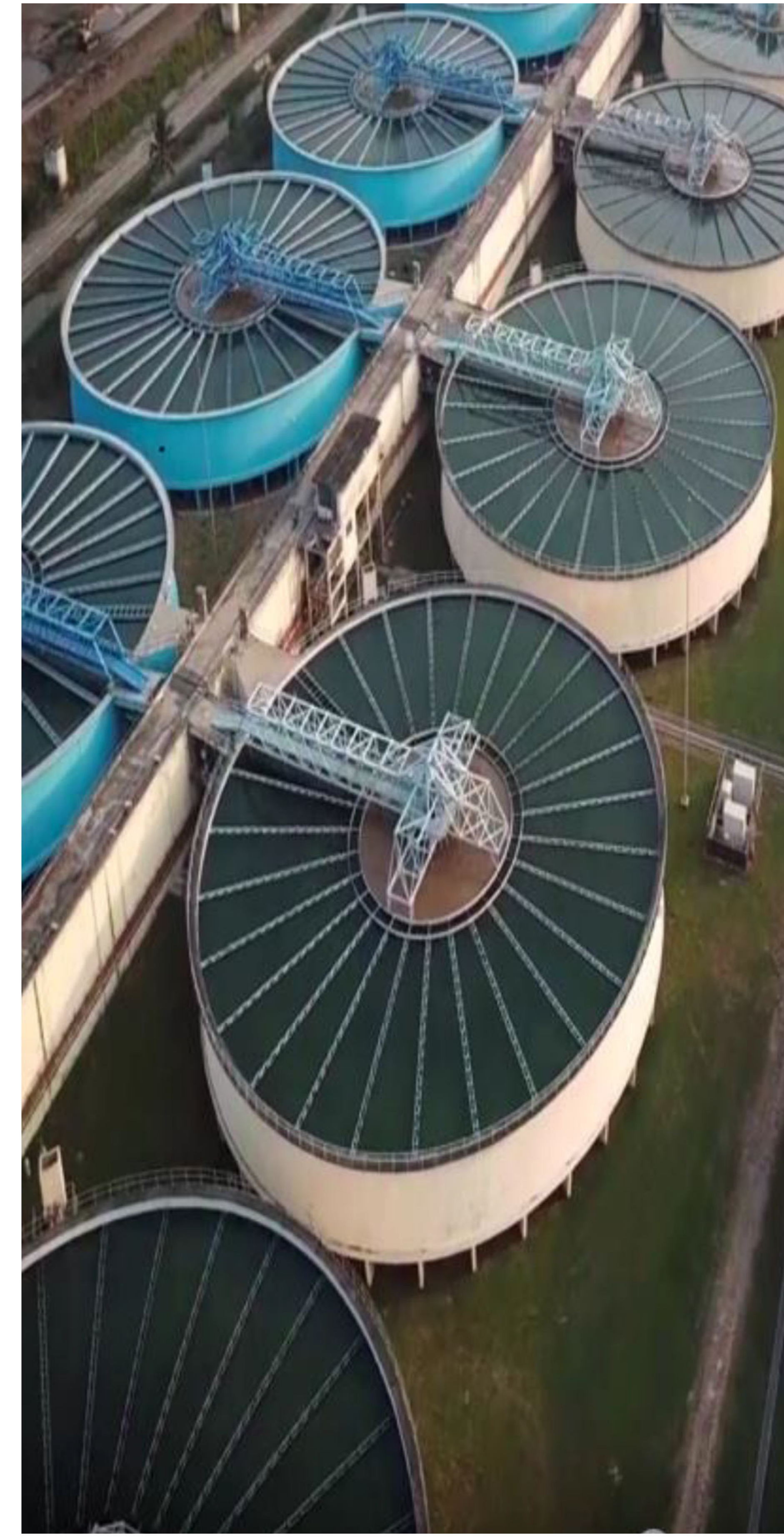
Key Considerations when selecting Medium Voltage AFD for Water/Wastewater Applications

