Center for Compact and Efficient Fluid Power

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Characterization and Calibration of a Power Regenerative Hydrostatic Wind Turbine Test Bed using an Advanced Control Valve

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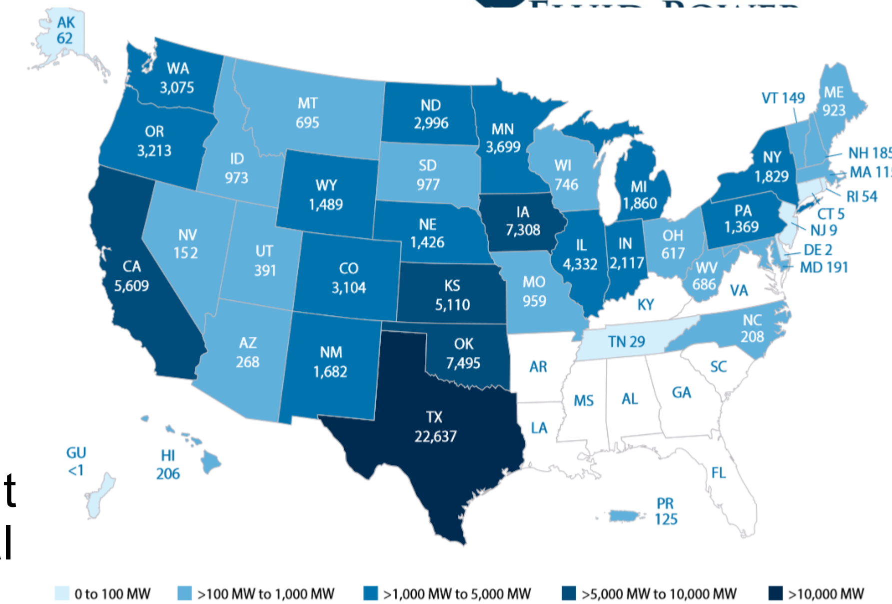
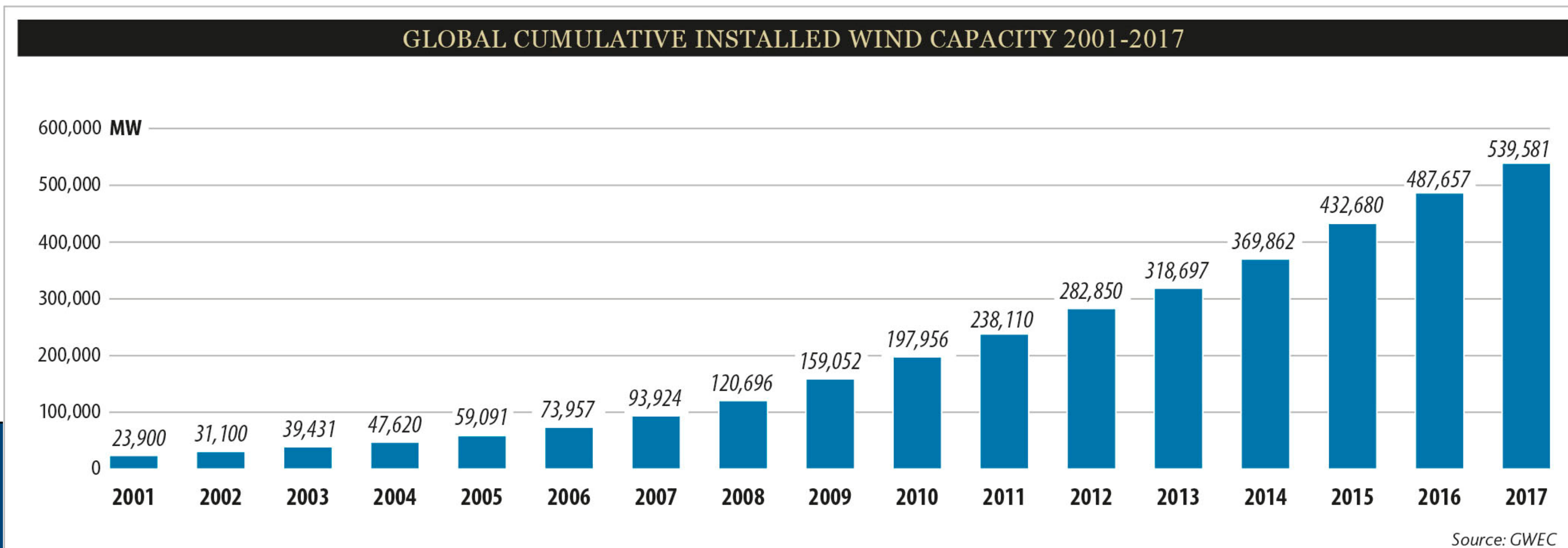
Wind statistics

