Concepts to Reality:

Creation of a cost-optimized Variable Frequency Drive System

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Reasons for VFD’s - Motor Starting – Green Energy

- Motor DOL start inrush causes grid “flicker”, momentary system voltage sag, mechanical impact
- “green energy” govt mandated
- Wind and solar (wide distributed generation) to replace coal
- Eliminating large spinning mass of large generators, inertia
- Motor DOL flicker has to worsen, no inertia in wind or solar
- Marginal softstart applications likely to exceed flicker limits

Need For VFD's in Industry

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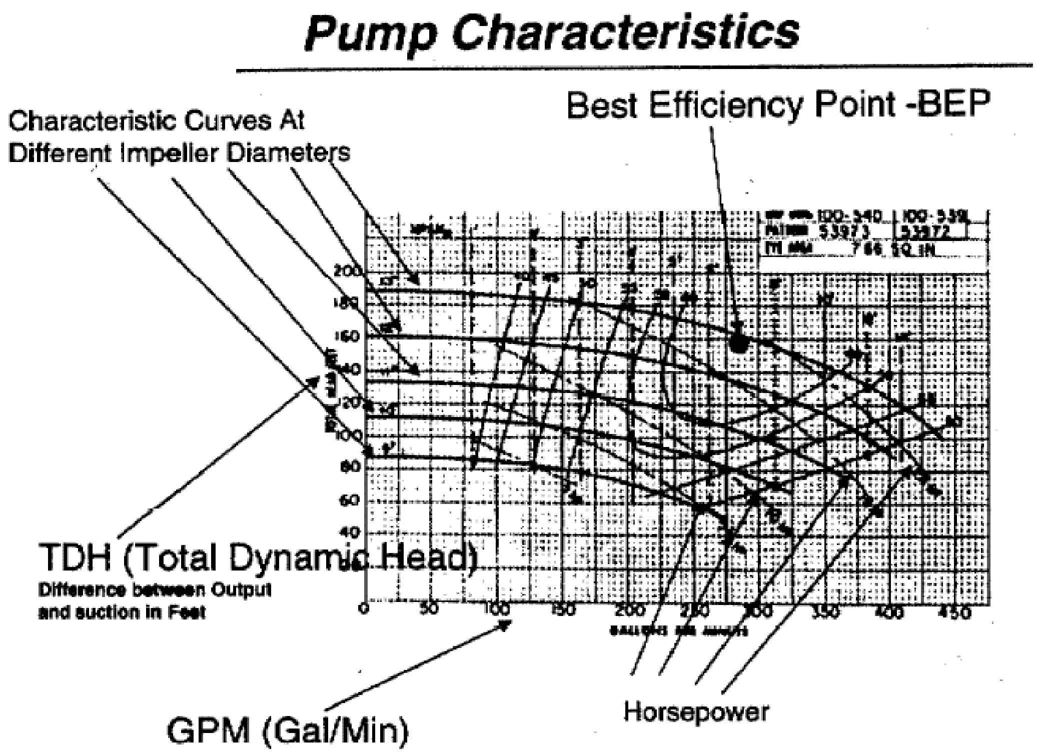
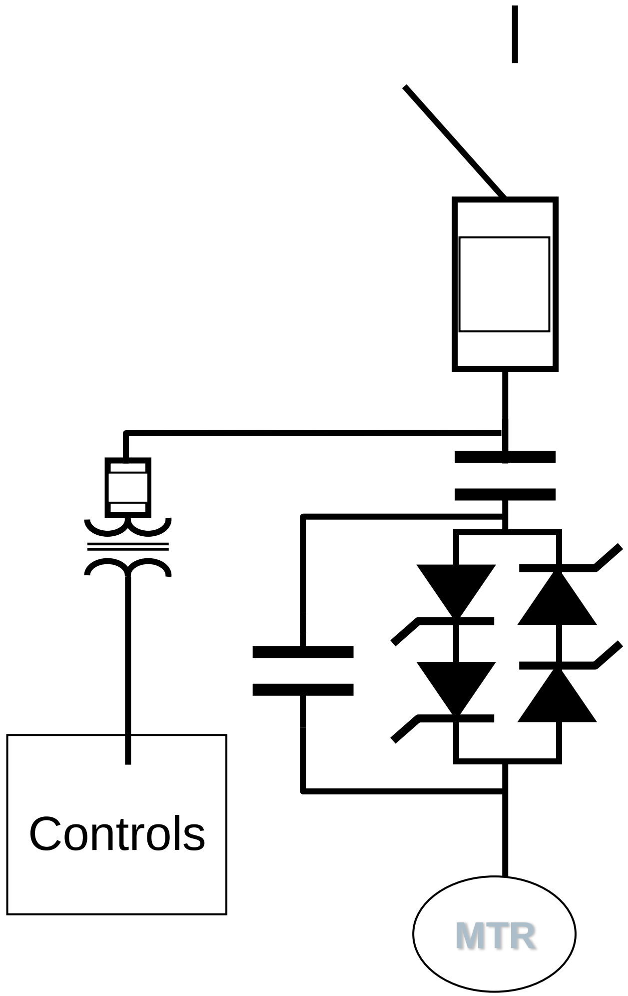
- VFD controls motor speed
  - Control Process
  - Energy Savings
  - Reduce Maintenance
  - Reduce utility flicker
- Currently the only viable technology for SCIM
- Mechanical speed control methods - waste power, maintenance.
- Carbon tax/cap and trade increase OPEX of mechanical speed control



Reduced Voltage Soft Start

- SS Soft starter reduces voltage magnitude, wave chopper
- Voltage magnitude ‘ramps” from zero, but frequency is still 60hz from zero speed
- Torque directly related to square of voltage magnitude applied
- 50% volts = 25% LRT
- torque limitation, motor won’t start turning until voltage reaches the level required to produce enough torque to overcome motor/load inertia and break free.



