High Frequency MV Power Conversion Systems to Enable Flexible Grid Interconnections

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Enrique Ledezma, Paolo Osgnach, Dean Sarandria
TECO Westinghouse
Round Rock, TX

Ramtin Hadidi
Clemson University
North Charleston, SC

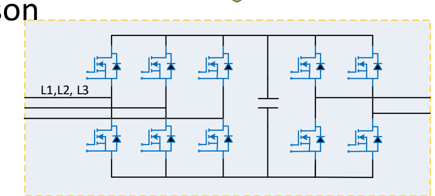
High Frequency MV Variable Frequency Drive

- Modular, multi-level system architecture
  - Scalable in voltage by adding slices in series
  - Scalable in power by adding units in parallel
- Suitable for high-speed motoring and generation applications
- Suitable for MVDC and distribution power station applications
- Able to use low voltage SiC MOSFETs, leveraging cost reductions from other industries
- Low input and output distortion reducing grid and induction machine requirements
- Designed and manufactured as part of DE-EE0007254 grant (Clemson and TWMC)

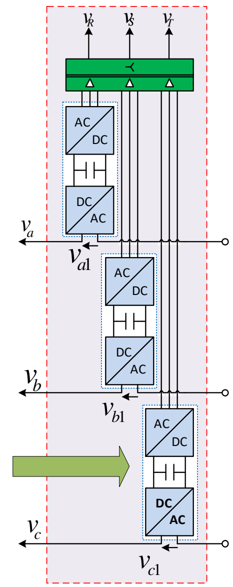
Item	Specification
Rated Real Power	1,244 kW
Rated Total Power	1,850 kVA
Input Voltage	4160 V
Output Voltage	4160 V
Output Current	250 A
Output Frequency	500 Hz
Switching Frequency	4 kHz Input / 6 kHz Output
Efficiency	~ 97 %

1 MW Reference Hybrid SiC based System Specifications

Power Cube Configuration



Power Cube Module Schematic



Power Slice Schematic

Power Slice Configuration

Modular, multi-level, medium voltage VFD architecture scalable in the 1 to 20 MWe range

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High Speed Medium Voltage Induction Machine

- Considered a squirrel-cage induction motor topology for the high-speed application because of its robustness
- Selected commercially available materials with low losses and high strengths
- Optimized the geometry for the application to achieve the required performance with lowest cost
- Designed the stator coils using type 8 Litz conductors to minimize eddy current proximity losses
- Designed and manufactured as part of DE-EE0007254 grant (Clemson and TWMC)

Prototype 1 MW, 15,000 RPM Induction Machine

Item	Specification
Frame Size	F#3506 SPCL
Voltage	4160V
Full Load Amps	226A
Efficiency	95.9%
Pole	4
Speed	14983 RPM
Enclosure	WPII
Exp. Proof	Class I, Div2, C&D

1 MW Reference System Specifications

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High-Speed MV CHP with Grid Support Concept

- High Speed CHP systems operating directly at medium voltage provide smaller footprint
- No 60 Hz power transformer with direct interface to medium voltage
- High speed machine drive may provide advanced grid support functions, i.e. reactive power support, voltage regulation, harmonic filtering and frequency regulation.
- The primary goal of this project is to be in a position to develop a medium voltage commercial grid-tied system with advanced grid support functions validated against IEEE-1545-2018 and UL 1741 SA
- Enable a TRL 5 demonstration of 1 MW, 500 Hz, 15,000 RPM machine system for advanced CHP grid integration

The demonstration system will:

- Validate the grid-tied SiC enabled high frequency CHP generator converter
- Demonstrate island mode transitions and resynchronization with the power grid with fully coupled system prototype setup
- Demonstrate voltage and frequency ride-through

Demonstration System Specifications	
Generator Voltage	4.16 kV
Power Rating	1 MW
Operating Speed Range	11,000 – 15,000 RPM
Grid Voltage	480 V – 13.8 kV
Enabling Technology	WBG SiC MOSFET
Interconnection and Interoperability	Compliant with IEEE Std. 1547-2018