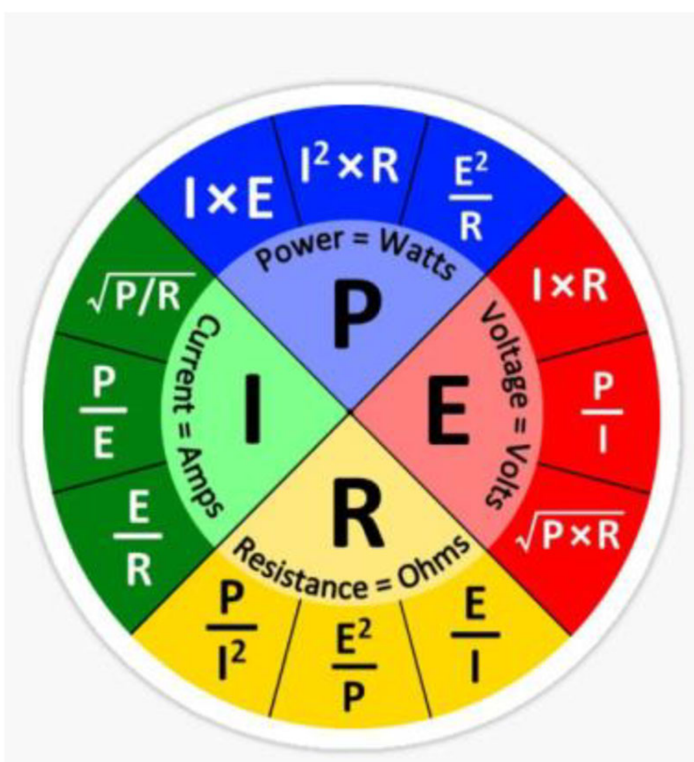
Presented by Biju Cherian
PE , SMIEEE,

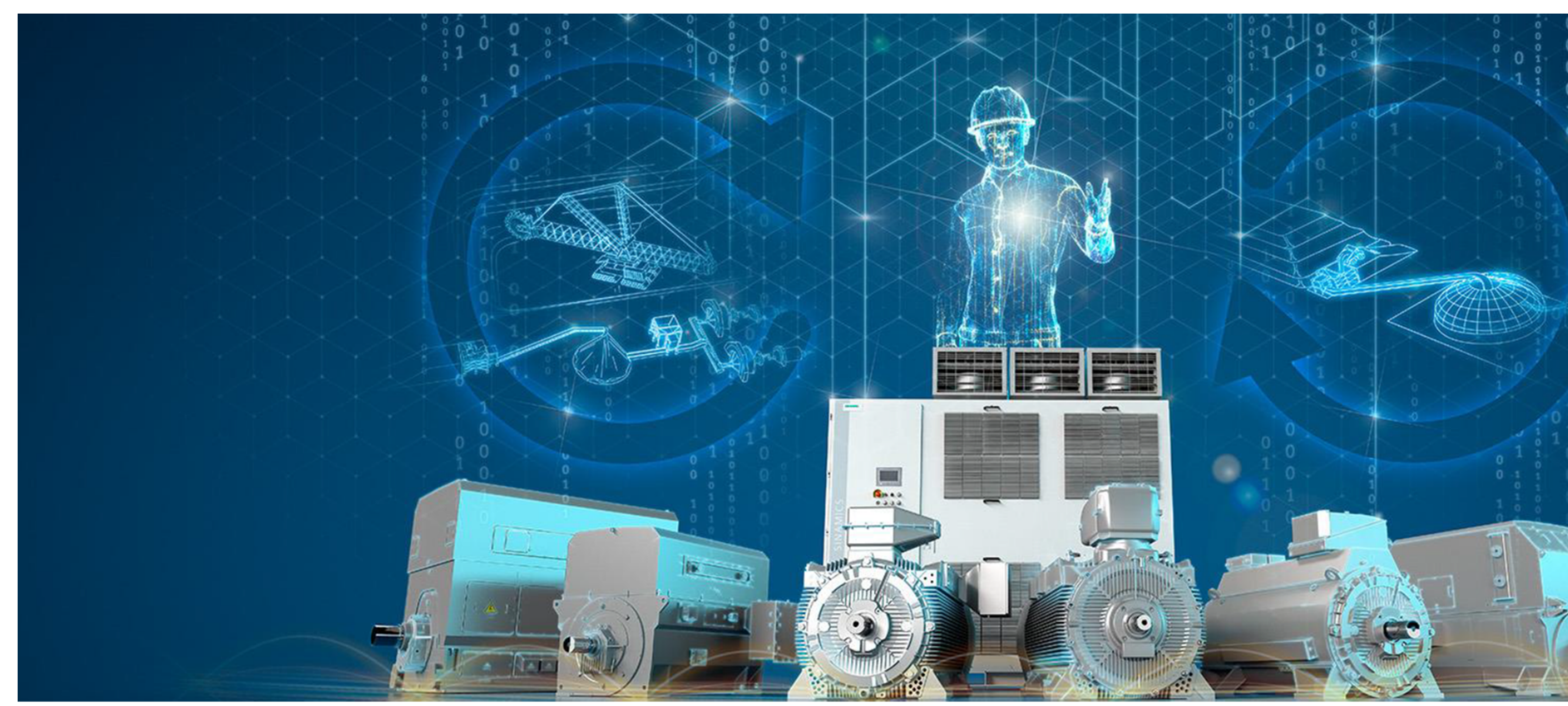
North Texas Municipal
Water District



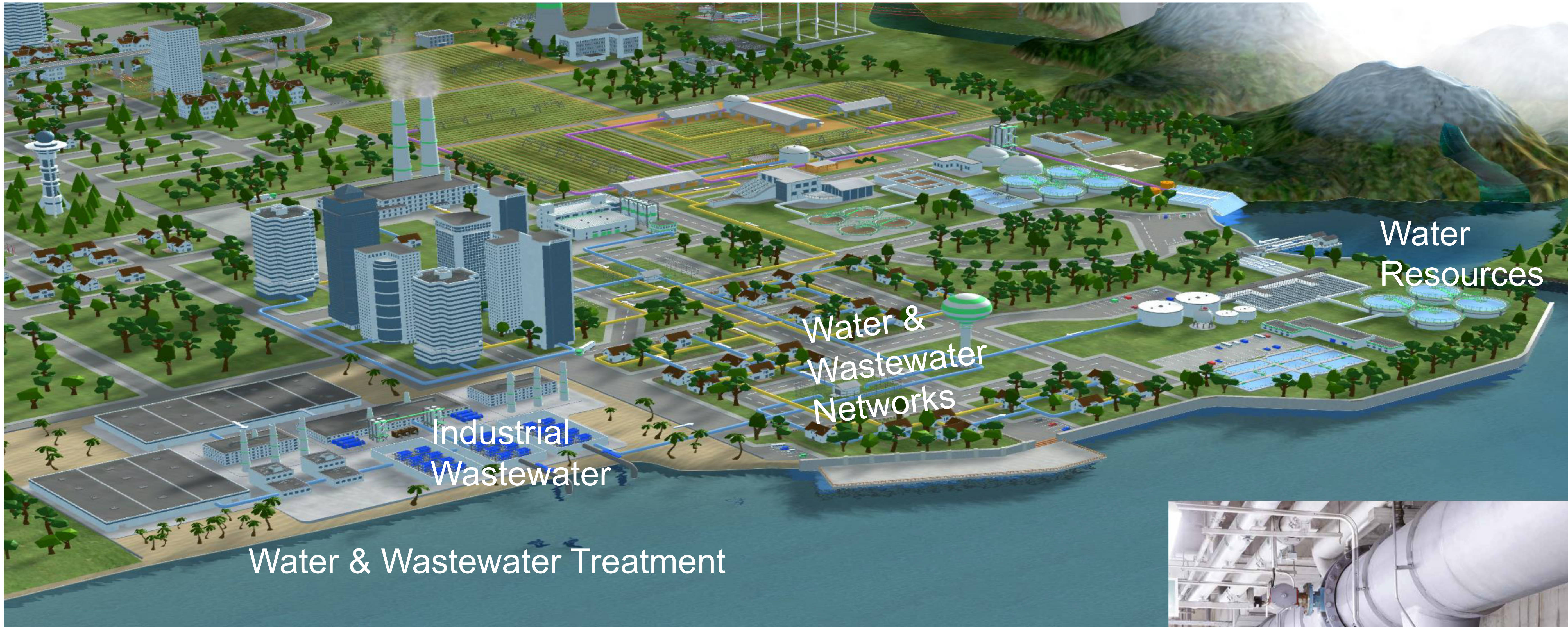
Objectives

- General understanding of Electrical power distribution in regional water Transmission & Waste water Conveyances.
- Key considerations when selecting MV AFDs for water and wastewater industry applications.
- MV AFD & its benefits for Lifting /pumping in water waste water industry
- AFD application overview & installation considerations.
- AFD cooling methods and strategies.





Water & Wastewater



THE NORTH TEXAS MUNICIPAL WATER DISTRICT - A LARGE REGIONAL DISTRICT

NORTH TEXAS MUNICIPAL WATER DISTRICT

BY THE NUMBERS

DID YOU KNOW?

SERVE up to 80 COMMUNITIES

Service area of 2,200 square miles in 10 counties

Serving 2 million people in one of the fastest-growing regions in the country

20 MAJOR RAW & TREATED WATER PUMP STATIONS

7 WATER TREATMENT PLANTS
946 MGD Capacity
(million gallons/day)

695+ MILES WATER TRANSMISSION PIPELINES

237+ MILES LARGE-DIAMETER WASTEWATER PIPELINES

13 WASTEWATER TREATMENT PLANTS

163+ MGD WASTEWATER TREATMENT CAPACITY
MGD (million gallons/day)

3 TRANSFER STATIONS
up to 3,370 tons of solid waste/day

around 1 million tons/year accepted at landfill

Rev. March 2023

Electrical power distribution in regional water transmission & waste water conveyance.

- The nominal Voltage of Electrical power intake in regional water transmission at POD from the utility is typically at 138 k V, which is bucked down to 25 k V distribution within the campus to feed various treatment plants at 6.9 k V or 4.2 k V . Over 95% pumps, related switchboards & AFD's/starters are all medium voltage equipment.
- The nominal Voltage of Electrical power intake in regional waste water conveyance at POD from the utility is typically at 25 k V, which is bucked down to 11 k V distribution within the campus to feed various plants at 4.2 k V . Around 45% pumps, blowers, related switchboards & AFD's /starters are all medium voltage equipment.
- NTMWD is a public utility district that provides water and wastewater services to 2.2 million population of North Texas. We at North Texas Municipal Water District have to meet our mission of providing dependable, high quality water every day for which it is very important that the Electrical power distribution in our regional facilities are available and reliable at all times.
- One of the critical equipment we should rightly choose is the Adjustable Frequency Drive (AFD) for resilient, reliable and sustainable power distribution network within our plants. With pumps being the largest energy consumer within the water industry, it is critical that the selection of AFDs and motors are decided against a clear understanding of just how the latest technology has evolved.
- The Challenges presented by cybersecurity, electrical system efficiency, turbidity and harmonics are just some of areas which impact on our plant resilience and can be resolved using the latest AFD and motor technology.

When is Medium Voltage AFD used based on the capacity of the motors.?

Various definitions of medium voltage (MV) exist. In general, medium voltage is a term used by the electrical power distribution industry.

- Multiple ANSI and IEEE specifications state that MV is between 1kV and 35kV.
- From Ohm's Law: Power = Voltage x Current => Current = Power / Voltage

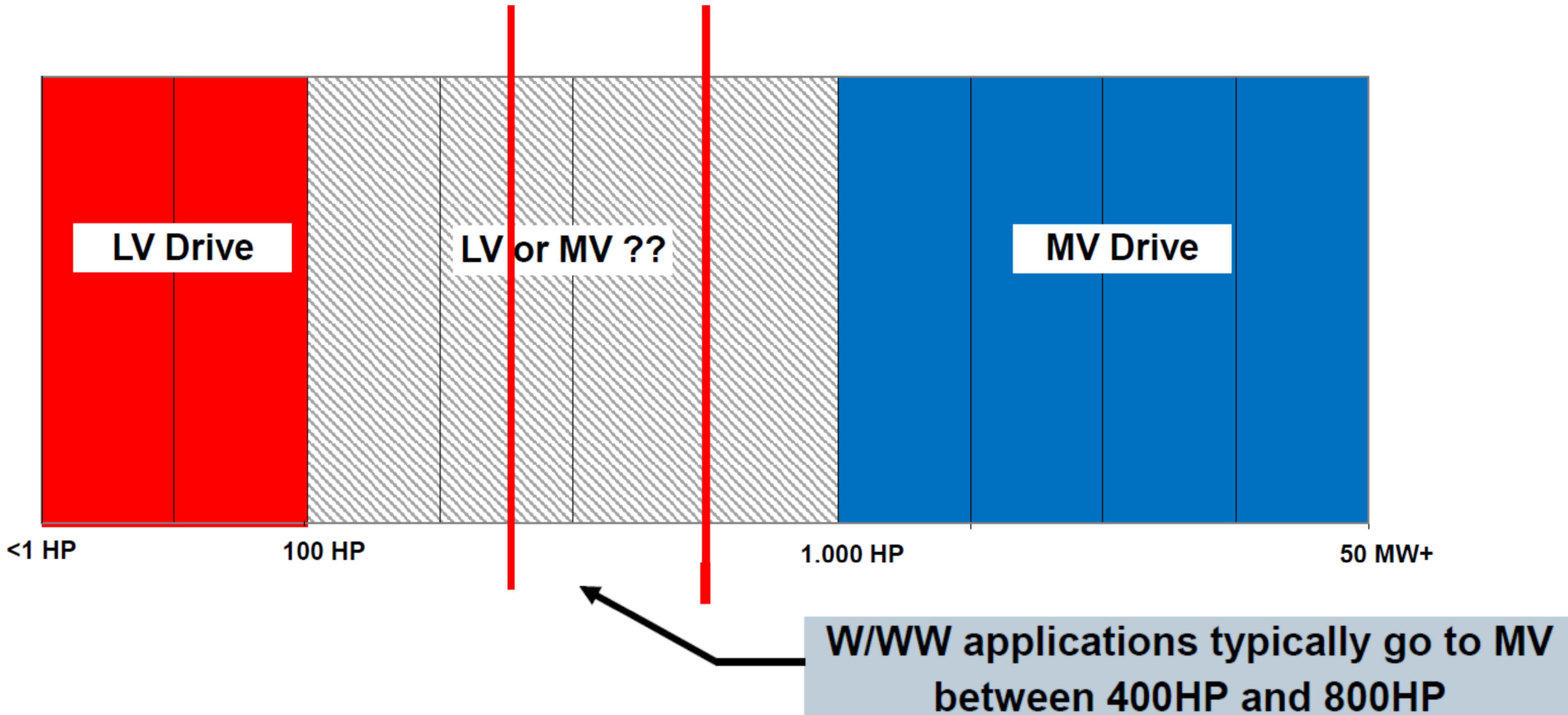
With the voltage constant, the current in a circuit increases with the power. A practical limit in current will be reached when using a LV 480V three-phase supply.