VFD Principle

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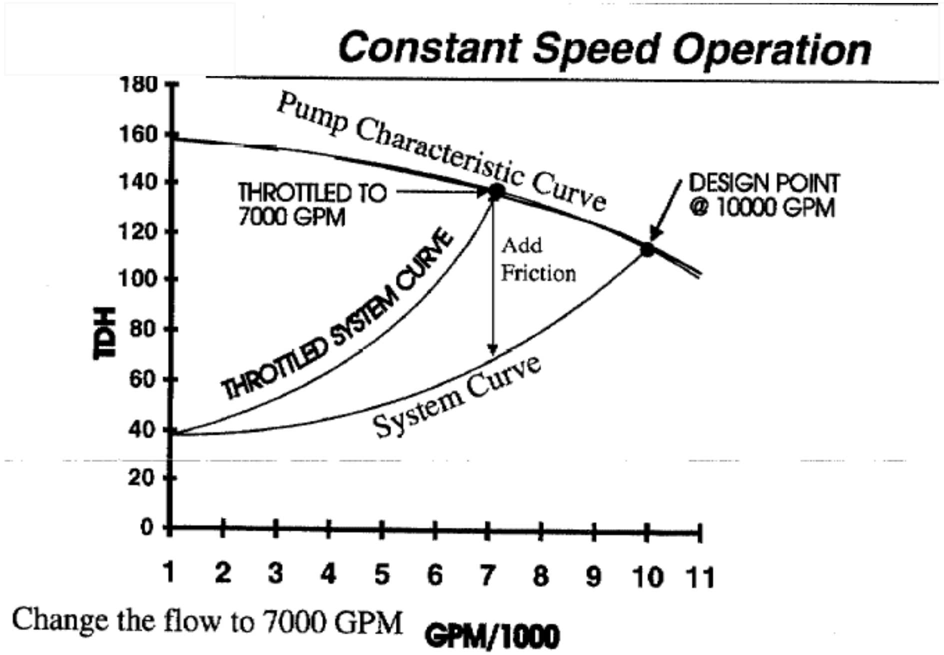
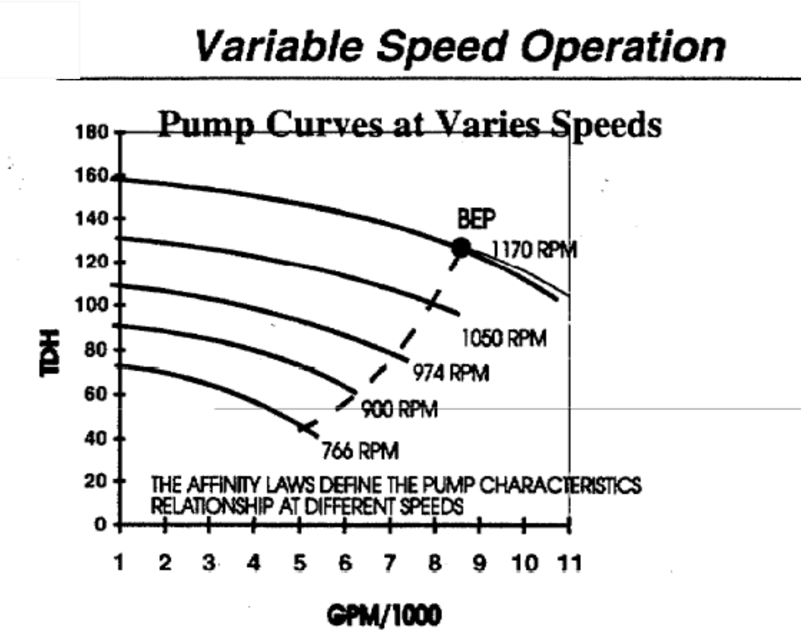
- VFD controls motor speed by varying frequency, S=120 x F/P
- Linear ramp V&HZ from zero speed, no mech/utility impacts





- Carbon tax effectively **<u>doubles</u>** cost of energy, at minimum
- Still taxed even with self-generation