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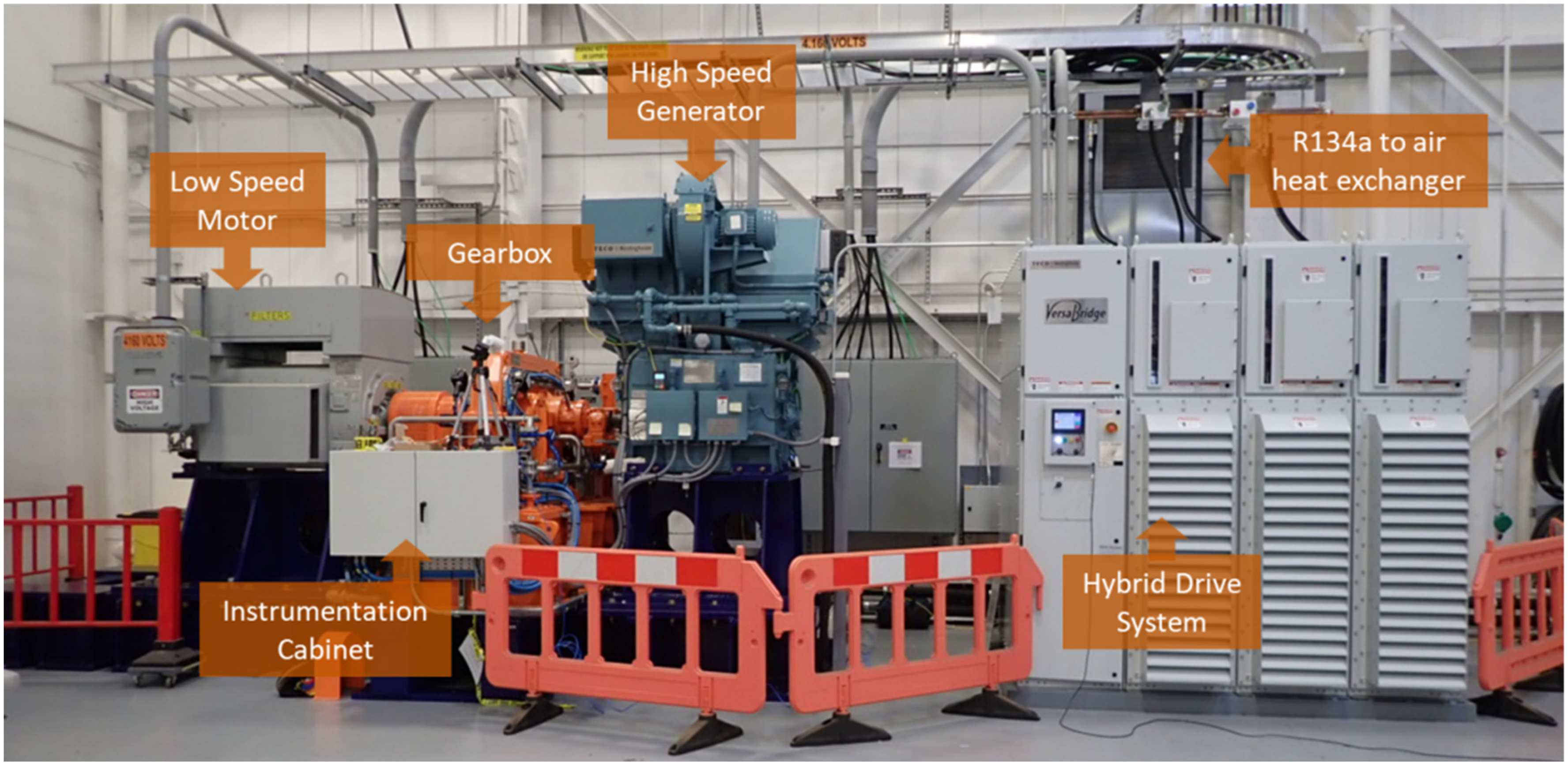
1 MW CHP PHIL System Test Setup



