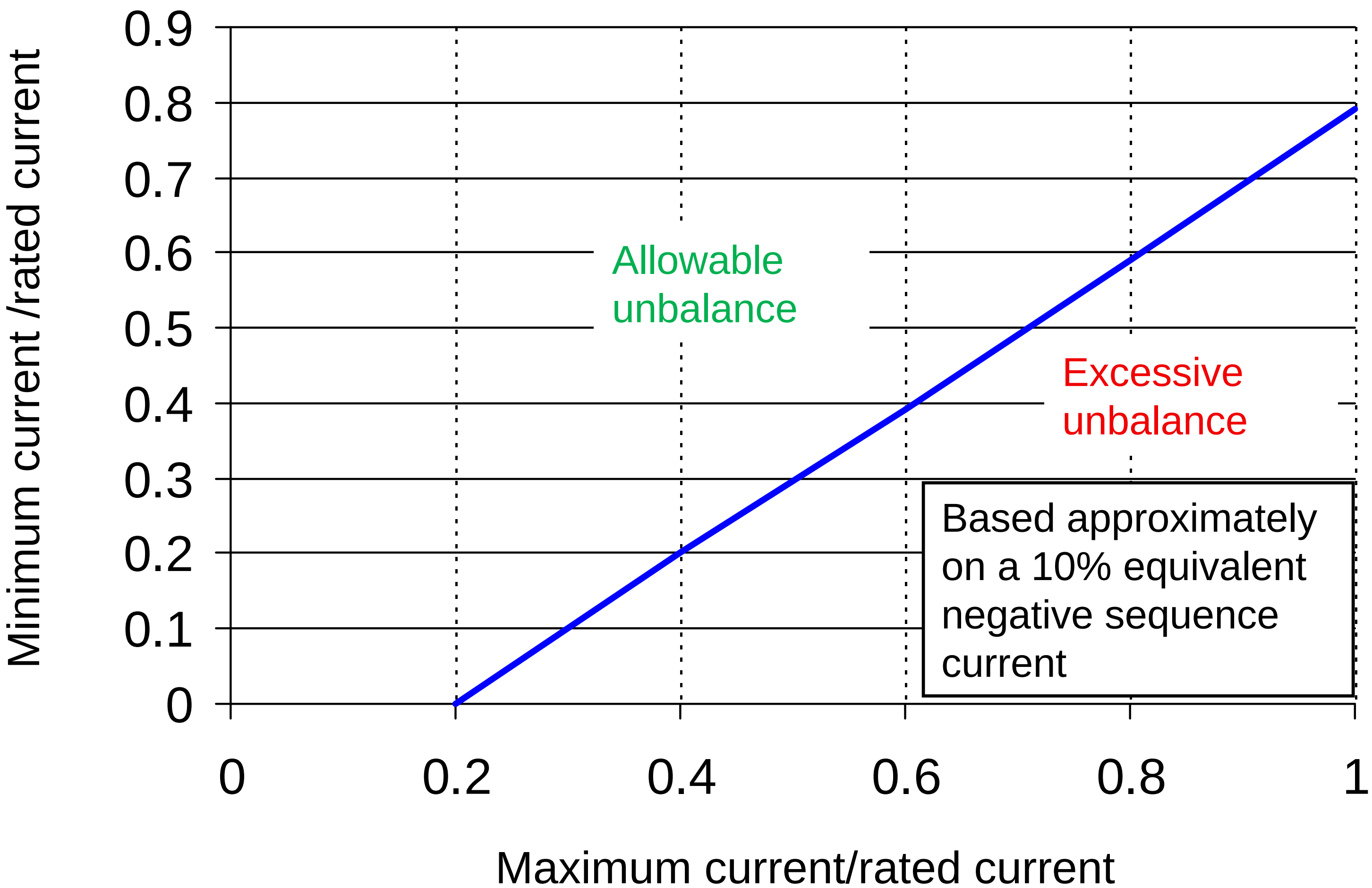
kW and kVA loads vs % lagging PF



Reactive Capability Curve



Continuous Unbalanced Loading