Cost vs HP for MV VFD and Motors

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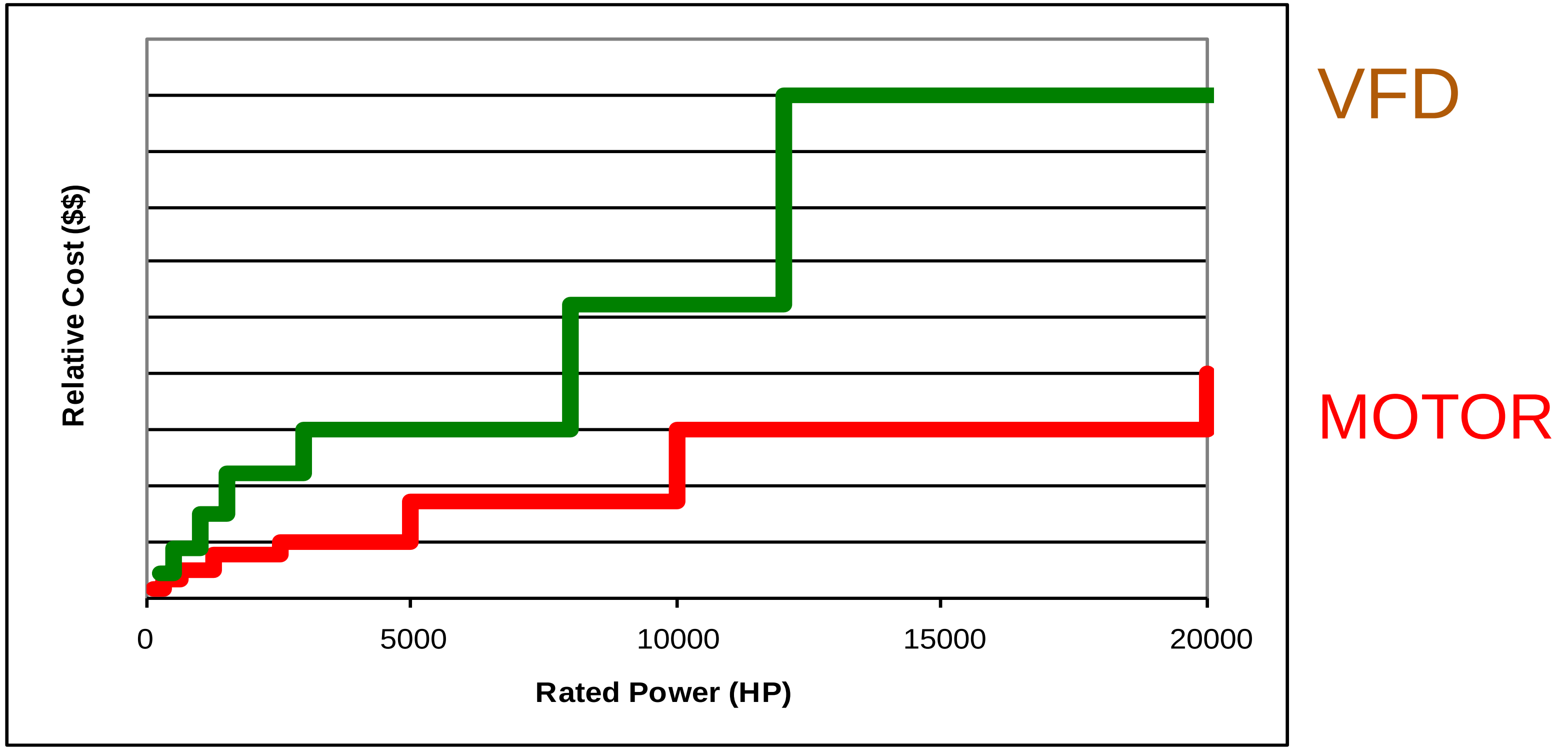
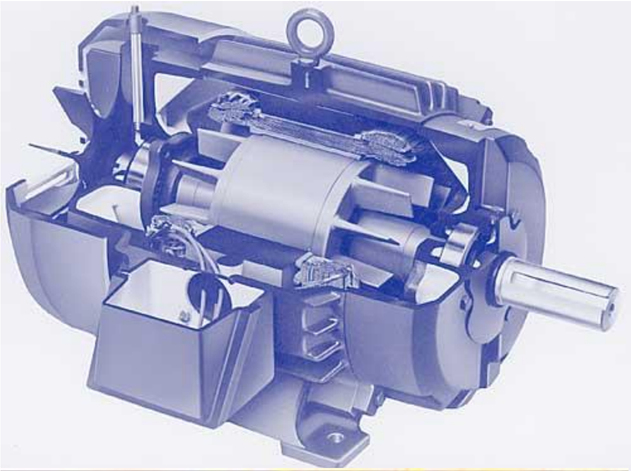
- VFD TIC (total installed cost) far exceeds motor TIC cost
- Tailor motor to VFD topology for relative cost impact



Specification Points for VFD

- MV motors are Engineered, there is no standard MV motor above NEMA
- 4160, 6900, 13,800 are *distribution* voltages
- Motors usually selected independently, with or without intent of VFD in final design
- Historical reasons
- VFDs are ~**2-3x** motor TIC when done right, **4-6x** when done wrong
- NEMA MG1 Part 31, IEEE1566, Overload spec, Motor Voltage and VFD cooling impact CAPEX/OPEX



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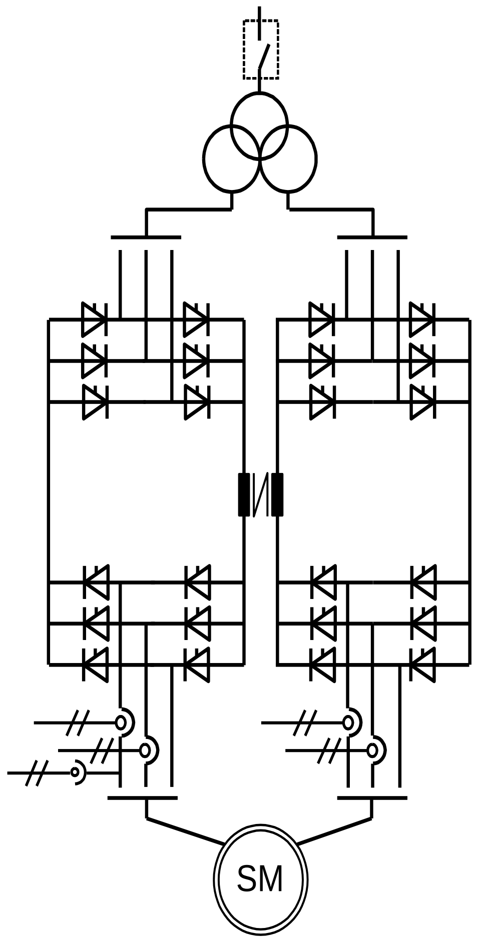
Influence of Motor Voltage on VFD Design

- VFD’s add devices in series to increase output voltage rating, multi-level
- Can use EHV devices, less “levels”- motor impact
- Higher voltage generally means;
  - Increased parts count in VFD design
  - Larger physical VFD size
  - Larger building and plot plan allowance
  - Higher CAPEX
  - Lower reliability
- VFD topology **must** be considered before finalizing motor selection to minimize cost