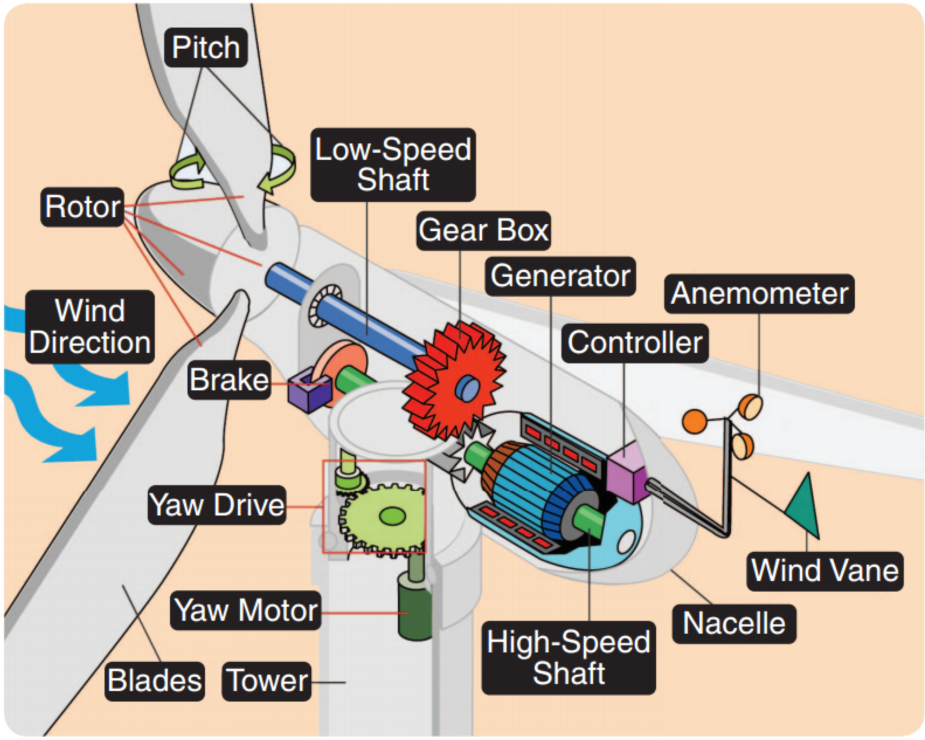
- Fastest growing green energy source
- 5% of the global electricity, 540 GW in 2017
- 6% of the U.S. electricity, 89 GW in 2017
- DOE goal of 20% of U.S. energy from wind by 2030
- Midsize wind turbines are an attractive but under recognized means to meet this goal

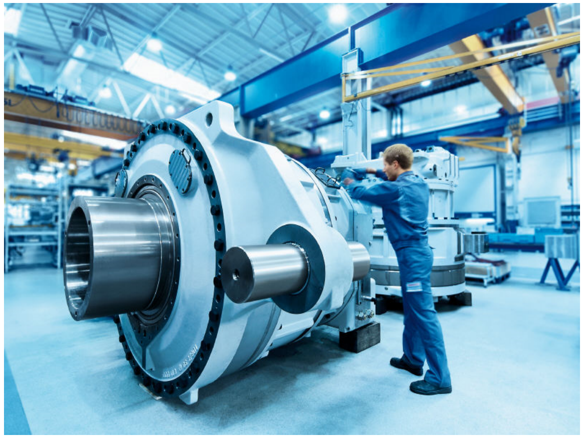


erican Wind Energy Association | U.S. Wind Industry Fourth Quarter 2017 Market Report | AWEA Public Version



Conventional wind turbine





Two-Stage Planetary with One-Stage Parallel Shaft	
Power:	2.3 - 2.9 MW @ 14 - 16 RPM input speed
Input Torque:	1500 - 1920 kNm
Ratio:	78:1 - 136:1
Output Shaft Type/ Location:	Horizontal output shaft located at a 550 mm centerline distance
Approx. Weight:	21,100 kg (46,500 lbs)
Overall Length:	2550 mm

- Two or three stages of planetary or parallel shaft gear train
- Three actuators: yaw motor, pitch motor & generator
- Synchronous or asynchronous generator