- 800HP, 480V => AFD Current Rating = 960A Rating
- 800HP, 4160V => AFD Current Rating = 140A (typical motor FLA at 800HP 4160V = 104A).
- Other considerations:
- Operation philosophy, opinions and traditions.
- Voltage available on site, MV may not be available.
- Distance from AFD to motor. Long cable runs for high HP LV AFDs can tip the financial evaluation in favor of a MV VFD and motor.
- Some MV AFD topologies have an output waveform that are nearly sinusoidal. This offers many benefits when used with long cable runs as compared to LV AFDs.
- Regeneration, high dynamic torque response and other performance criteria.

When is **M**edium **V**oltage **AFD** used based on the capacity of the motors.?

- A techno-commercial analysis is required to assess the need of an MV AFD.
- Installation cost, reliability, special AFD cable cost & Harmonic mitigation cost decides the selection between LV AFD and MV AFD.
- From 250 HP to 500 HP motors, it can be either way, if cost is the ultimate decider then LV drives is commonly selected.
- From 500 HP to 1000 HP motors, again it can be either way, still if cost & safety are the ultimate deciders, then MV drives are used.
- For > 1000 HP motors MV AFD is ideal.
- In general $/HP for MV AFD decreases with HP and the large capacity motors and drives are mostly Medium Voltage drives.

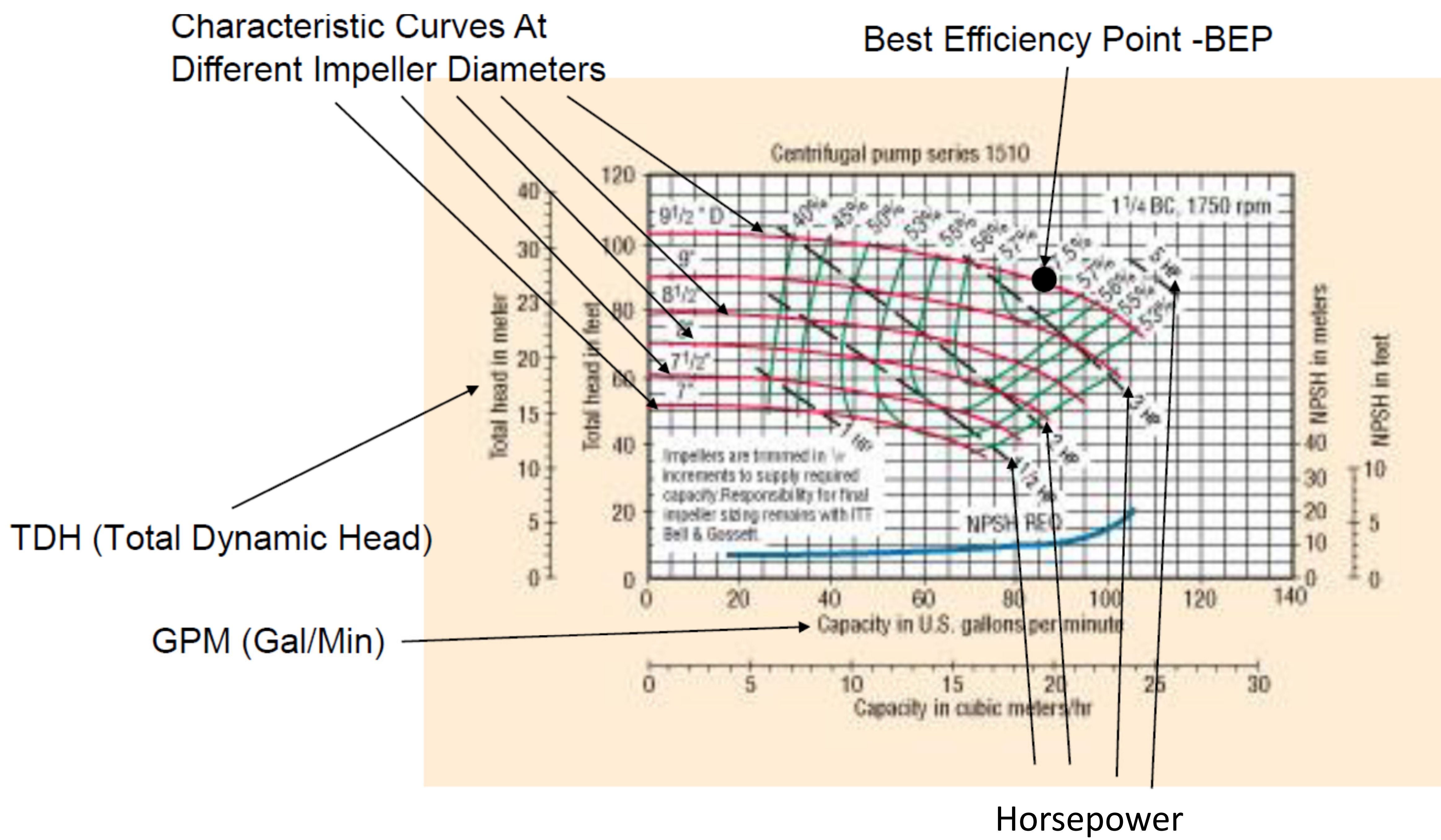
Where is the break point where we switch from MV to LV drives?



Key considerations when selecting MV AFDs for water and wastewater industry applications.

- At higher capacity motors, the major deciding factors are **reliability, resilience and sustainability**, not necessarily cost.
- For water – waste water industry, MV AFD's should be capable of accurately controlling the connected motor. Efficient **control** should be provided by use of direct torque control or vector control.
- The 2 common AFD topologies are 1. Constant Voltage invertors with capacitor DC link for energy storage & 2. Constant Current invertors with inductor DC link for energy storage. Either way a **tested and tried** MV AFD available in the particular high capacity HP of the motor, will decide the preferred topology for the end user.
- Modular, built in cabinet AFD with withdrawable –redundant drive modules or cells are used in high capacity MV AFD's.
- Neutral point shift, automatic cell bypass , higher short circuit rating, withstandibilty of larger % swells, withstandability of larger % sags and more cycles of availability in case of power loss, gives edge to certain products in the case of selection process of MV AFD's for large capacity motors.
- From a **hydraulic** point of view, certain abilities of the MV AFD affect the selection. These are "sleep & boost during low demand", soft filling, back spin protection, quick ramp, coast to stop, turbidity reduction & reduction in torque pulsation.
- Other general factors considered in design selection process of large MV AFD are the backup ability during **communication** loss, cooling redundancy and the response time in asset management.

MV AFD Applications - Improving plant efficiency- pump curves



MV AFD Applications- MV AFD Vs Throttling valve- Improving plant efficiency

Affinity Laws:

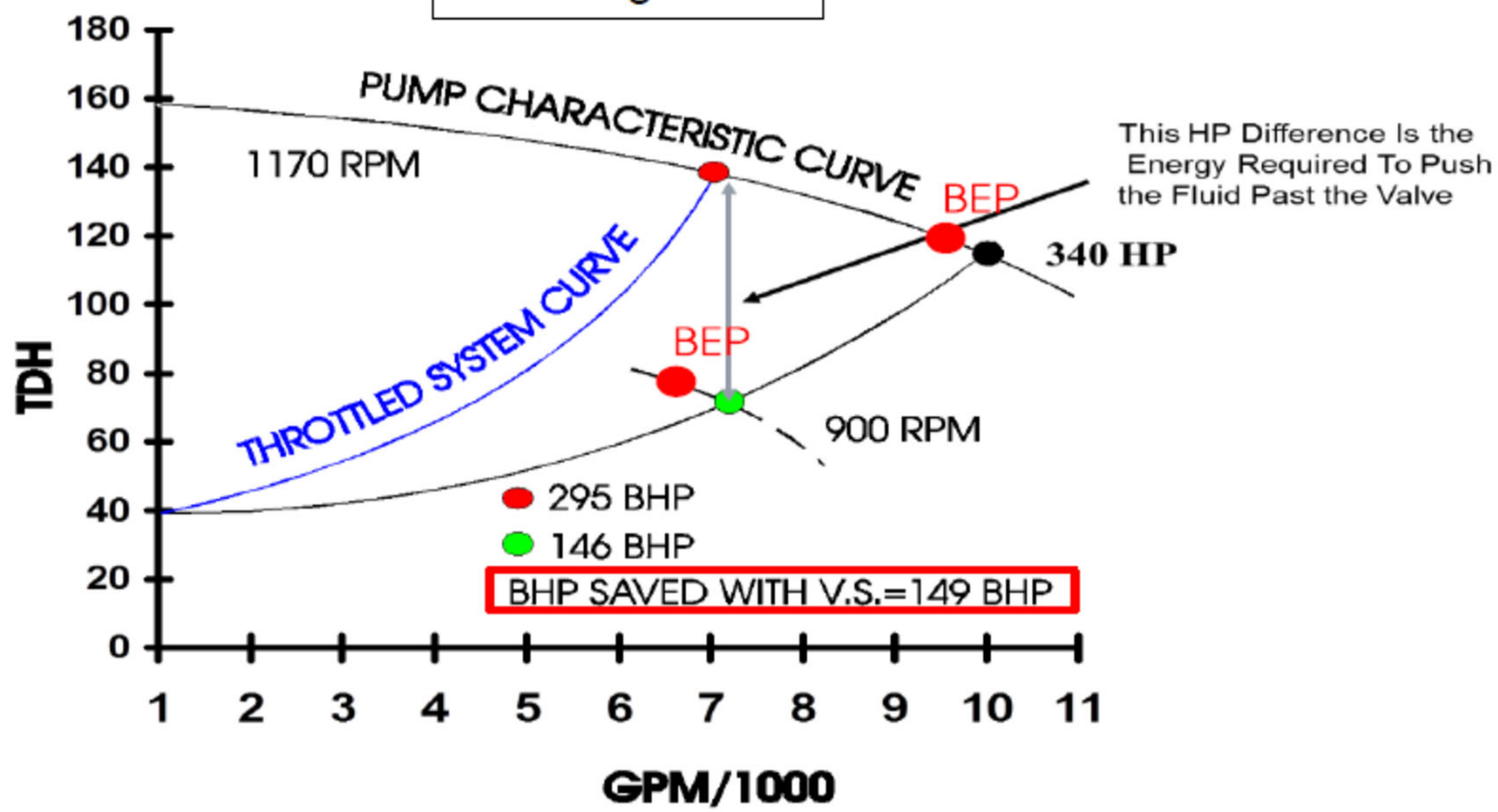
Pump Flow (Q) is proportional to Speed (N)