Influence of Motor Current on VFD Design

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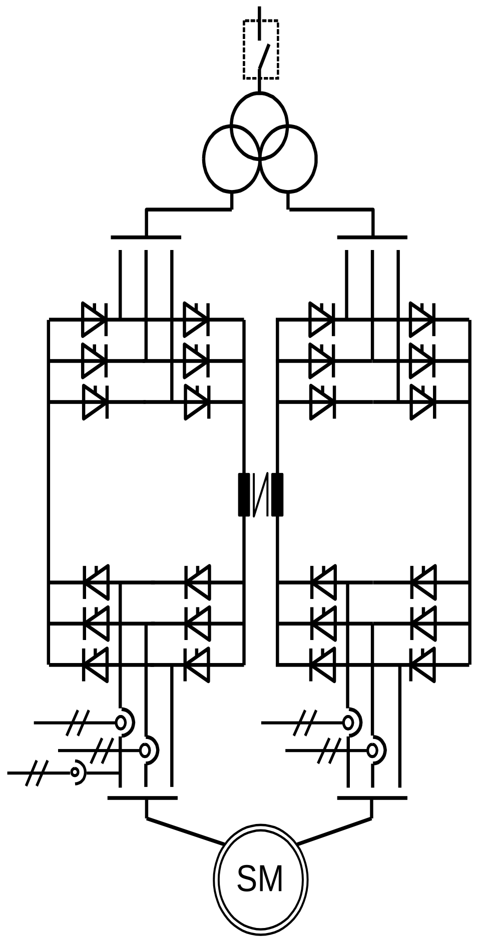
- VFDs rated in Current (Amps) as well as Voltage – Amp “frame” can change physical size
- Drives with fewer, but higher current-rated output devices = lower cost, however, that can result in motor/cable system impacts – take care
- Motor current and application (overload requirements) determines VFD current rating
- Specifications can >current rating which can affect drive cooling system (wide cost delta)



Influence of Motor on VFD Cooling

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- VFDs create significant losses compared to SWG/MCC:
  - Conduction losses
  - Forward switching losses
  - Voltage across switches
  - Magnetic losses
- VFDs can be air or liquid cooled

- Liquid more efficient, moves more heat (24X) but complex
  - greater CAPEX and far more OPEX
- Very large VFDs almost always liquid cooled

Air Cooling Options

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•Conventional: Hot air exhausted into the building and cooled with air conditioning:

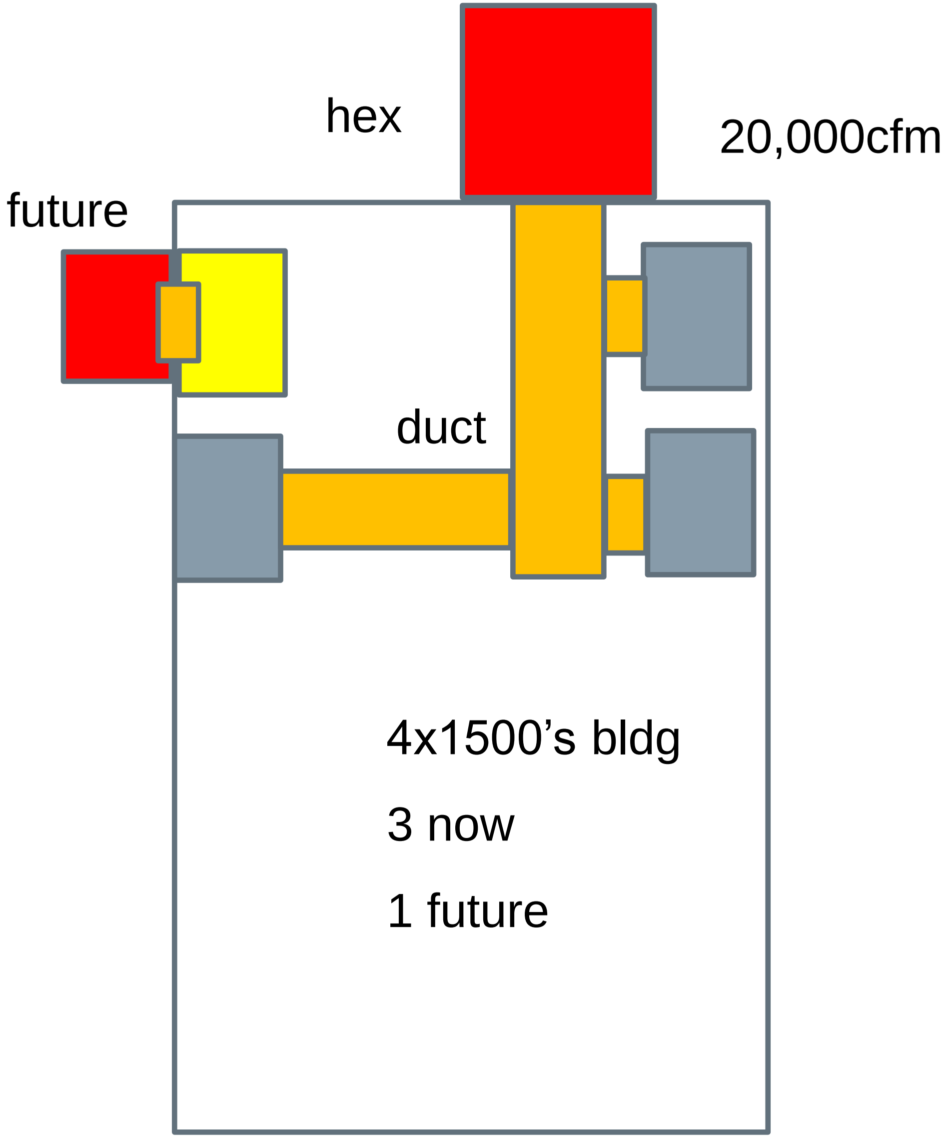
•Duct in/Duct out: Duct hot air outside with make up air unit. Duct hot air inside to heat the building in the winter with temperature actuated louvers. Air mixing box required.

