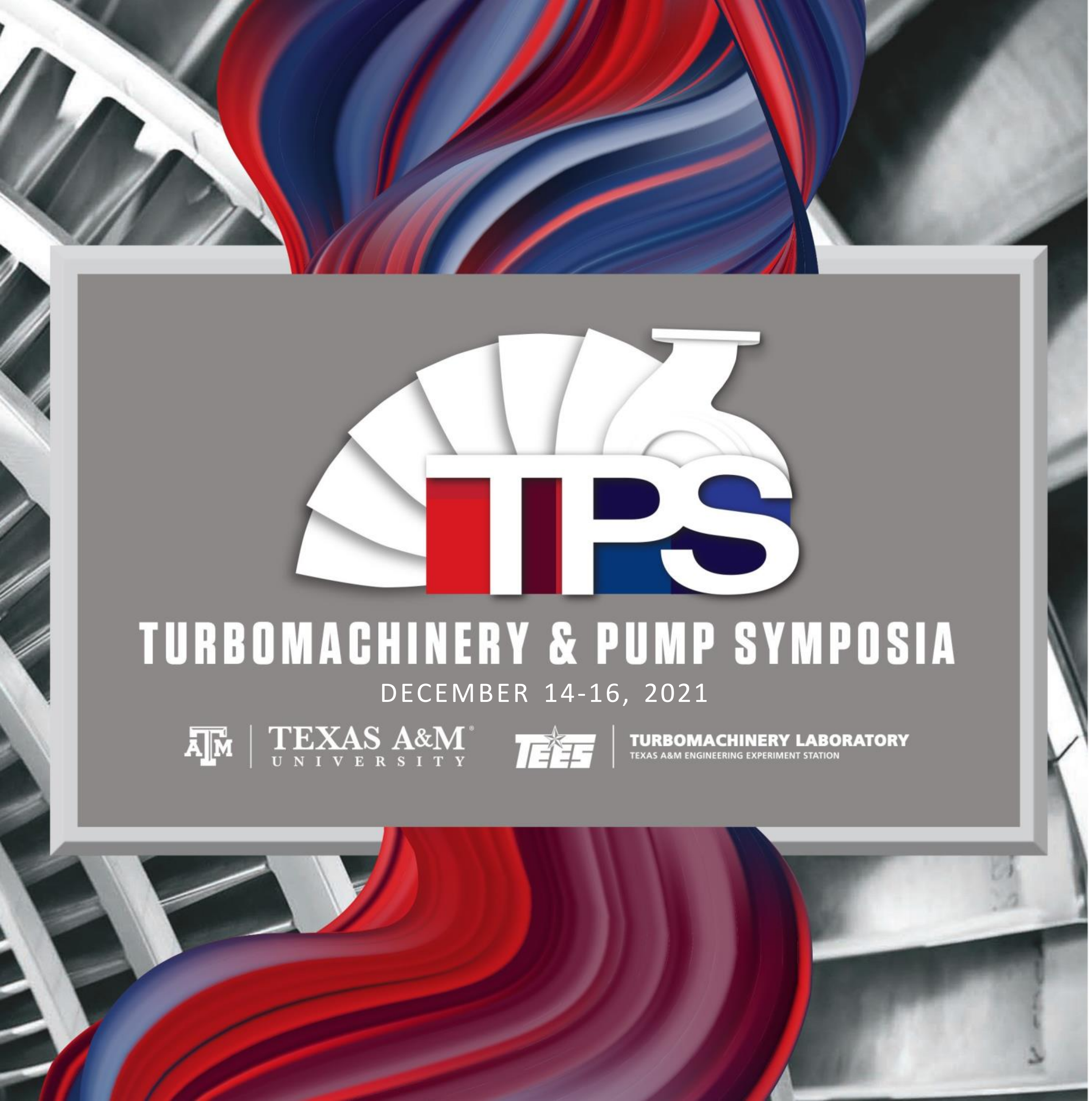

TECHNICAL TRENDS FOR ELECTRICAL COMPRESSOR DRIVE SYSTEMS ABOVE 30,000 hp

Presenter/Author Bios

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Jeremy Andrews graduated from the University of Sussex in 1991 with a BEng degree in Mechanical Engineering with honors. He has worked with medium voltage drives in the oil & gas industry for 30 years and is currently employed at Siemens Large Drives. He is a member of the PCIC Europe committee and holds the position as Secretary.

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Abstract

The presentation will give an overview of electrical drive technology that can be used to drive compressors in the power range above 30,000 hp. Technical trends will be discussed with a focus on variable speed drives (VFD) and their impact on operational costs and reliability of large compressors will be shown.