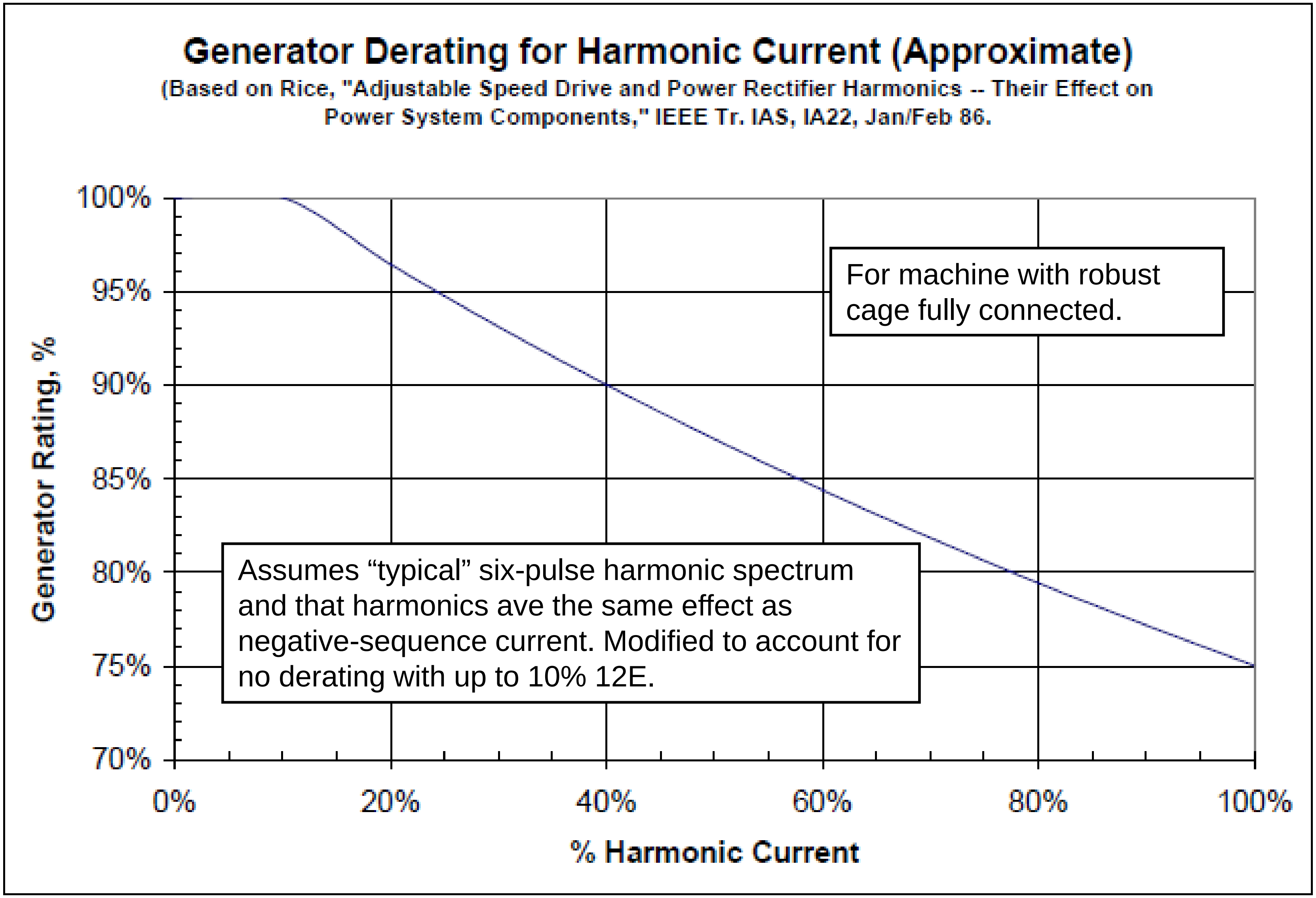
Unbalanced Load

- 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.)