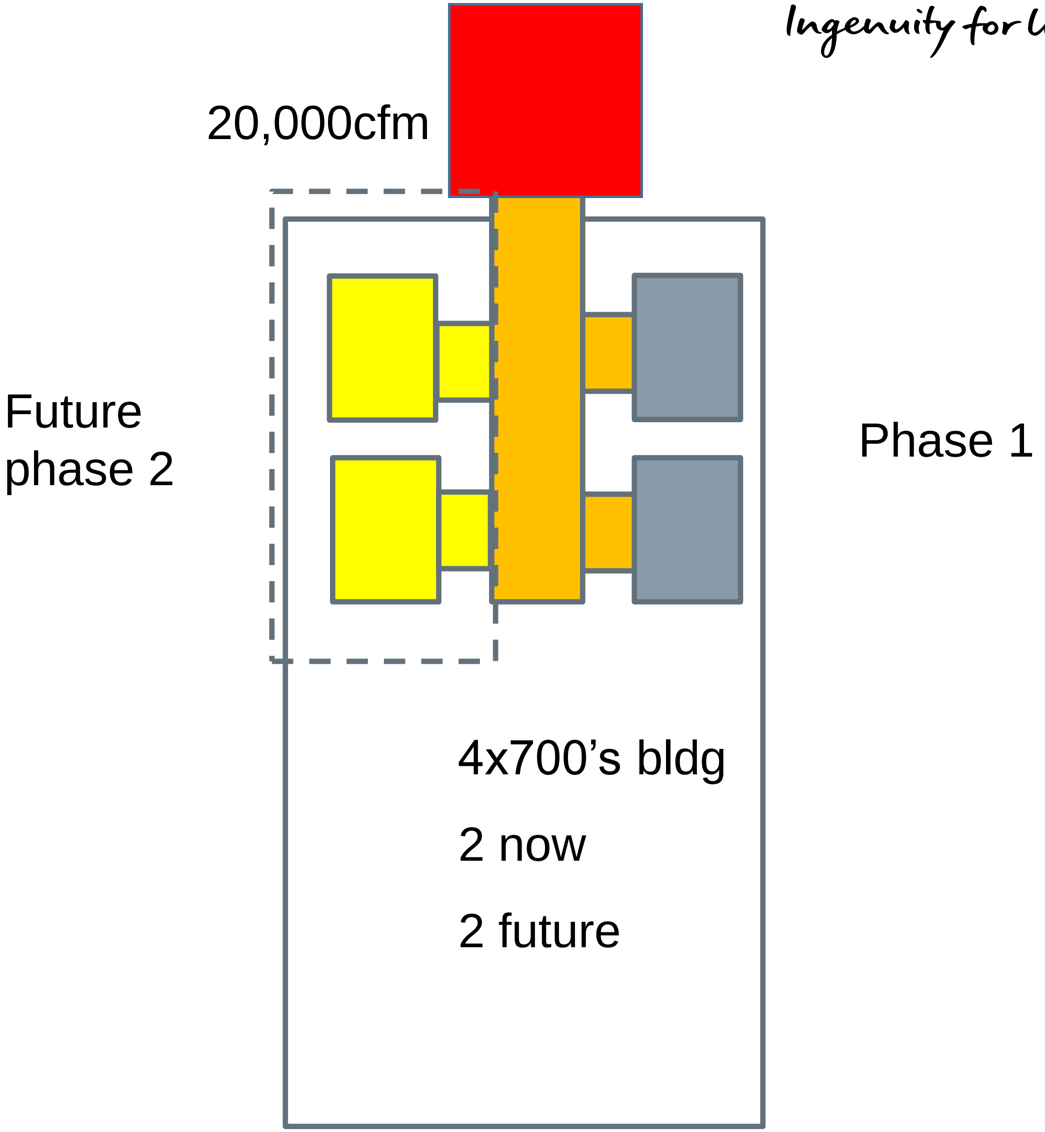
•Air to Air Heat Exchanger: Self Contained <u>Closed loop cooling system.</u> Common hex or dedicated hex.

Influence of Motor on VFD Cooling

- Industry consensus favors air - cost, complexity and maintenance issues
- Air cooling solutions can be;
  - HVAC
    - High CAPEX and OPEX, low reliability
  - Mixing box make up air handling
    - Lowest CAPEX but..
    - Exposes VFD to ambient, contaminants
  - Air to Air Heat Exchanger solutions
    - Medium CAPEX, maintains clean inner loop, lowest *system* OPEX

Common Hex Design to reduce CAPEX

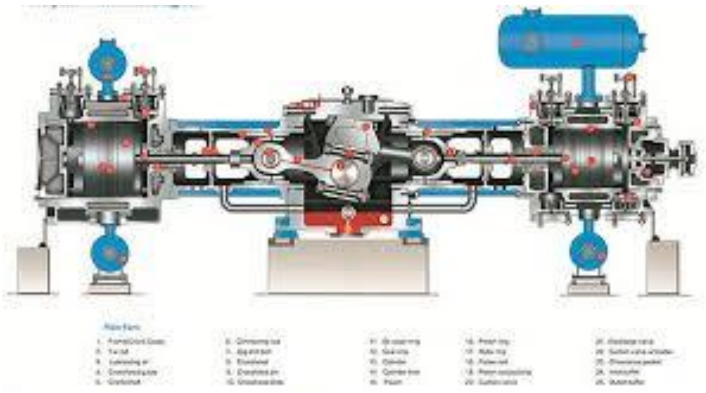




Specification Adherence

- Specifications can multiply load ratings, driving up costs needlessly
- Margin added at every stage of process design, motor typically oversized for application before the VFD is even considered

- Specs can ask for 110% continuous motor *current*, misinterpretation of IEEE1566
- 1566 requires 100% output *torque* at -10% input voltage
- Also asks for 100% output amps with -10% voltage variation and so covers the reasoning behind 110%A