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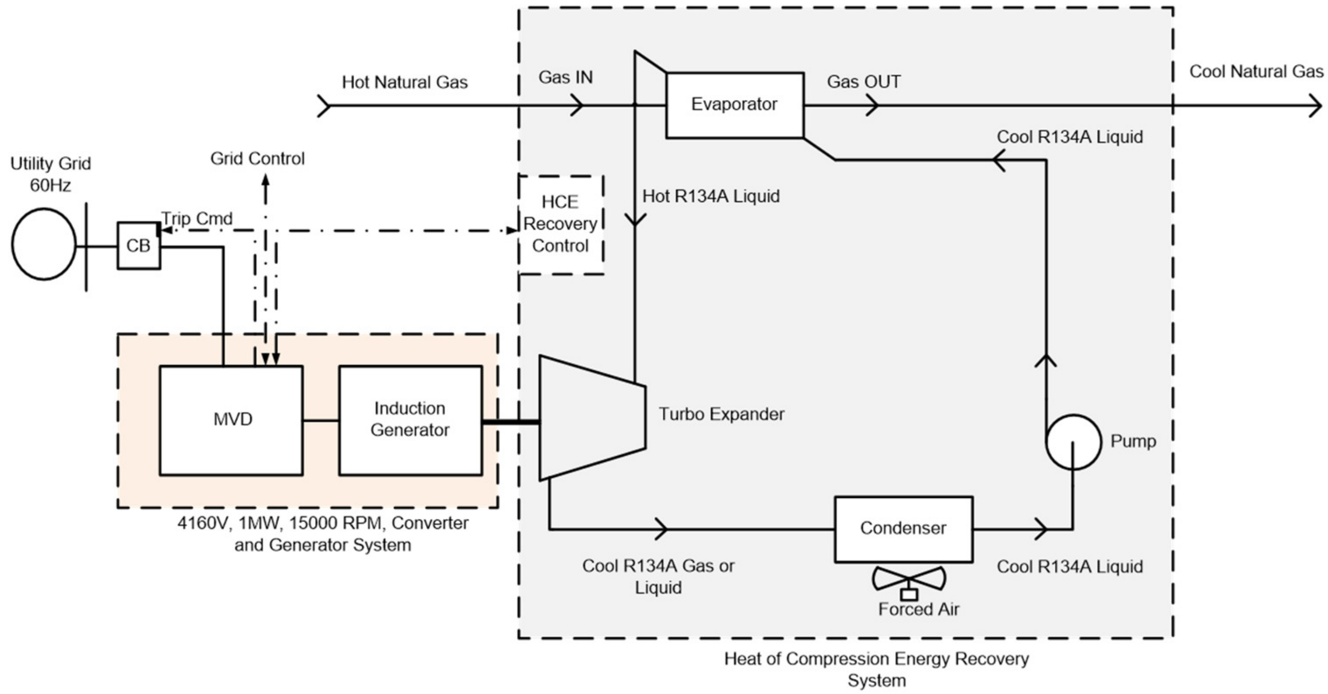
Organic Rankine Cycle (ORC) Heat Recovery System

- Organic Rankine Cycles have been used since the 1950's where lower grade heat is available

- ORC Key Components
  - Working fluid
  - Turbo expander
  - Evaporators
  - Condensers
  - Pumps

- Research Opportunity
  - System monitoring and control for multiple heat sources



Example ORC Heat Recovery System

Heat Recovery System Concept and Motivation

- Recovering waste heat to generate electricity
  - Heat of compression
  - Biomass fired boilers
  - Geothermal sources
  - Hydrogen electrolyzers
- Improves the overall system efficiency
  - Electricity generated can be directly used locally or integrated to the grid as a distributed energy resource (DER)
- Reduces CO2 emissions
  - 1 MW of heat recovery is equivalent to 8,672,400 lbs. of CO2 annually according to the U.S. Energy Information Administration
- Combining multiple heat sources reduces total system components and cost

Significant opportunities for reciprocal gas compression applications either engine or motor driven greater than 1,500 HP in gathering plants, cryogenic plants and gas pipelines

Acknowledgements

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- DE-EE0009423 - Megawatt Scale, Multi-Source Heat Recovery System with a Flexible Grid Interconnect

Prior related awards:

- DE-EE0008409 - High Speed Medium Voltage CHP with Advanced Grid Support
- DE-EE0007254 - Fully Integrated High Speed Megawatt Class Motor and High Frequency Variable Speed Drive System

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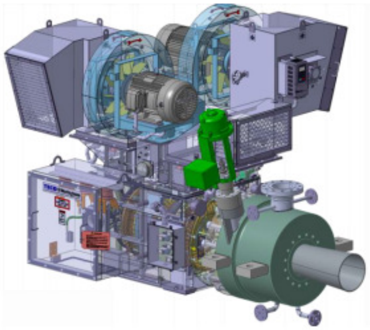
Heat Recovery Design: Turbo Expander

Integration:

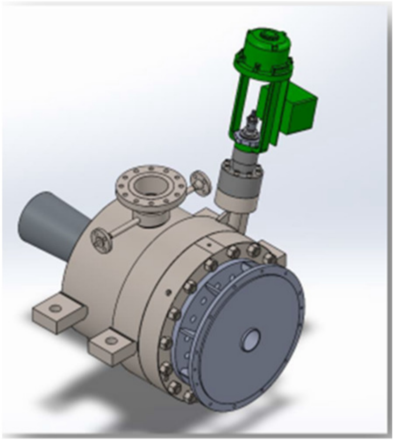
- Turbo-expander system and HS induction generator assembly.