Conventional wind turbine

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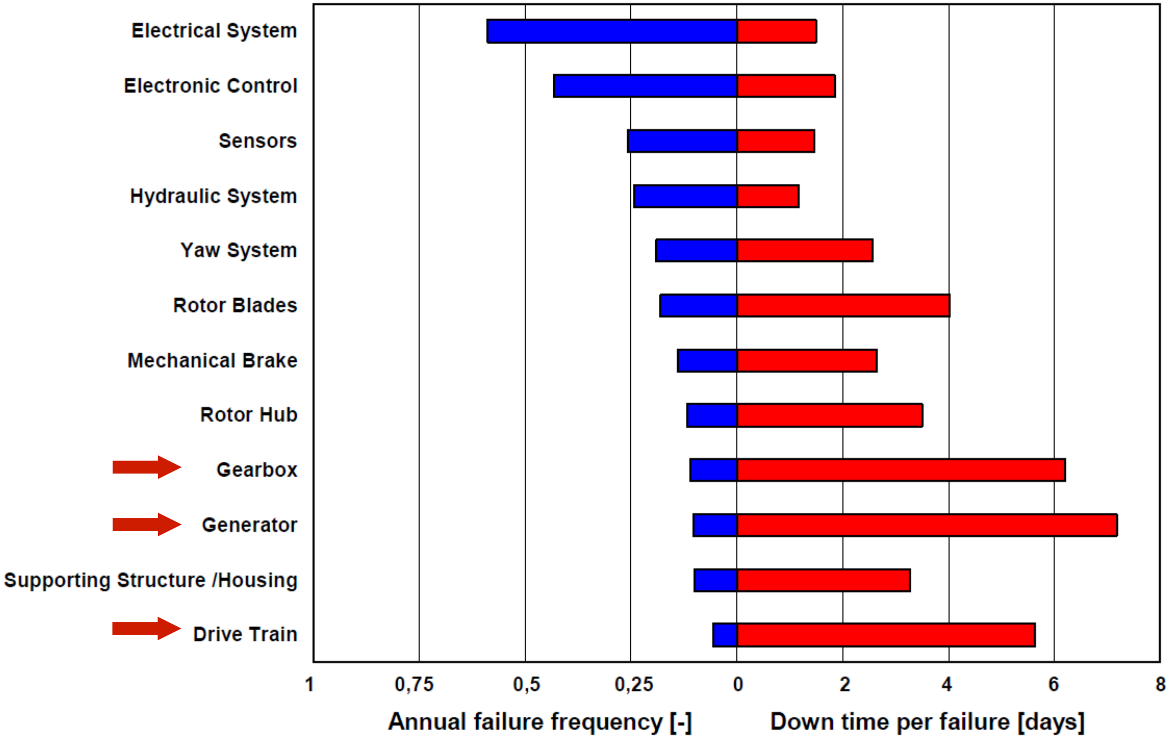

Failure frequency and downtimes of components

- Studies show the major components contributing to low reliability and increased downtime of turbines are found to be the **gearbox, generator and the drive train**.*

* http://www.reliawind.eu/
* C Ensslin, M Durstewitz, B Hahn, B Lange, K Rohrig (2005) German Wind Energy Report 2005. ISET, Kassel

Midsize wind opportunity

Midsize wind (100 kW-1 MW):

- Community wind - cost-effective for farms, communities, factories and rural electric cooperatives.
- Relatively easy permitting process
- Mid-size turbines can operated in local niches, eliminating the need for costly electric power transmission upgrades.
- Distributed wind makes the power grid more stable and reliable.
- Few midsize turbines in the market today
- Commercially hydrostatic units are available in required size.

Community wind

Potential of HST wind turbine

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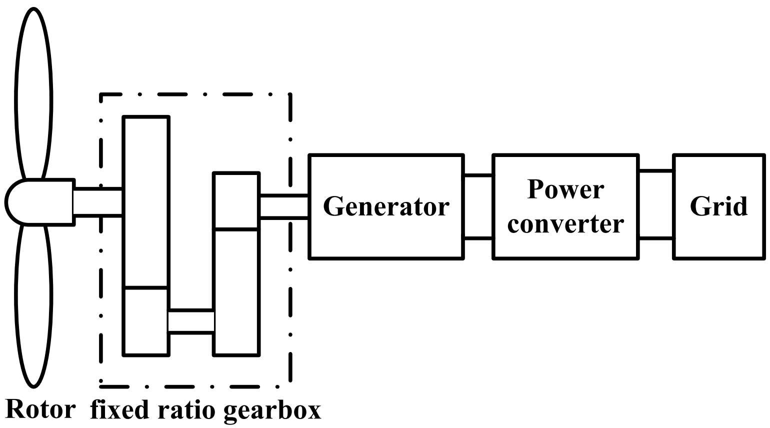
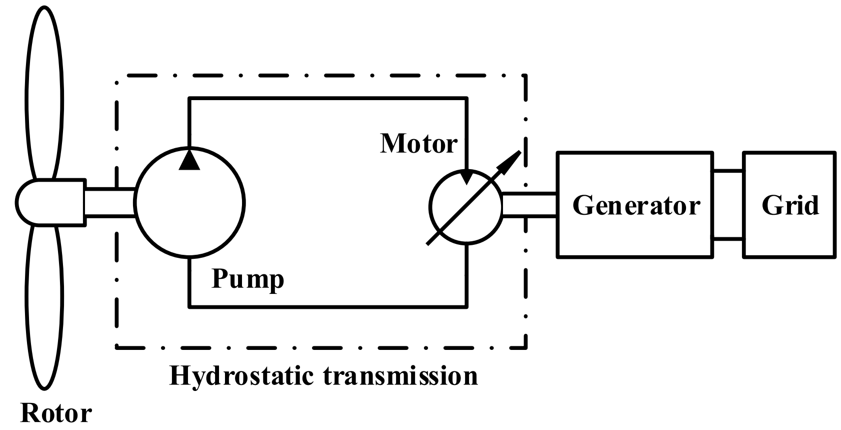