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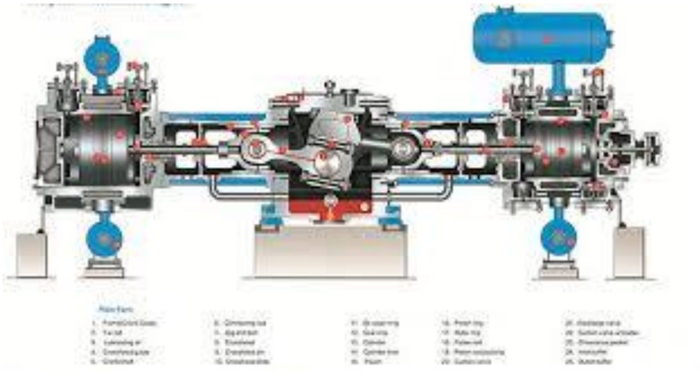
Specification Creep - Constant Torque Loads

- Specifications generalize based on torque profiles
- Eg; VFD's for Constant torque loads "must" be 150% torque capable for one minute
- Recip compressors are constant torque *profile* but start unloaded (<100%) 150% is overkill, $$
- Conveyors, crushers, ball mills; applications that cannot be unloaded to start
- >200% might be needed

- Engineering required!!!
- **Avoid blanket application of specs, can result in undersized equipment as easily as it can result in oversizing**.



Influence of NemaMG1 Part 31 (Inverter Fed IF) on Motor Design

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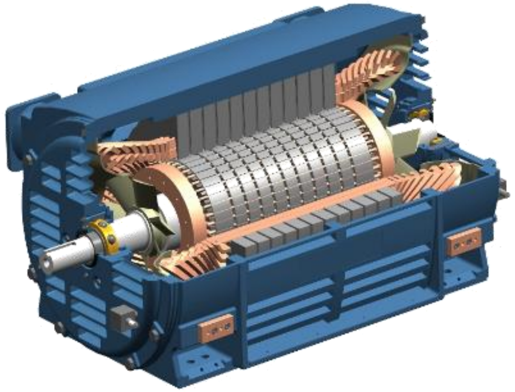
- NEMA defines IF motors by:
  - >insulation, 2.04 PU for MV
  - >metal in the rotor and stator
  - Elevated requirements to protect bearings
- IF Motors have a 1.0SF on VFD, 1.15SF on utility or “clean” waveform
- Insulation may not fit in slots requiring jump to larger frame for same HP
- Extra copper and steel for VFD-induced harmonic heat can also cause a frame jump
- Add cost to the motor, 5- 25%

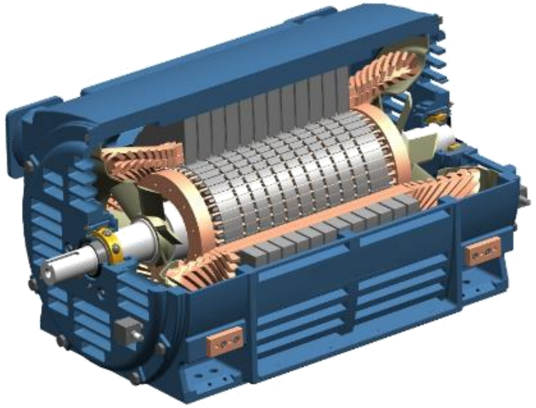


NEMA MG1 Part 31 Motor Efficiency

- VFD motors typically purchased to start DOL as well
- Motor then has max application flexibility but..

- Also has maximum cost and minimum efficiency as motor has additional copper and steel in stator/rotor to meet DOL locked rotor conditions

- Non-inverter motor for VFD operation and no DOL start saves CAPEX as well as OPEX



Nema MG1 Part 31 Inverter Motor VFD Compatibility

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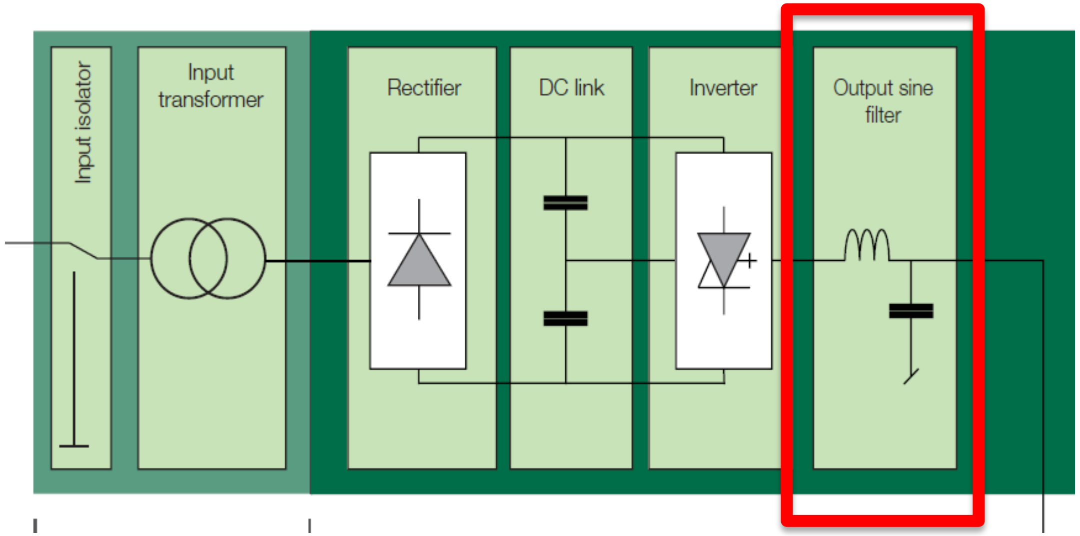
- VFDs claim safe for “standard” motors, ie. non-VFD rated
- Most include output filter, if failed- motor may be damaged
- Filters = losses, point of failure, reduction of motor control
- These topologies aren’t **inherently** or **intrinsically** safe for motor