Pump Head (H) and torque is proportional to Speed2 (N2)

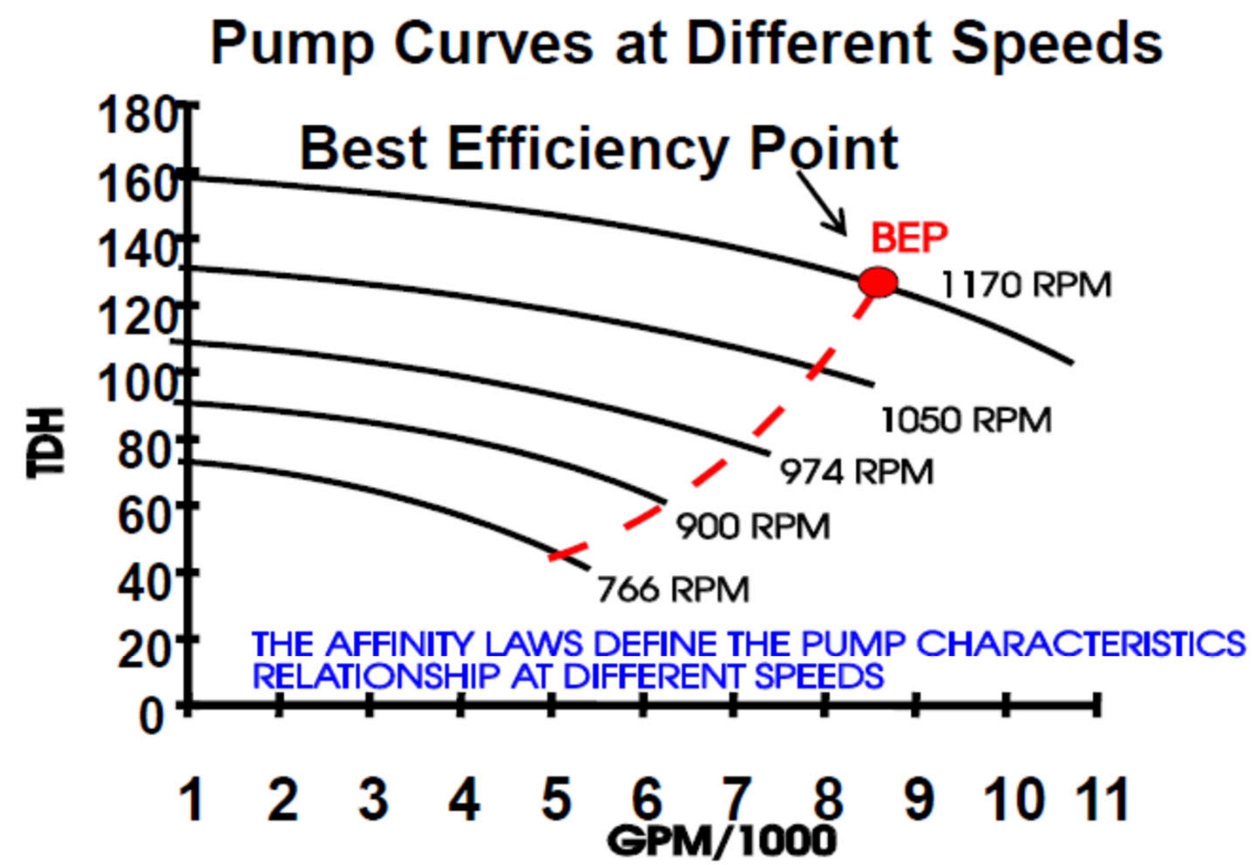
Pump Power is proportional to Speed3 (N3).

Affinity laws apply to centrifugal pumps, fans and blowers.

Throttling Valve



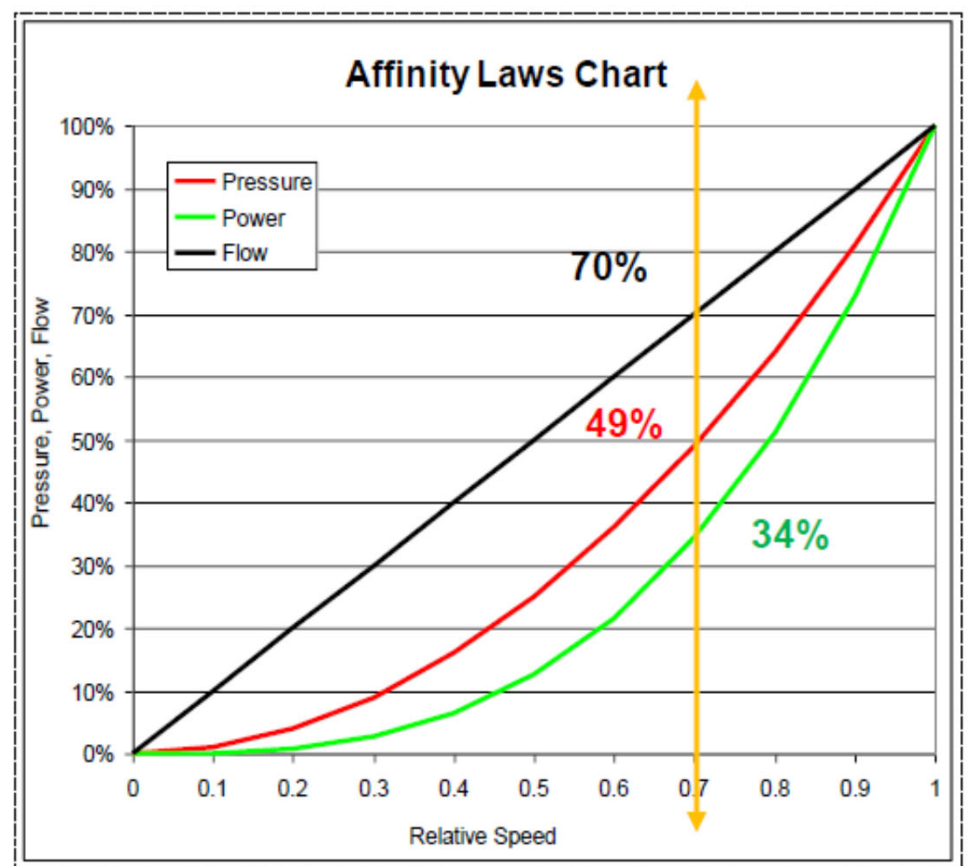
Variable Speed



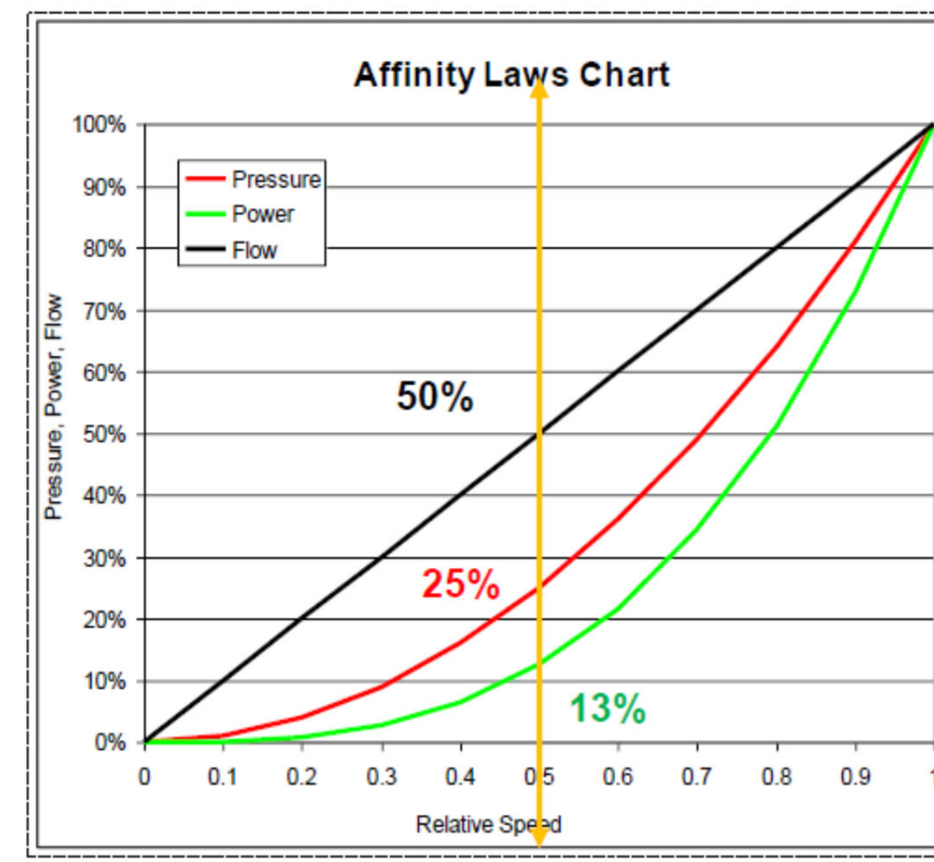
MV AFD BENEFITS - Affinity Laws at Work –Pump stations

Reducing the motor speed can significantly reduce the electrical energy consumption which saves money and improves sustainability.