Motor Starting: Examples

- NEMA MG1 32.18.5.3 Motor starting equation

$$\% \text{ Dip} = 100 * \frac{X'd}{X'D + \dfrac{\text{Base kVA}}{\text{Starting kVA}}}$$

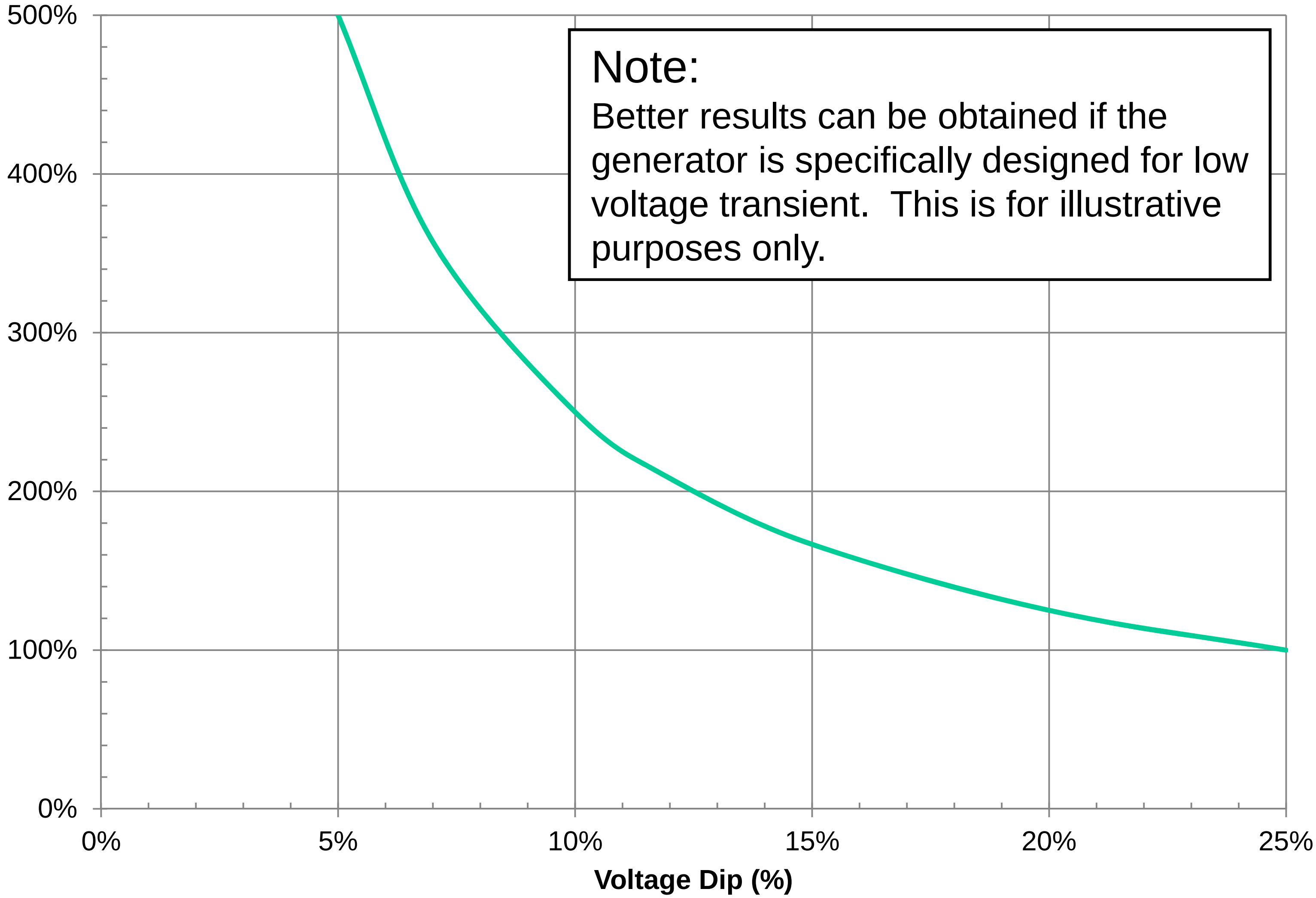
Where X'd is in per unit of the KVA base