This presentation will also help to give an audience that is not familiar with the details of electrical drive technology an overview and guidance for possible future investments involving high-power electrical drive systems.

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Why Go Electrical? (1)

- Strong push for CO_2 reduction globally → Increasing cost for CO_2 emissions and stricter regulations
- Depending on source of electrical energy, CO_2 footprint can be significantly reduced

Example: 30 MW Drive System, CO2 Emissions per day	
Industrial Gas Turbine Drive	Approx. 430 tons
Electrical Drive System / U.S. Energy Mix 2020 (40.5% Gas, 19.3% Coal, 19.7% Nuclear, 19.8% Renewable, 0.7% Other)	Approx. 260 tons
Electrical Drive System / Improved Future Energy Mix (40% Gas, 20% Nuclear, 40 % Renewable)	Approx. 140 tons
Comparison: Commercial flight London-New York	Approx. 200 tons

Sources: U.S. Energy Information Agency / European Commission Joint Research Center / Own calculations

Why Go Electrical? (2)

- Electrical Drive Systems now available up to 100 MW
  → Even large industrial Gas Turbines can be replaced
- Continuous operation possible for up to 5 years without shutdown for maintenance
- High Reliability due to rugged design and/or redundancy concepts

Variable Speed Drive Systems up to 75 MW are in operation in the Oil & Gas Industry today

Plenty of references for Ratings above 25 MW

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Electrical Drive System

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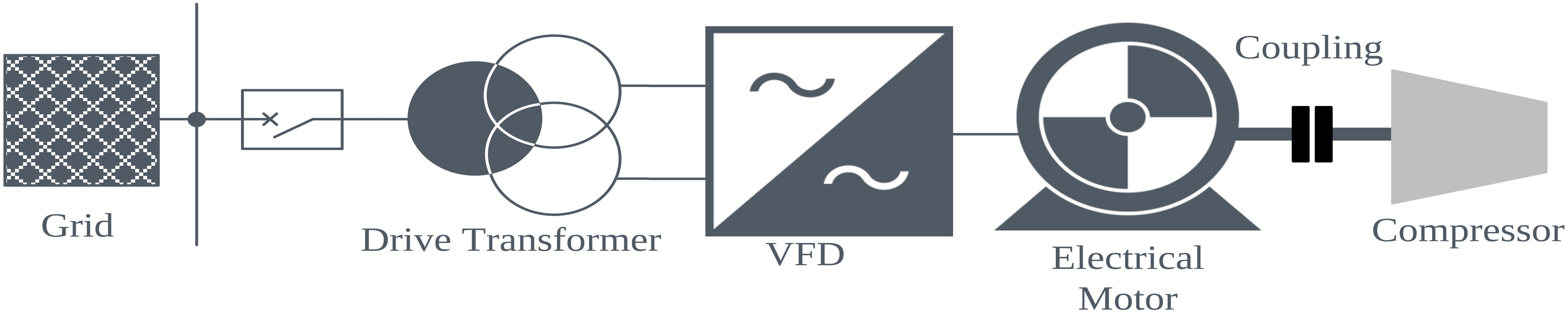
Components of Drive System



- Transformer: Very Mature Technology
- Motor: Induction or Synchronous: Very Mature Technology
- VFD: Various Topologies, ongoing Innovations

VFD Topology Overview

Medium Voltage Drives
High Power industrial applications

- Line/Load Commutated
  - Thyristor based cyclo converter (CC)
  - Load commutated Thyristor inverter (LCI)
- Self Commutated with current source DC link
  - Current source inverter (CSI)
- Self Commutated with voltage source DC link
  - VSI with decentralized DC link
    - SC-2L-H bridge [1]
    - SC-3L-H bridge [2]
  - VSI with common DC link
    - 3L-NPC/NPP
    - Modular Multilevel Converter (M2C)

1) Cell based topology with LV semiconductors
2) Cell based topology with MV semiconductors