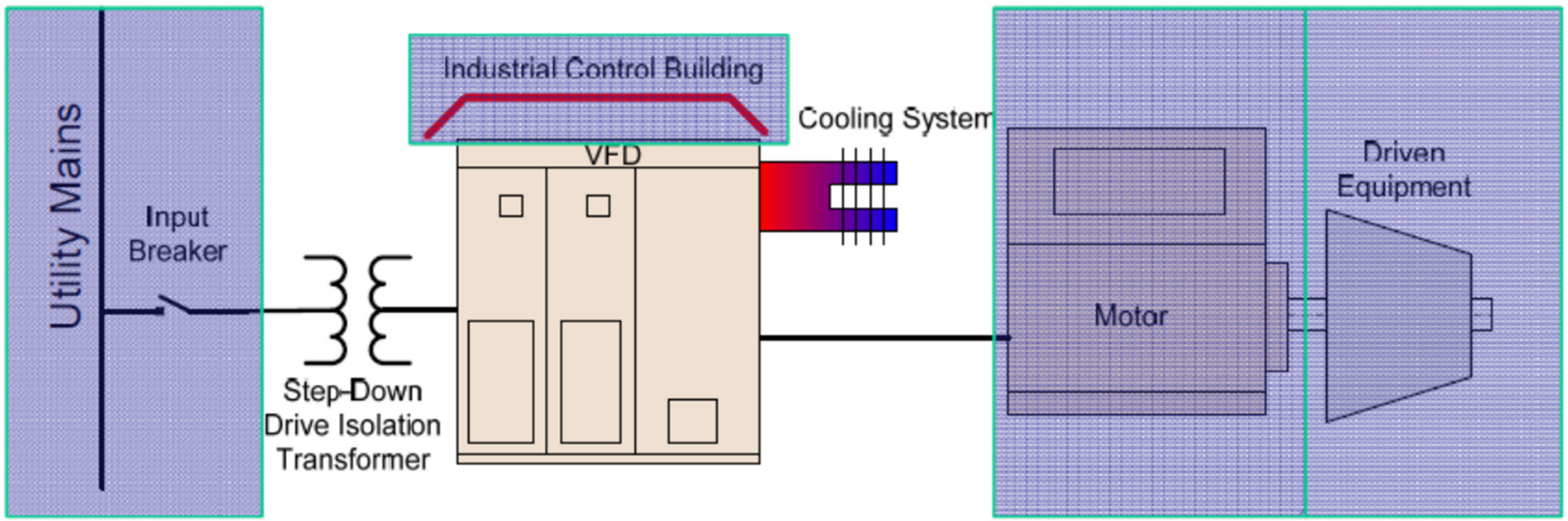
The electricity required to operate the motor at 70% of full speed is 34% of the amount required if the motor was running at 100% speed.



The electricity required to operate the motor at 50% of full speed is 12.5% of the amount required if the motor was running at 100% speed.



MV AFD & its benefits for Lifting /pumping in water waste water industry



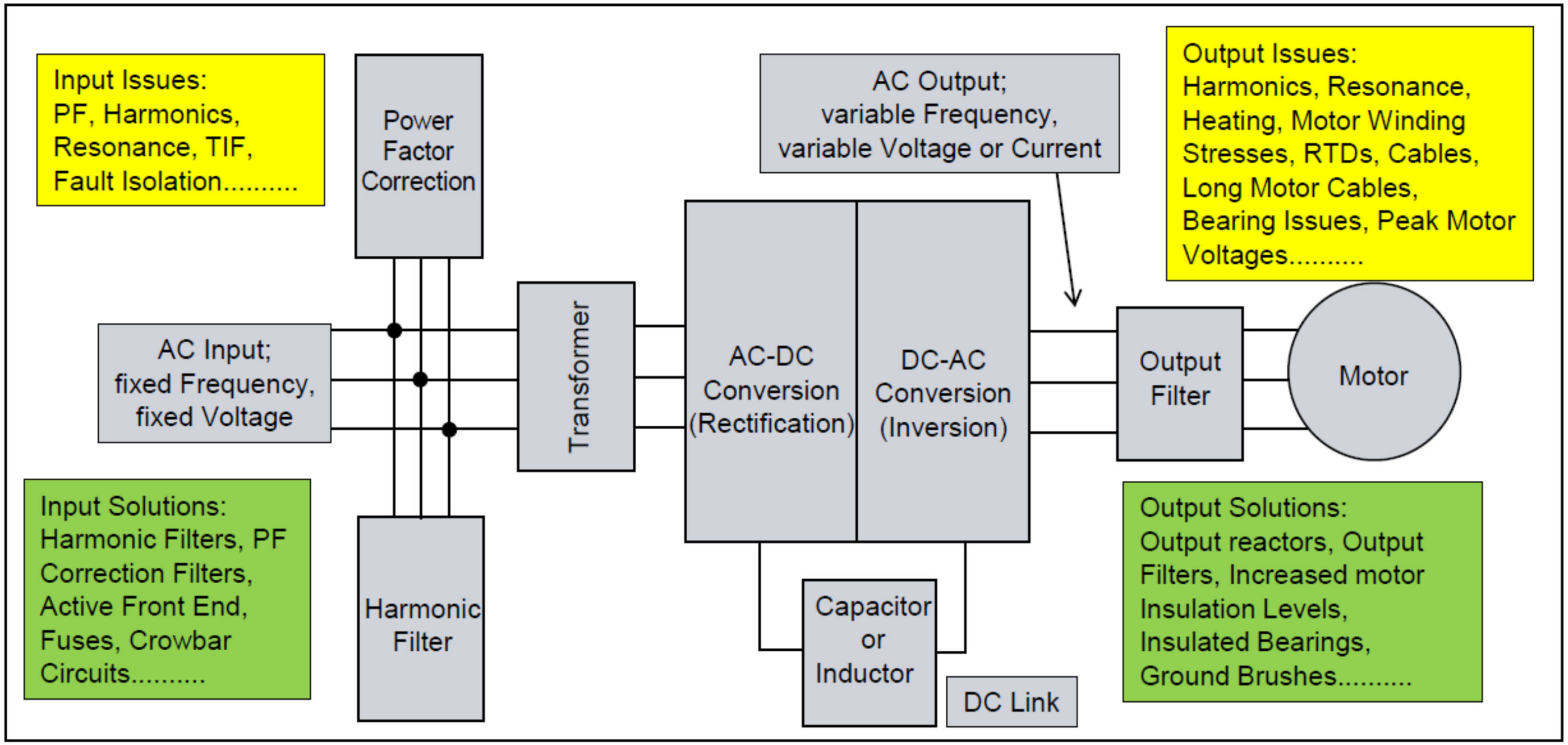
Typical MV AFD System

MV AFD & its benefits for Lifting /pumping in water waste water industry

- MV AFD plays an important role in limiting the **life cycle cost** of larger pump stations.
- The **3** important components of life cycle cost are **construction cost**, **energy cost** while in service and the **maintenance cost.**
- If a large MV pump runs more than 2000 hours a year then the energy cost emerges as the most expensive life cycle cost.
- Construction cost is the 2nd most expensive life cycle cost & maintenance cost the 3rd.
- MV AFD minimizes the energy consumption and plant down time. If designed with proper selection, 20% savings energy can be achieved by using MV AFD.
- With MV AFD lower repair cost and maintenance cost by reducing water hammer, reduced stress on power supply, reduced risk of cavitation, minimize harmonics & easy SCADA integration.

MV- AFD application overview & installation considerations

Typical MV AFD System (All components may or may not be utilized depending on design, topology, etc.).