- NEMA defines the harmonic voltage factor, “HVF”, for each topology
- If HVF is below 0.03 the VFD is “safe”

Motors for VFD Start Only – Efficiency Gain to Offset CAPEX

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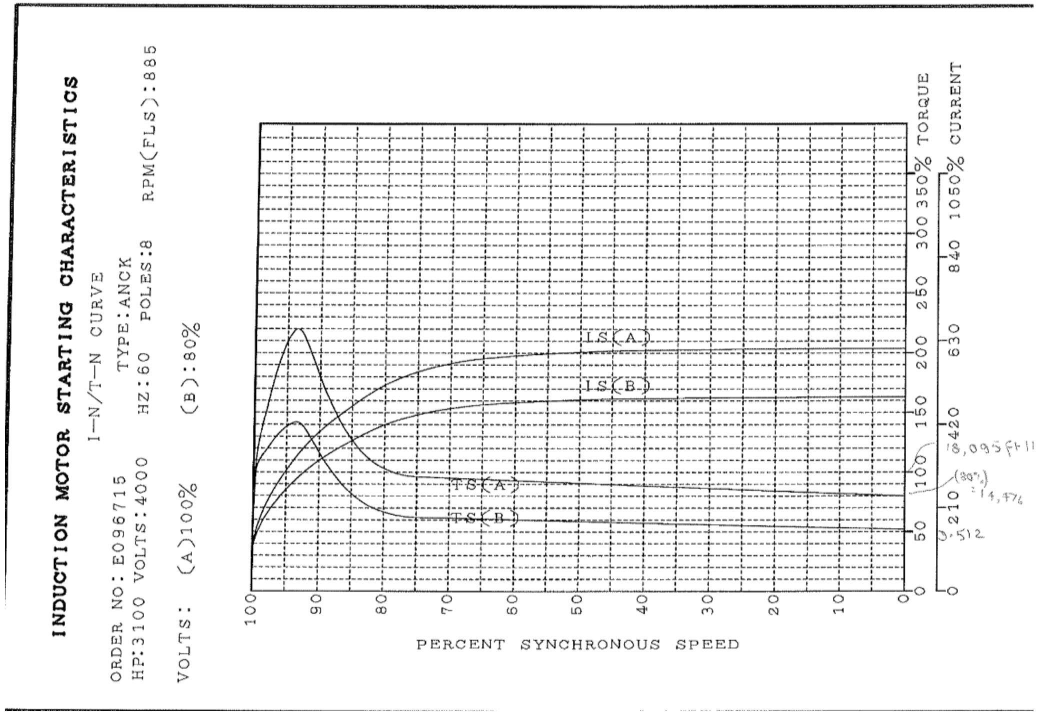
- Motors can be designed for VFD start only
- VFD only motor has less copper/ steel
- Don’t need to develop LRT at zero speed
- Higher motor efficiency offset some VFD losses

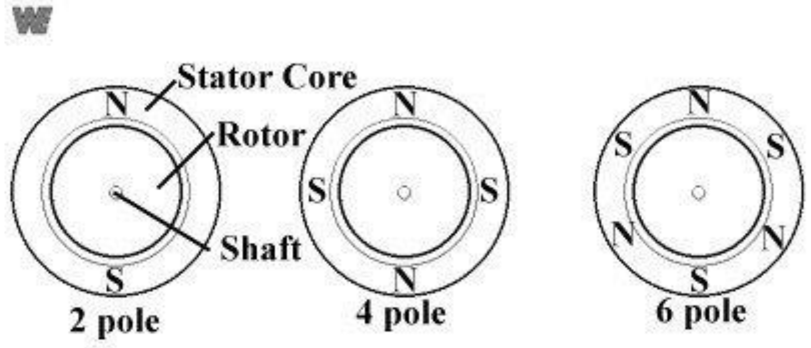


- 5000hp motor, ~1% efficiency gain, 8000hr/year/20 years with $40/MWHR effective power cost, ~$300k power saving, doubles with carbon tax
- Small change saves >double motor cost