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%

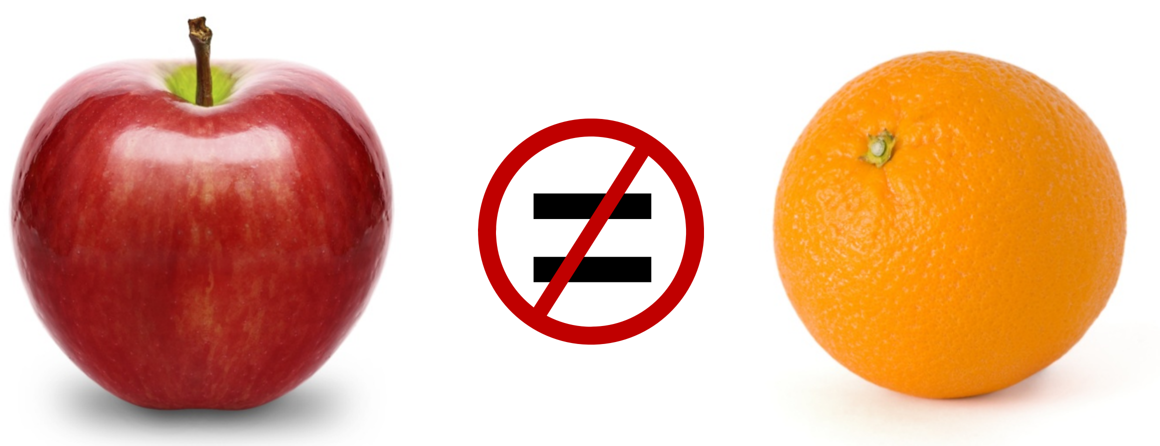
- Note: To reduce the dip, reduced voltage starters can be used. Engine transient response will add to this dip, but the engine response is usually much slower than the generator. This assumes a very low starting power factor.

Generator Size vs. Required V Dip (%)



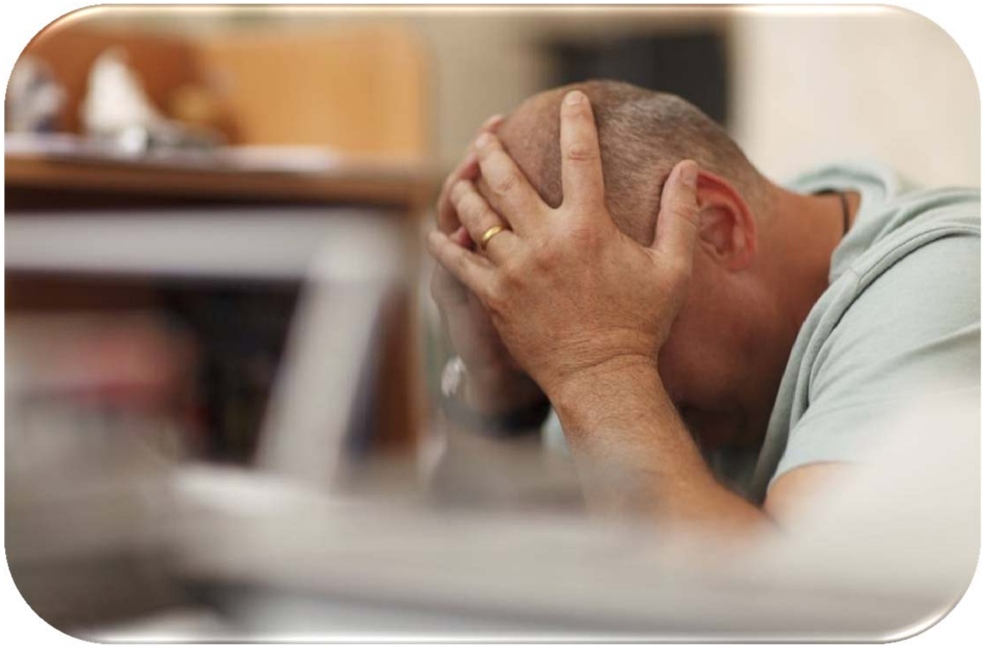
Design Comparison Keys

- 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.