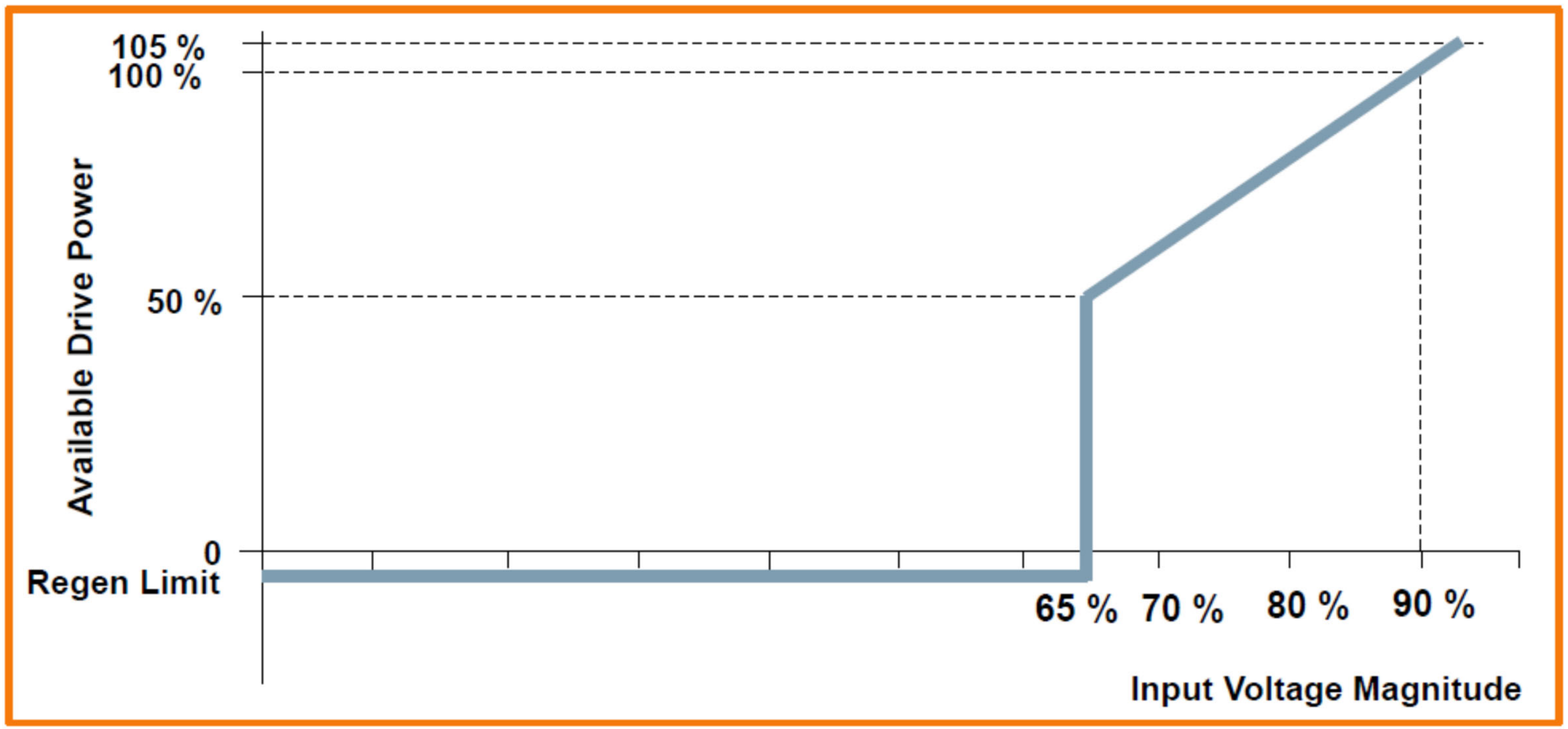


Other Items to Consider:

- Input disconnect
- Control Power – external or internally supplied?
- Control interface
- Application specifics

MV- AFD application overview & installation considerations

MV AFD- Input Under-voltage Considerations



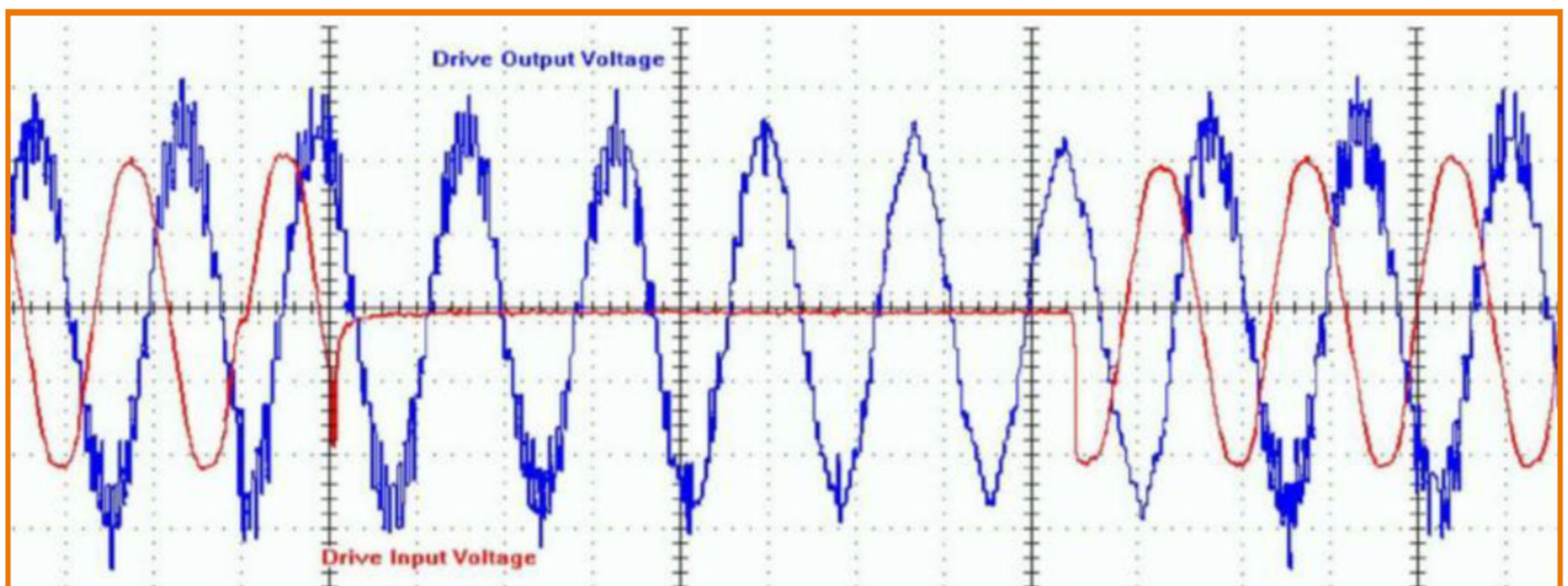
Input AFD Voltage Within ±10% of Rated Value
100% AFD continuous output power available

Input AFD Voltage Falls Within 90% to 65% of Rated Value
AFD output power to be rolled-back linearly from *100% power at 90% input voltage* down to *50% power at 65% input voltage*
Output power is reduced by limiting the available motor torque
The AFD can operate continuously in this mode

MV- AFD application overview & installation considerations

MV AFD Power Loss Ride-Through Considerations

Ride-Through Input Voltage when Falls Below 65%
The MV AFD shall "ride-through" without tripping for at least 5 cycles
Automatically restart Into spinning load with no load or line disturbance as long as motor flux is present
If input voltage is not re-established before the energy stored in the power cells is depleted, AFD shall trip