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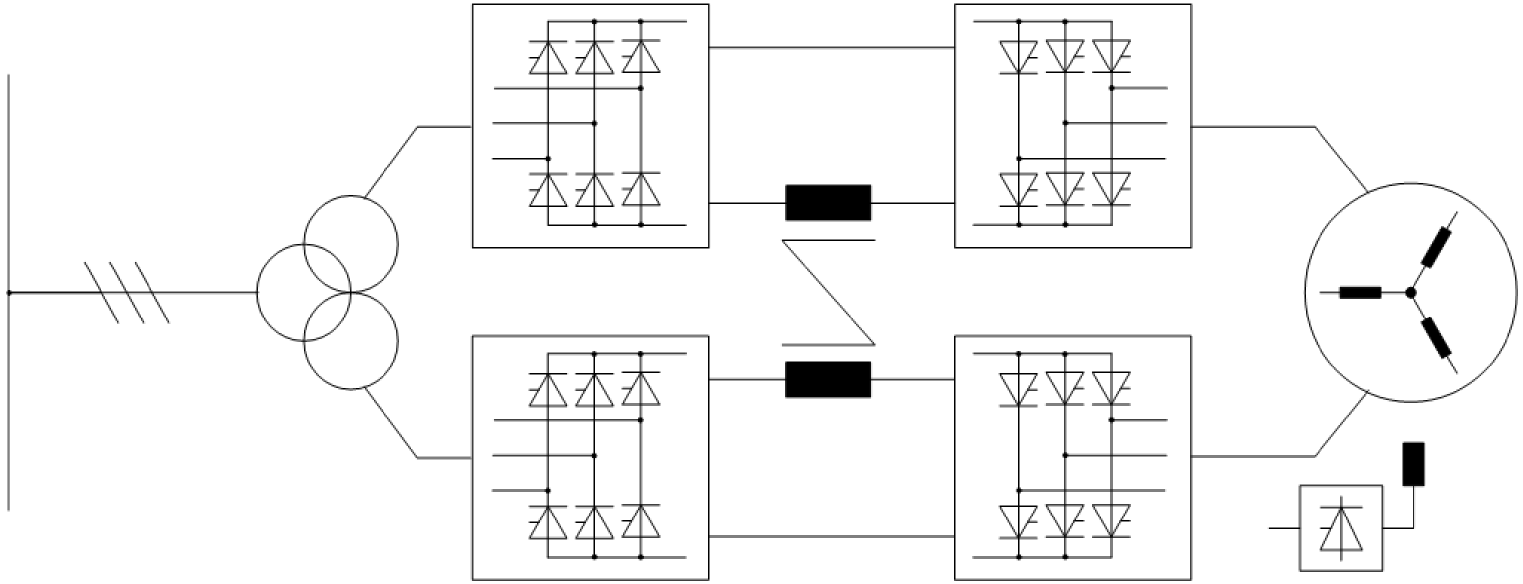
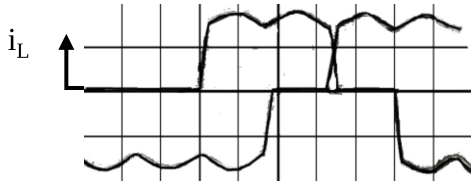
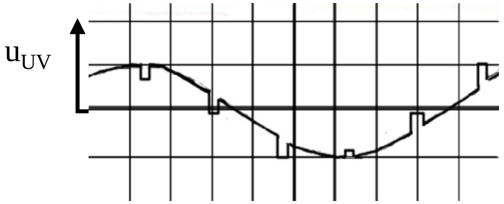
LCI Basics





phase current



motor voltage

- LCI Drives consist of simple and robust Thyristors
- The motor speed is controlled by switching the current
- LCI Drives can only operate with Synchronous motors

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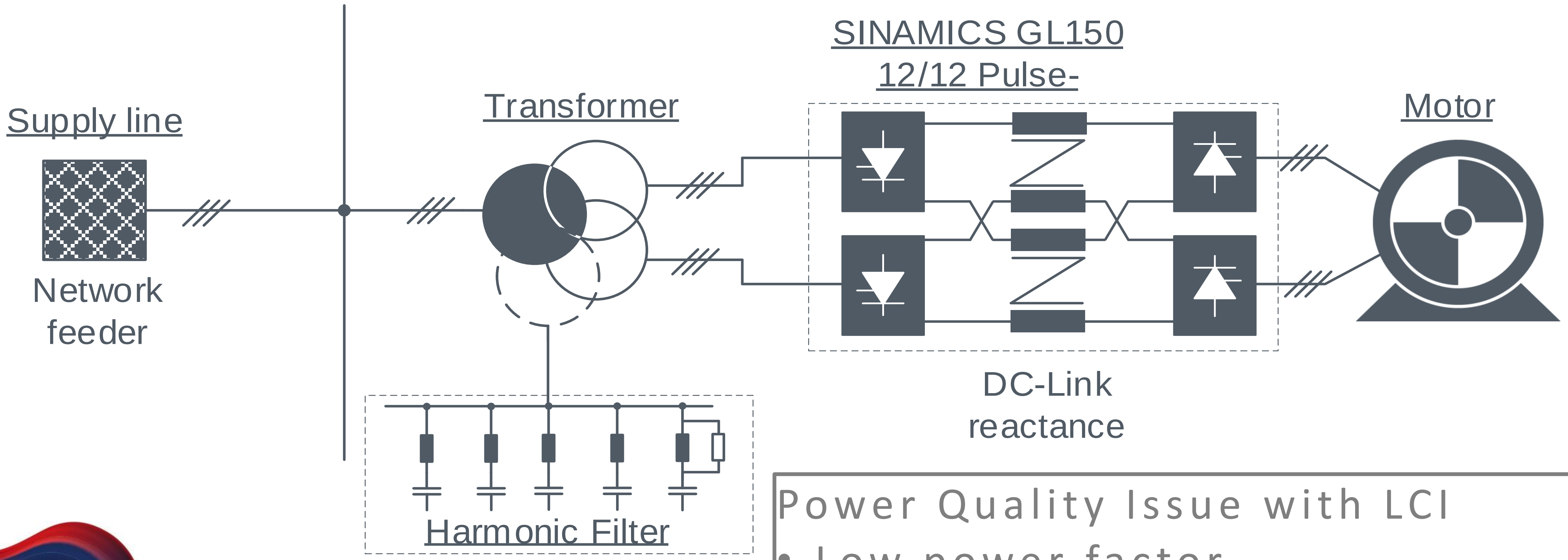
System with LCI Drive



