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

• 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

![Pump Characteristics](image-url)
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

• VFD controls motor speed by varying frequency, \( S = 120 \times \frac{F}{P} \)
• Linear ramp V&HZ from zero speed, no mech/utility impacts

- Carbon tax effectively **doubles** cost of energy, at minimum
- Still taxed even with self-generation
Cost vs HP for MV VFD and Motors

- 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
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

• 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

• 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

• 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 Closed loop cooling system. 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

Future phase 2

Future

Phase 1

Future

Common Hex Design to reduce CAPEX

Future

Phase 1

Future

Common Hex Design to reduce CAPEX

Future

Phase 1

Future

Common Hex Design to reduce CAPEX

Future

Phase 1

Future
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
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

• 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

- 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

• 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?

- Use VFD’s
- Save Polar bears
Thank you
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