HSM-Turbo expender integration

Turboexpander General Specifications:

Expander Design Conditions

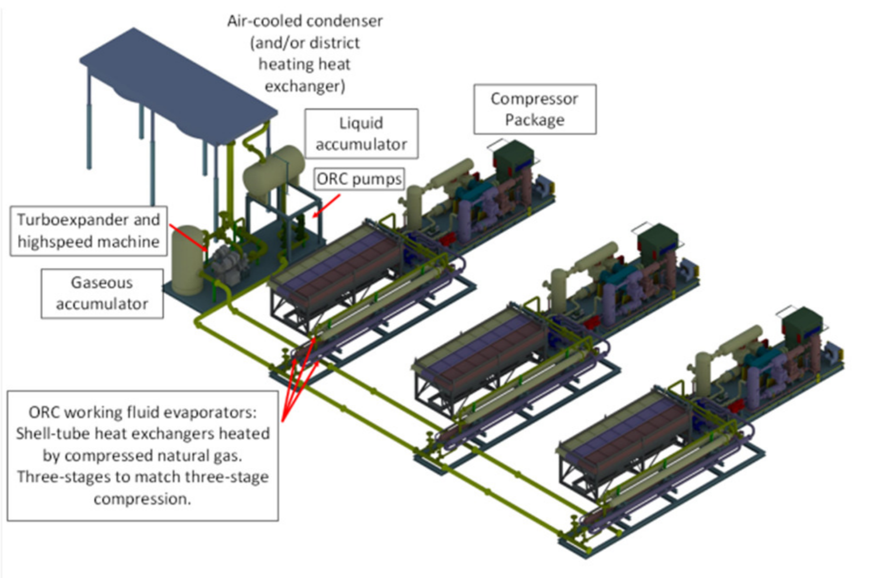
D1:	9.250	in	**Efficiency:**	86	%
Flow:	268,000	LB/HR	**Power:**	1,101	KW
P1:	550	PSIA	**T1:**	195	F
P2:	200	PSIA			


Turbo expender assembly

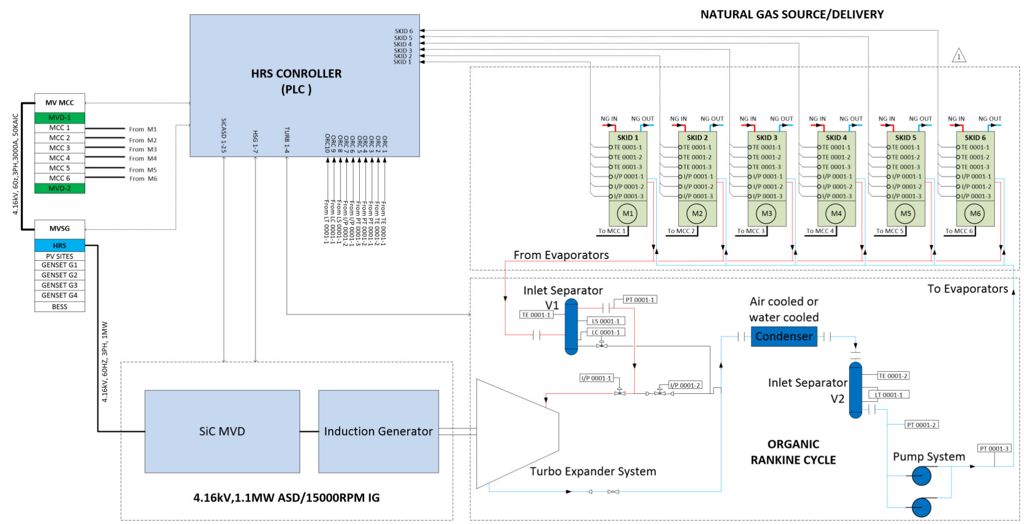
Key Attributes and Technologies

- Able to concentrate multiple heat resources to a single stream
- Centralized ORC and generation systems provide economies of scale in the 1 – 20 MWe range
- Directly application to geothermal energy harvesting and geothermal energy storage systems
- High speed generator and turbo expander simplify mechanical designs and maintenance
- Power electronics grid interface improves flexibility in dynamic power flow control
- Asynchronous, variable speed connection from the electrical grid and the turbo expander allow wider operating range efficiency than fixed-speed ORC designs
- SiC enabled medium voltage, multi-level power converter and induction generator directly scalable to 20 MWe

Dynamic Multi-Source Heat Recovery Case



HRS ORC Application: Natural Gas Compression



HRS ORC Application: Plant controls

Questions