Power Quality Issue with LCI
- Low power factor
- High Harmonic impact on supply grid
- Harmonic Filter required on line-side

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LCI Torsional Interactions

- LCI produce operating speed dependent interharmonic air-gap torque components (pulsating torque)
- Methods are available to prevent excitation of torsional vibrations of the drive train.
  - Design of drive system to avoid excitation (e.g. 4-pole instead of 2-pole motor)
  - Active electrical damping of pulsations by VFD control
  - Mechanical design of train (e.g. coupling properties)
  - Blocking of critical speed ranges

- Effects and measures are well understood but must be carefully considered during planning phase

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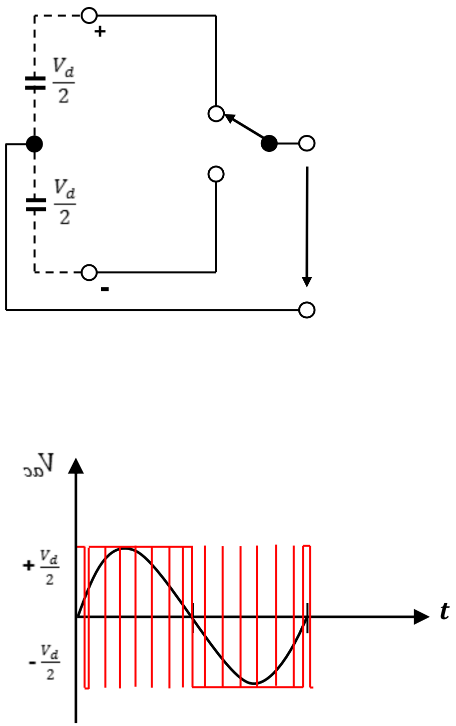
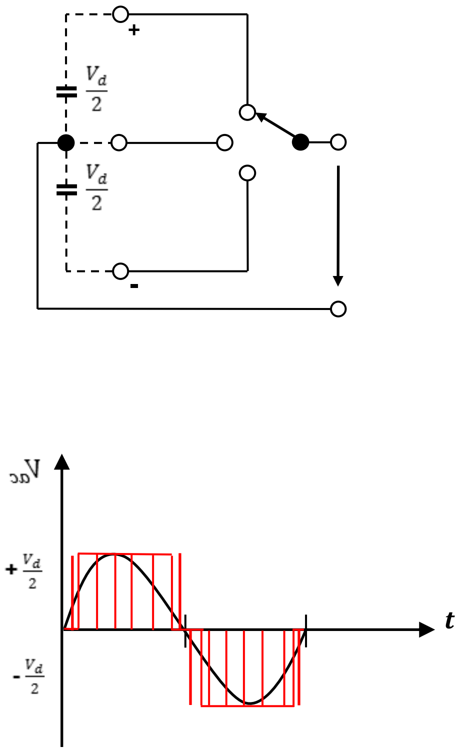
VSI Voltage Modulation