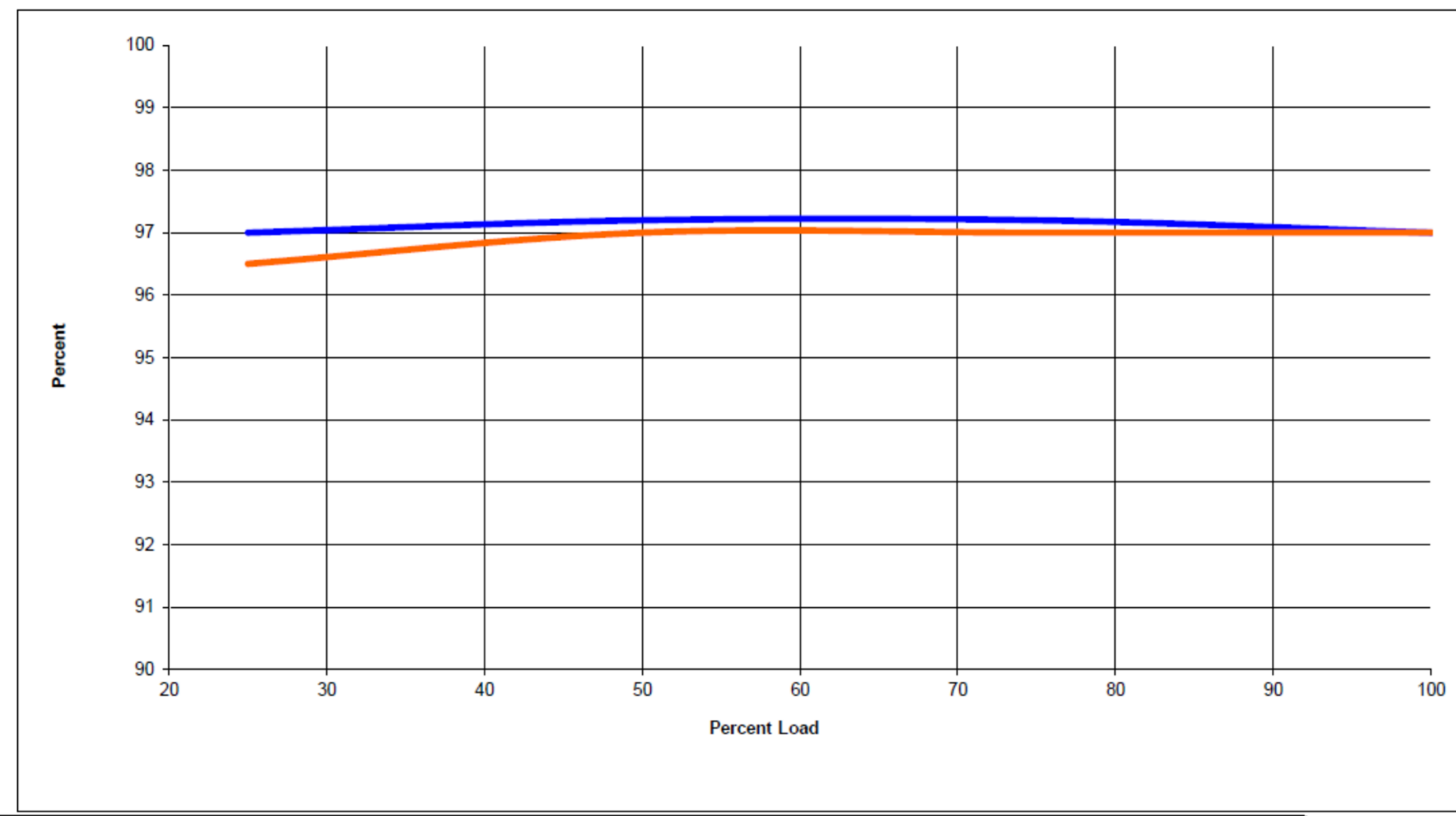


Five Cycle Power Loss Ride-through @ 100% Voltage

MV- AFD application overview & installation considerations

MV AFD- Efficiency and Power Factor Considerations

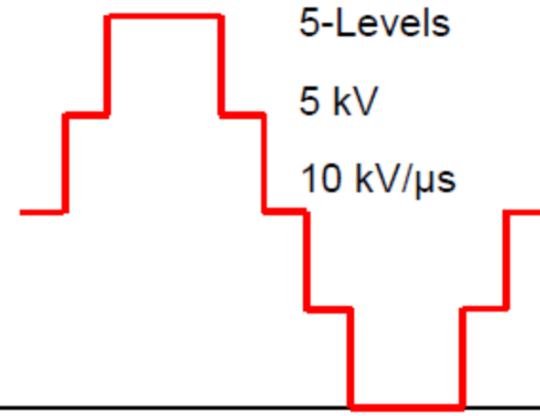
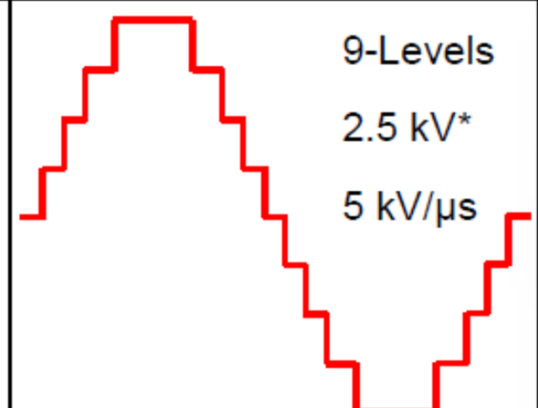
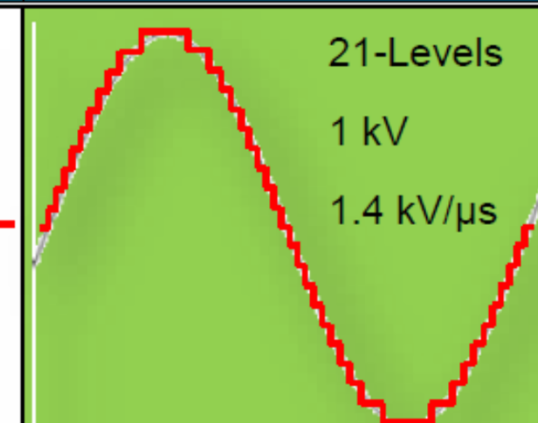
- Shall produce relatively constant Power Factors at medium to high speeds
- Desirably exceed .95 Power Factor
- Power factor shall not deteriorate at lower speeds and loads.
- Desirably shall eliminate the need for external correction capacitors.
- The efficiency shall remain high thru the speed range



KEY TAKEAWAY - Most topologies require at least some external fixes for some of the features discussed. Make sure all are included in the calculation

MV- AFD application overview & installation considerations

MV AFD & Motor Compatibility, Clean Power Output - Performance - (6.6 kV example)

		3L - Neutral Point Clamp Topology	5L – Neutral Point Clamp Topology	Series H-Bridge Inverter
Output Levels **(6.6 kV)**	**Phase to Phase Switching voltage dv/dt**	 5-Levels 5 kV 10 kV/µs	 9-Levels 2.5 kV* 5 kV/µs	 21-Levels 1 kV 1.4 kV/µs
Motor Friend-liness	**Long cable capability**	**Only with output filter**	**Only with output filter**	**Up to 2200 m**
	Filter required for retrofit/non-inverter duty motors	**Yes: Sine filter**	**Yes: dv/dt filter**	**no**

MV- AFD application overview & installation considerations

Cable length between MV- AFD and Motor

- Each of the MV AFD topology means different type of cables to be used in each case. In the 3 cases discussed, we can use normal cables only up to 600’, 2000’ & 6000’.

- For a variable sine wave to properly control the speed of the motor, the cables, AFD, and motor must all be properly grounded.

- Beyond the cable length mentioned in each topology, the cable must be properly shielded, properly armored and grounded, then the noise generated within the cable is to be confined to itself only.

- Beyond the cable length mentioned in each topology, when the drive sends output sine waves down the cable to the motor, they reach the motor and due to the motor’s impedance, reflect back towards the drive, while the drive is continually sending sine waves to the motor. Also the capacitance from the cables (phase to ground) too can create enough current to ground where there can be nuisance ground fault trips. These two factors – capacitance and voltage reflections due to improper impedance, can cause the reflected wave could be added to the fundamental waveform coming from the drive resulting in a significantly higher voltage at the motor terminals. So, if the distance is longer, then there will be more chances of unbalanced voltage peaks in between (due to the issue discussed earlier). This will also increase rise steepness (dv/dt) to a large extent. If the rise is more and unstable, then the voltage peaks will occur frequently. Hence based on the selected topology of MV AFD, the type of cable as well as the requirement of a sine filter or dv/dt filter will vary.

MV AFD- Cooling systems

-Two types of MV AFDs based on cooling.
- Air cooled & Liquid Cooled.
- Air cooling is normally used. It creates lot of noise, dust filters are to be specified in the inlet section requiring frequent cleaning/ replacement, fans &HVAC need n+1 redundancy,
- Water cooled is more efficient& normally used in higher power range. Specific (mass) heat capacity of water is about 4.23 times higher than air. Moreover, the specific density of water is about 784 times higher than air. Combining both, the impressive difference of factor more than 3’300. To evacuate the same amount of heat losses 3’300 times’ larger volume of air is needed compared to water. Following comparison illustrates why water is the cooling medium of choice in higher power range:

Quantity	**Unit**	**Air**	**Water**
Specific heat capacity	[kJ/(kg*K)]	0.993	4.200
Specific density	[kg/m3]	1.275	1,000
Volumetric heat capacity	[kJ/m3*K]	1.266	4,200

-Standard water cooled AFDs are used in 6.9 k V ratings from 6100 HP till 100000HP
- Below 6.9 k V, AIR cooled is the only choice. While in other voltages 2.2 k V till 11k V and from 100 HP up to 11000 HP due to simplicity air cooled is used. For high capacity > 6100 HP, operations air cooled MV AFD requires a lot of cooling and hence some techniques are used to be more efficient.

Air Cooling options for high power MV AFDs

-Conventional: Hot air exhausted into the building and cooled with air conditioning; High cost and electrical load, high failure rate, low reliability of one “9”, must be redundant to avoid frequent downtime.

-Duct in/Duct out w/economizer louvers: Duct hot air outside in summer with makeup air unit return. Direct some hot air inside to heat the building in the winter with temperature actuated louvers; complex air balance if more than 1-2 MV AFDs, over/under pressure building, difficult in gas sites needing clean pressurized building, wind tunnel effect, air balancing issues multiplied with more AFD’s but is the least expensive option.