Motor Design Savings
Pole Optimization

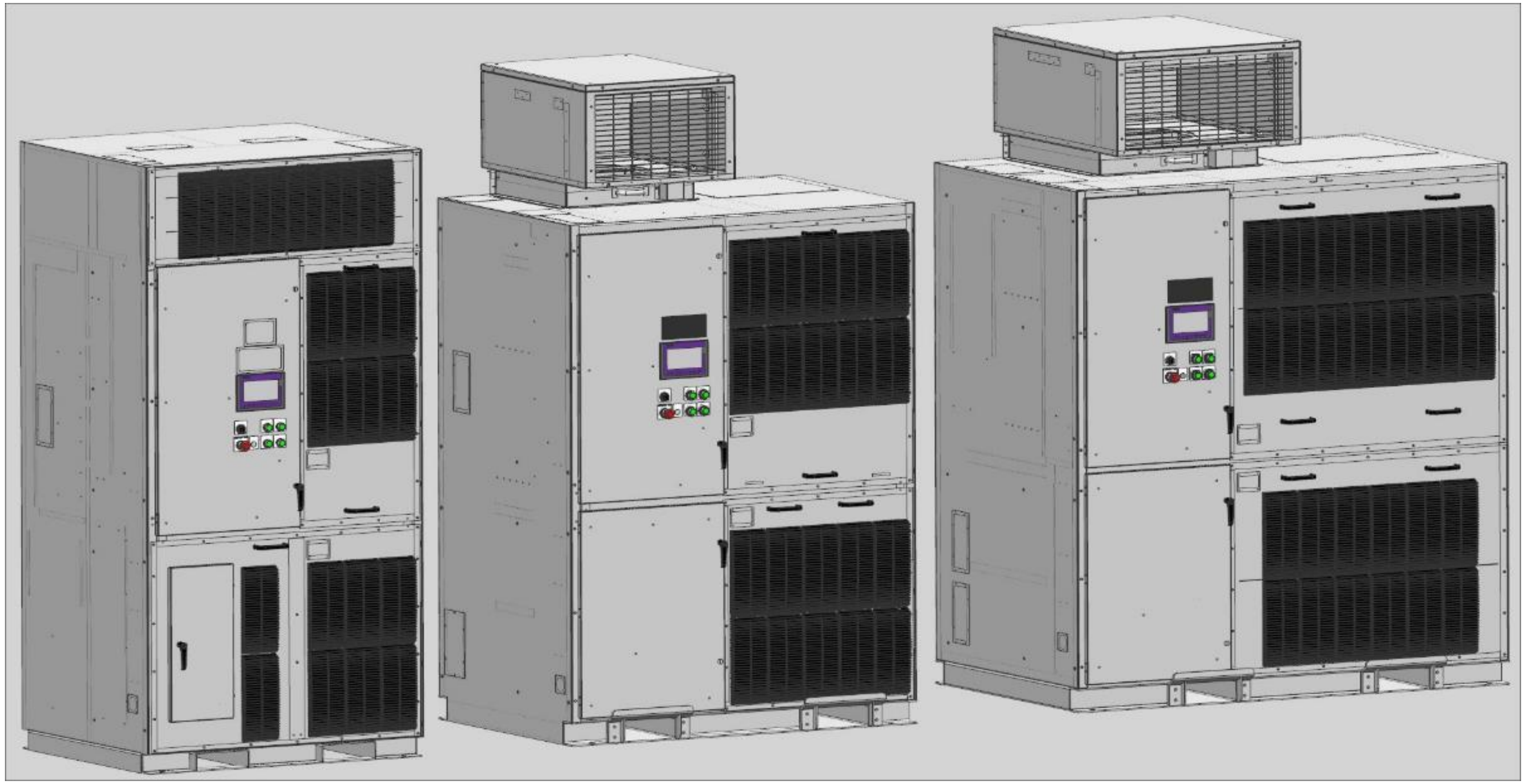
- Slow speed applications eg; slurry/hydro-transport
- Max 350-450rpm, VFD for varying speed
- Increase #poles to reduce motor full speed, 120xF/P
- 360rpm means 20 pole at 60hz, huge
- But VFD means max frequency *does not need to be 60hz*
- 10 pole/30hz or 8 pole/24hz
- Significantly smaller, <CAPEX

- Most VFD’s have minimum continuous output HZ – be aware derating may be required



VFD Updates

- GH180 40A-70A (48”), 100-140A (60”), 200-260A (75”)
- 54 pulse input, no input/output filter, Cell By-pass.
- Outdoor Drives



Conclusion

- VFDs will become more common. Climate change/energy savings concerns will increase the need and # of applications.
- Misapplication of specifications and/or failure to apply Engineering principals can greatly increase VFD TIC.
- VFD topology can significantly reduce motor CAPEX/OPEX.
- Considering VFD topology before specifying motor can significantly reduce total project CAPEX and OPEX
- Failure to do so can cause projects to be scaled down or even cancelled, the horror!!

Questions?

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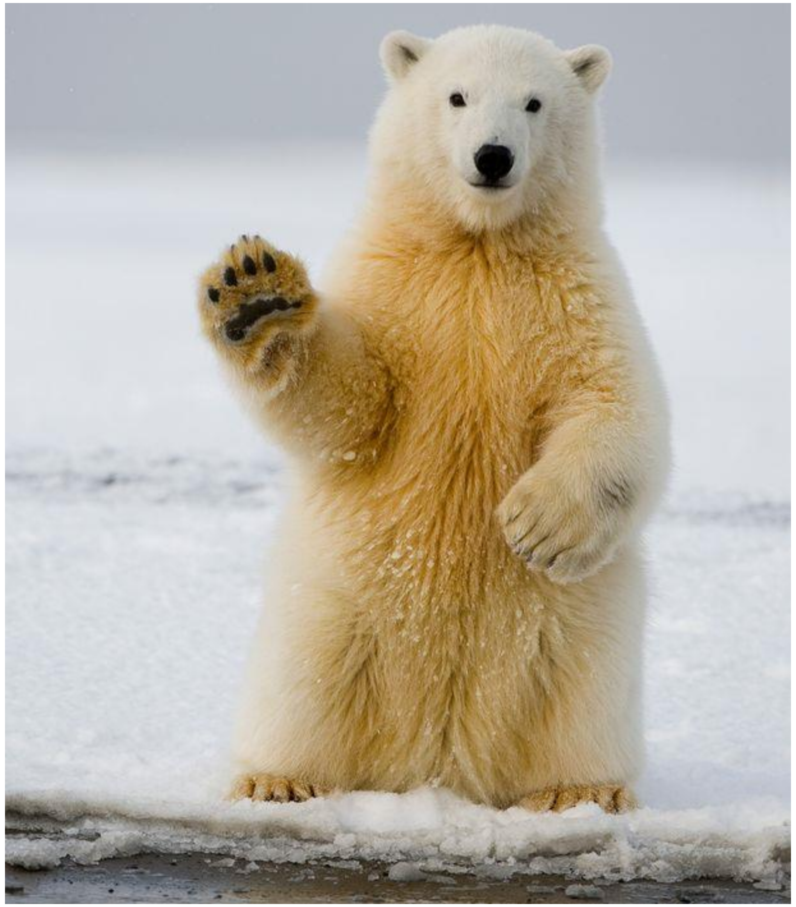
- Use VFD’s

- Save Polar bears



Thank you

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