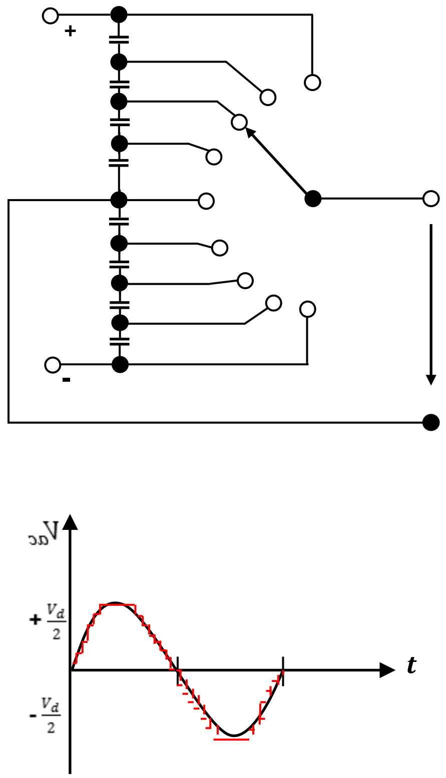
2-Level



3-Level



Multi-Level



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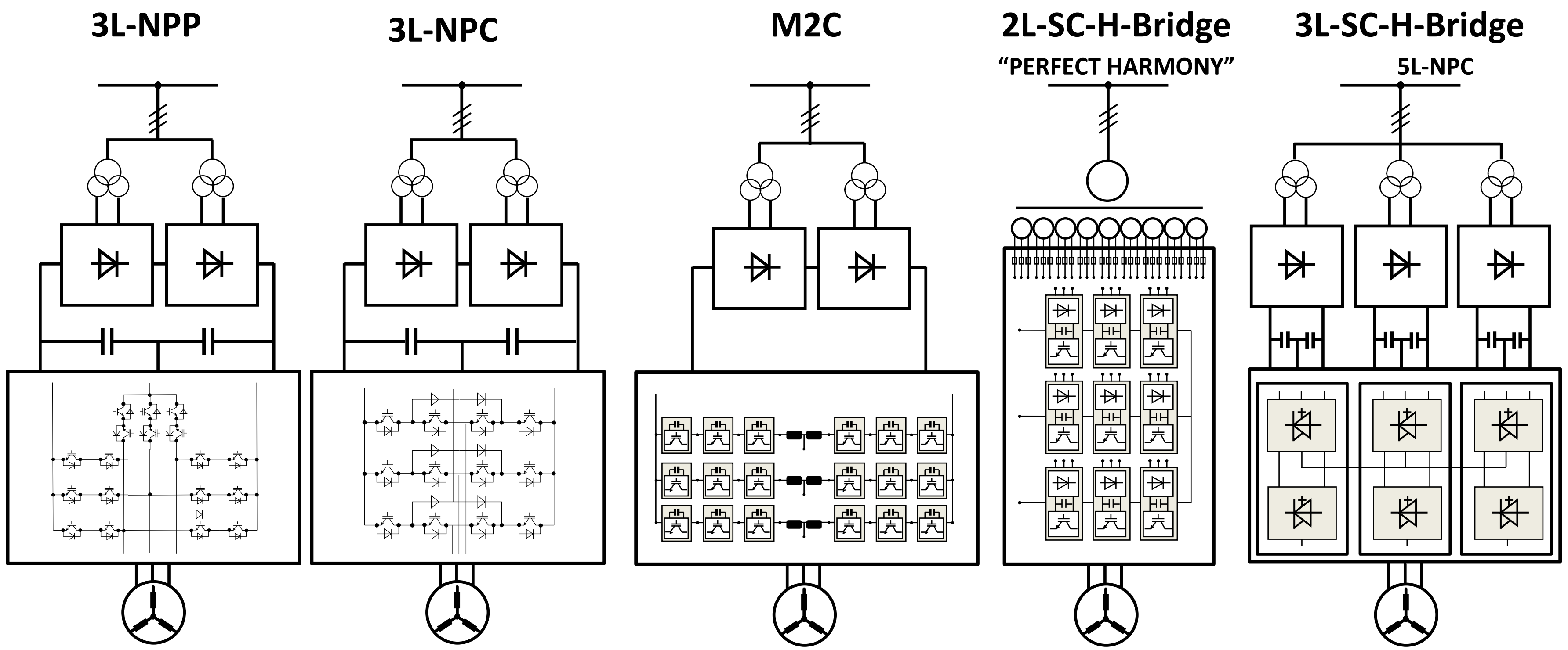
VSI Drive Topologies



Footprint Comparison

Power	50MW m^2		70MW m^2	
Component	**LCI**	**VSI**	**LCI**	**VSI**
Transformer	29.4	25	37.4	32.4
Harmonic Filter	45	N/A	60	N/A
Motor 3600rpm	27.7	26.4	33.6	31.7
Excitation	0.24	0.24	0.24	0.24
VFD	19.2	33.2	27.2	39.4
System Total	**121.5**	**84.8**	**158.4**	**103.7**