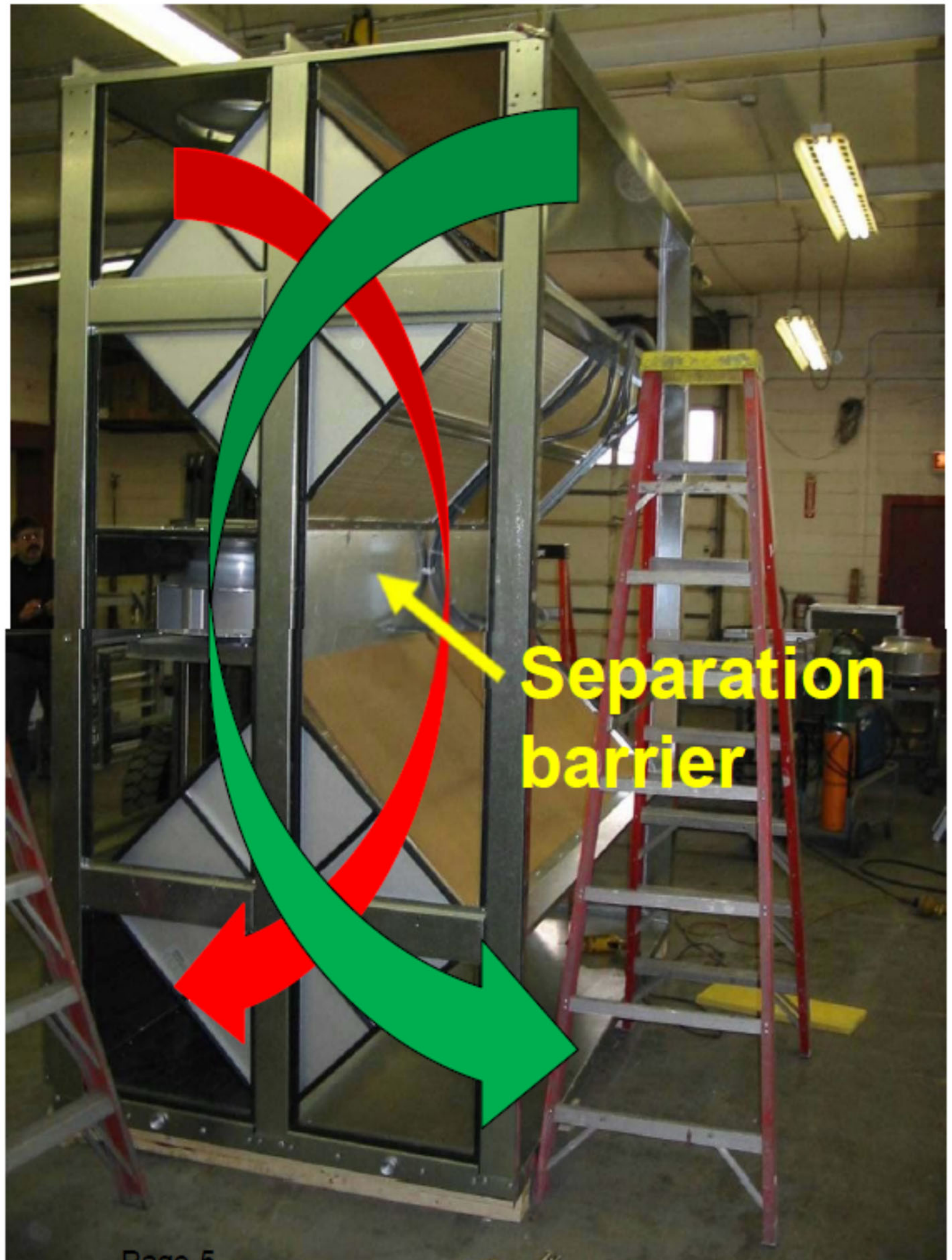
-Filtered Air movers; hybrid semi-closed loop air moving system, costly, one off designs, still have outside air (dust, moisture) into AFD.

-Air to Air Heat Exchanger: Self Contained Closed loop cooling system.

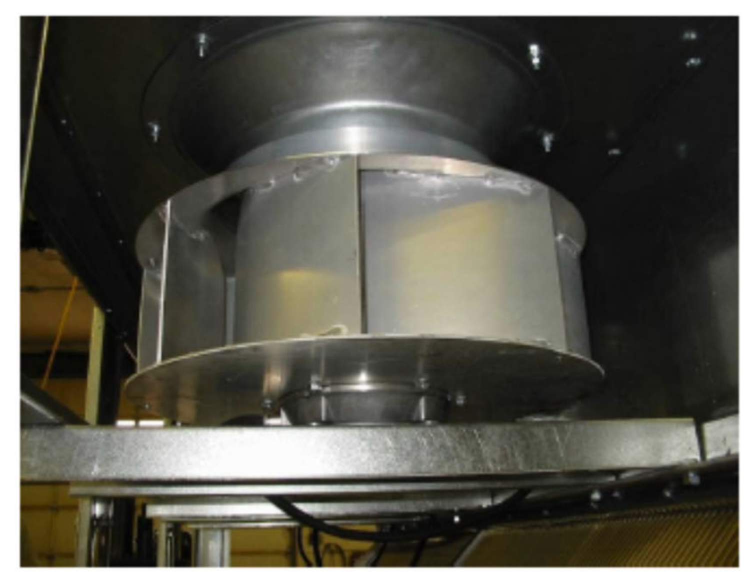
Air To Air Heat Exchanger – Energy/Carbon tax Saving Vs HVAC

- 20 ton commercial grade HVAC system provides ~155,000 BTUH of sensible cooling at 95$_o$F and consumes 50 to 60 amps of 3 phase, 480 volt power.
- Cooling a 7000 HP AFD with a 97% efficiency means cooling 534,837 BTUH of load
- Four 20 T HVAC units are required, without redundancy Two A-A HEXes are required – one for the transformer and the second for the power converter, includes blower redundancy in each hex
- The 480 VAC , 3 phase load of the A-A HEX, compared to the HVAC load becomes – 200 to 240 amps for the HVAC versus 40 to 52 amps for the A-A HEX solution. Using the smaller difference that means 160 amps at 480 VAC
- 8000 running hours per year that results in 1328MWHr saved, an annual cost benefit of ~ $60,000 per year in power savings plus $20,000 per year in carbon tax saved if power is gas generated, $40K if coal generated.

Air To Air Heat Exchanger – Plate style



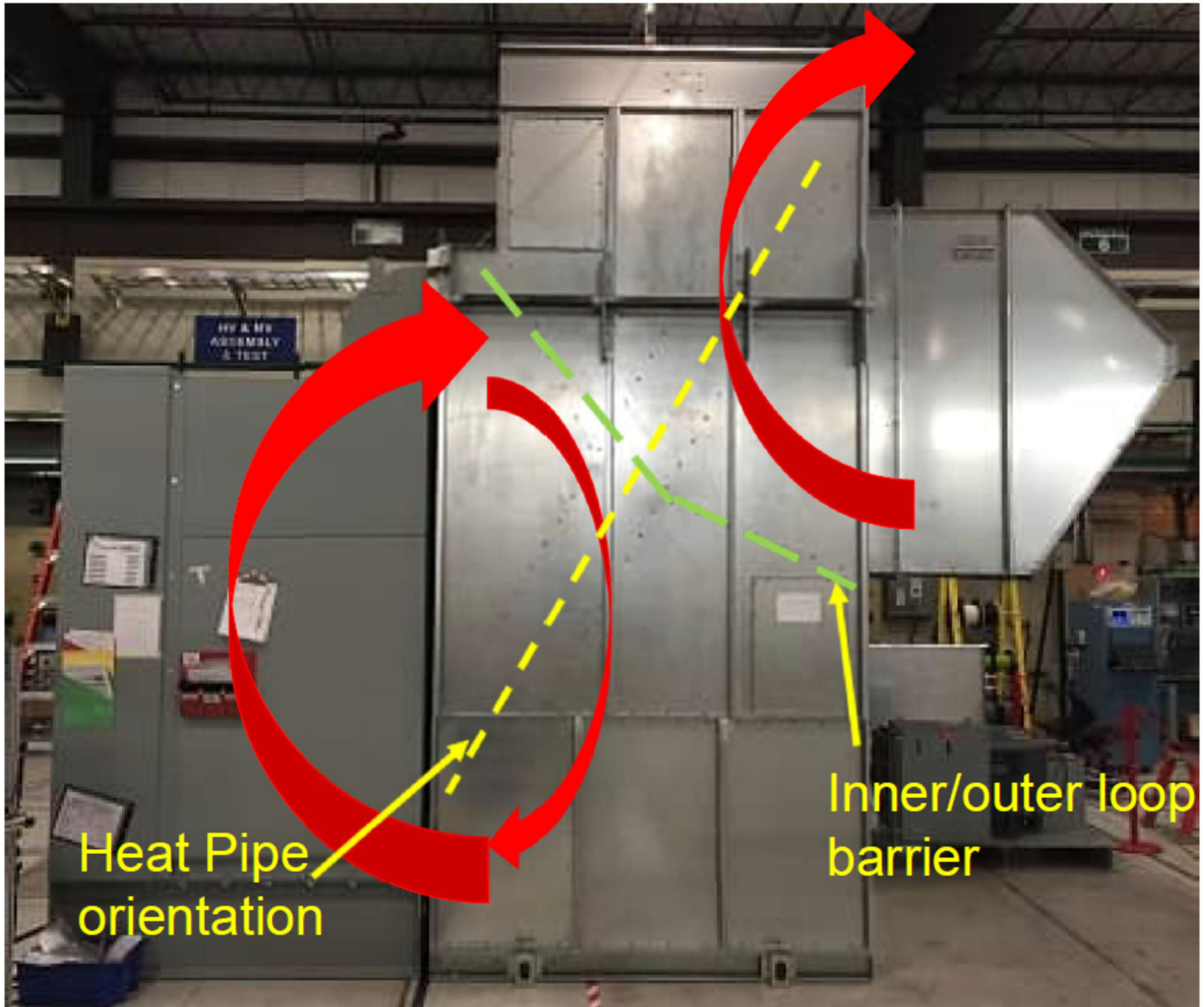
- Plate style Air Air hex very simple, No fluids
- Used in small home sized air exchangers all the way up to very large industrial applications



Air To Air Heat Exchanger – Plate style

Added Front and (optional bottom) plenums for air direction

Air To Air Heat Exchanger – Heat Pipe Style



BIJU CHERIAN PE, SMIEEE

bijucherian@ieee.org