- System with LCI has significantly larger footprint due to Harmonic Filter requirement

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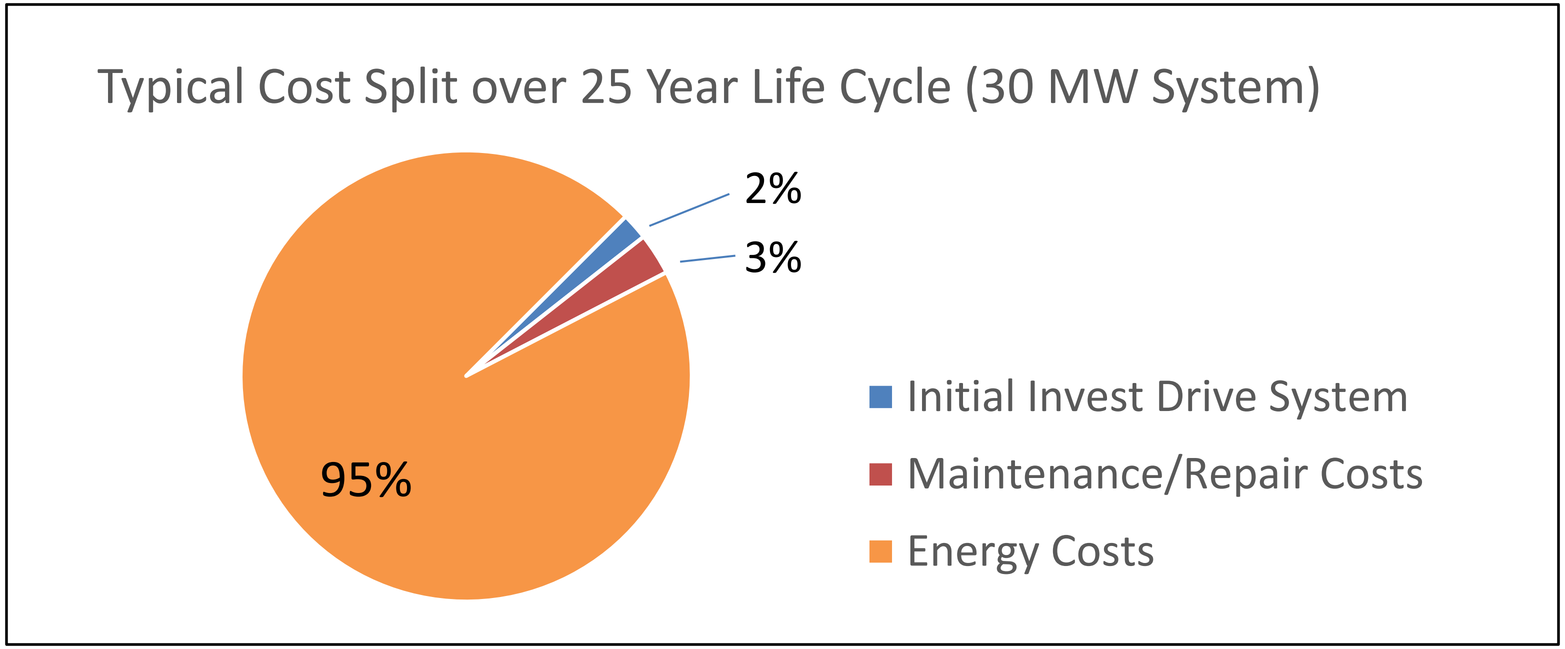
CAPEX or OPEX?



- CAPEX are insignificant compared to OPEX over Life Cycle
- Energy consumption is the main cost factor
- What is the impact of the VFD technology?

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CAPEX Comparison*

Component	LCI VFD system	VSI VFD system
Transformer	100%	95.0%
Harmonic Filter	100%	0%
Excitation	100%	100%
Motor	100%	95%
VFD	100%	125%
System Total	**100%**	**90-95%**

- VSI Systems don’t require harmonic filter and have cost advantage for transformer and motor
- 5-10% overall CAPEX advantage for VSI Systems (Even higher if additional E-House must be considered for Filter)

*Example >50 MW

Efficiency Comparison

Component	LCI VFD system	VSI VFD system
Transformer	99.2%	99.0%
Harmonic Filter	99.9%	-N/A-
Motor	97.9%	98.1%
VFD	99.0%	98.5%
System Total	**96.05%**	**95.66%**

- Systems with LCI can achieve slightly higher efficiency due to lower losses in the VFD and transformer
- Overall difference in system efficiency is small due to higher losses in motor and harmonic filter

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Reliability Comparison

Component	LCI System MTBF	VSI System MTBF
Transformer	540y	540y
Harmonic Filter	95y	N/A
Motor	65y	65y
Excitation	140y	140y
VFD (N)	6.5y	5.3y
VFD (N+1)	11.5y	11.8y
VFD system (N+1)	**6.5y**	**6.5y**

- LCI Drives inherently have higher MTBF due to the smaller quantity of critical components
- In case N+1 redundancy is applied, the MTBF for both systems is on a similar level

Influence of VFD Cooling System

- Release of heat losses to E-House by high power air-cooled drives is not economical due to excessive HVAC requirement (25MW VFD → approx. 250-500kW heat load)
- High Power VFDs are usually water-cooled due to easier heat transfer out of E-House
- Typically, active parts are mounted on water cooled heat sinks and cooled with closed loop non-conductive de-ionized water circuit. Closed loop circuit cooled through heat exchanger against external raw water supply

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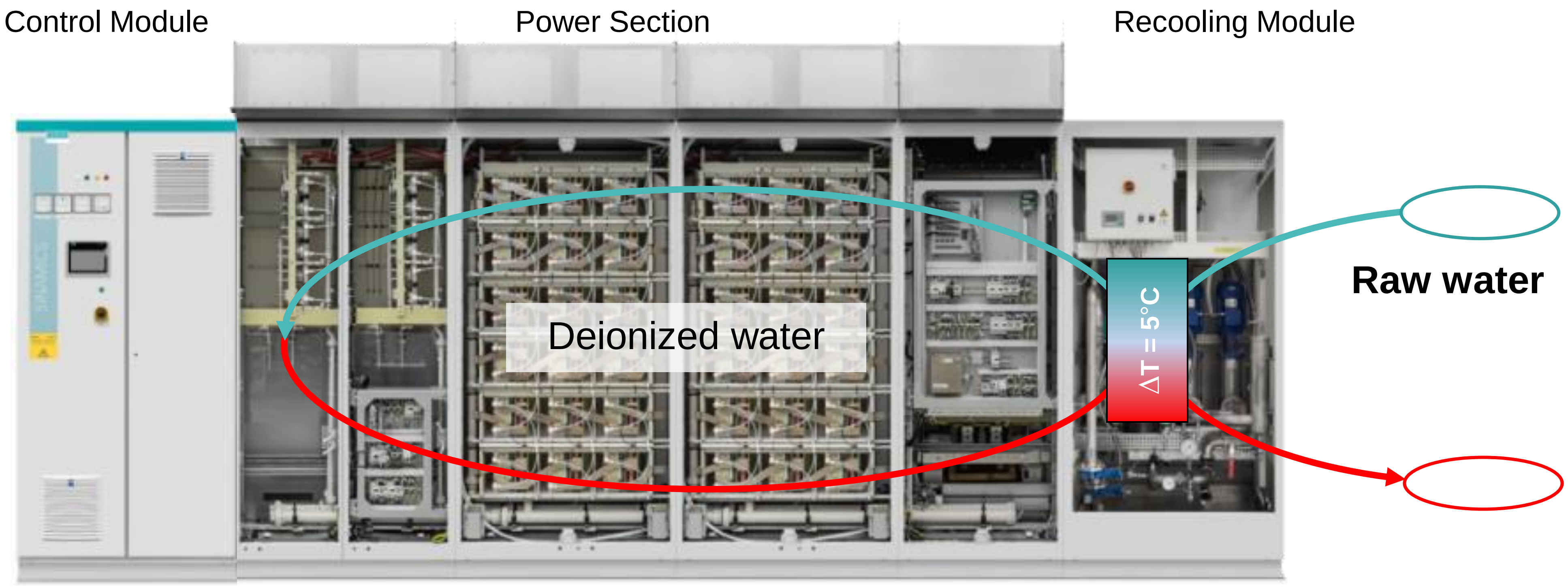
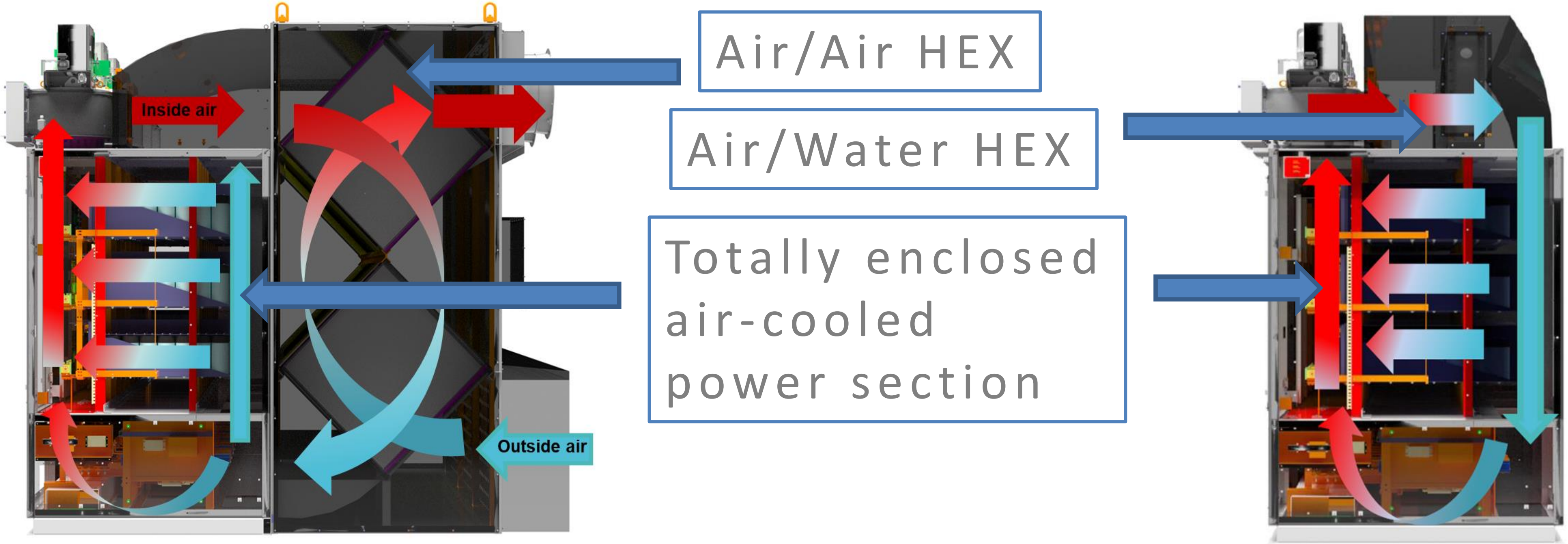
VFD Water Cooling System

- Closed-loop de-ionized water circuit directly cools the power cells
- Separate Re-cooling unit with water/water HEX and pumps



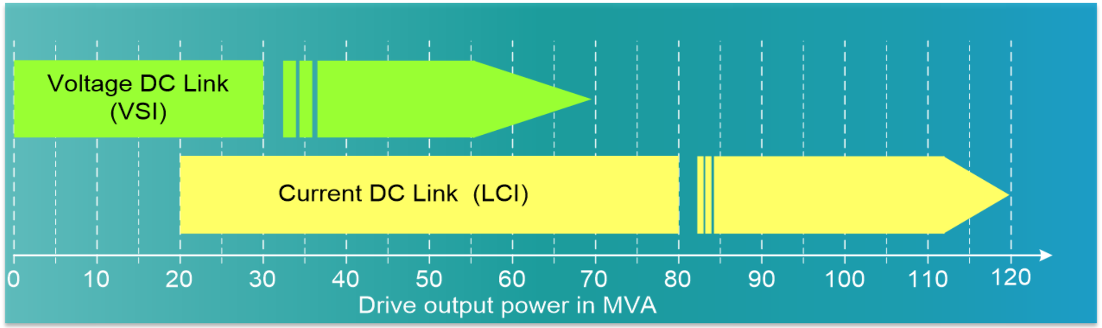
High Power Air Cooled VFD



- Simple air-cooled power section w/o water circulation
- Heat dissipation via air/air or air/water HEX
- → Rugged design with reduced complexity

Summary of Comparison

	LCI System	VSI System
Efficiency	+	(+)
Reliability w/o redundancy	+	−
Reliability with N+1 redundancy	+	+
CAPEX	−	+
Footprint/Weight	−	+
Torsional Vibrations/Interactions	−	+
Flexibility	−	+
References >25 MW	+	−



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Conclusions

- High-Power VFD Systems with LCI Drive are very mature, efficient and robust technology with many references
- The trend is moving towards VSI Drives due to higher flexibility, simpler integration and lower overall System-CAPEX
- Redundancy concepts should be considered for high power VSI drives in order to improve reliability
- Rule of thumb: VSI <25 MW and LCI >50 MW. 25-50 MW range depends on boundary conditions and priorities
- Current lack of references for VSI > 40 MW in a conservative market. Compelling reason required for most users to consider VSI.

Thank you for your attention

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