Conventional gearbox turbine



Hydrostatic wind turbine

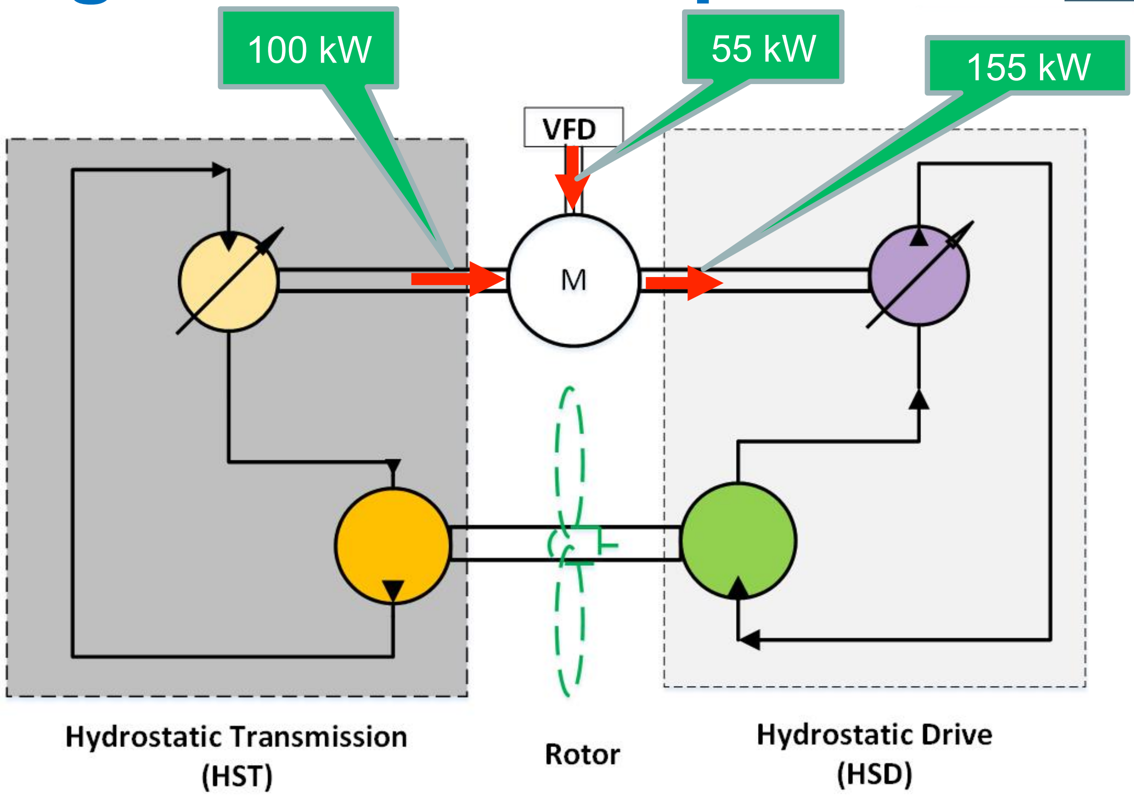
Performance Objective

- ❑ Maximize power capture
- ❑ Minimize loads
- ❑ Reduce downtime
- ❑ Reduce maintenance cost

Hydrostatic transmission (HST):

- ❑ Simple system structure
- ❑ Continuous variable transmission ratio
- ❑ No need of power converter
- ❑ All power transmitted through a fluid link; hence less stiff
- ❑ Improves reliability and reduce cost

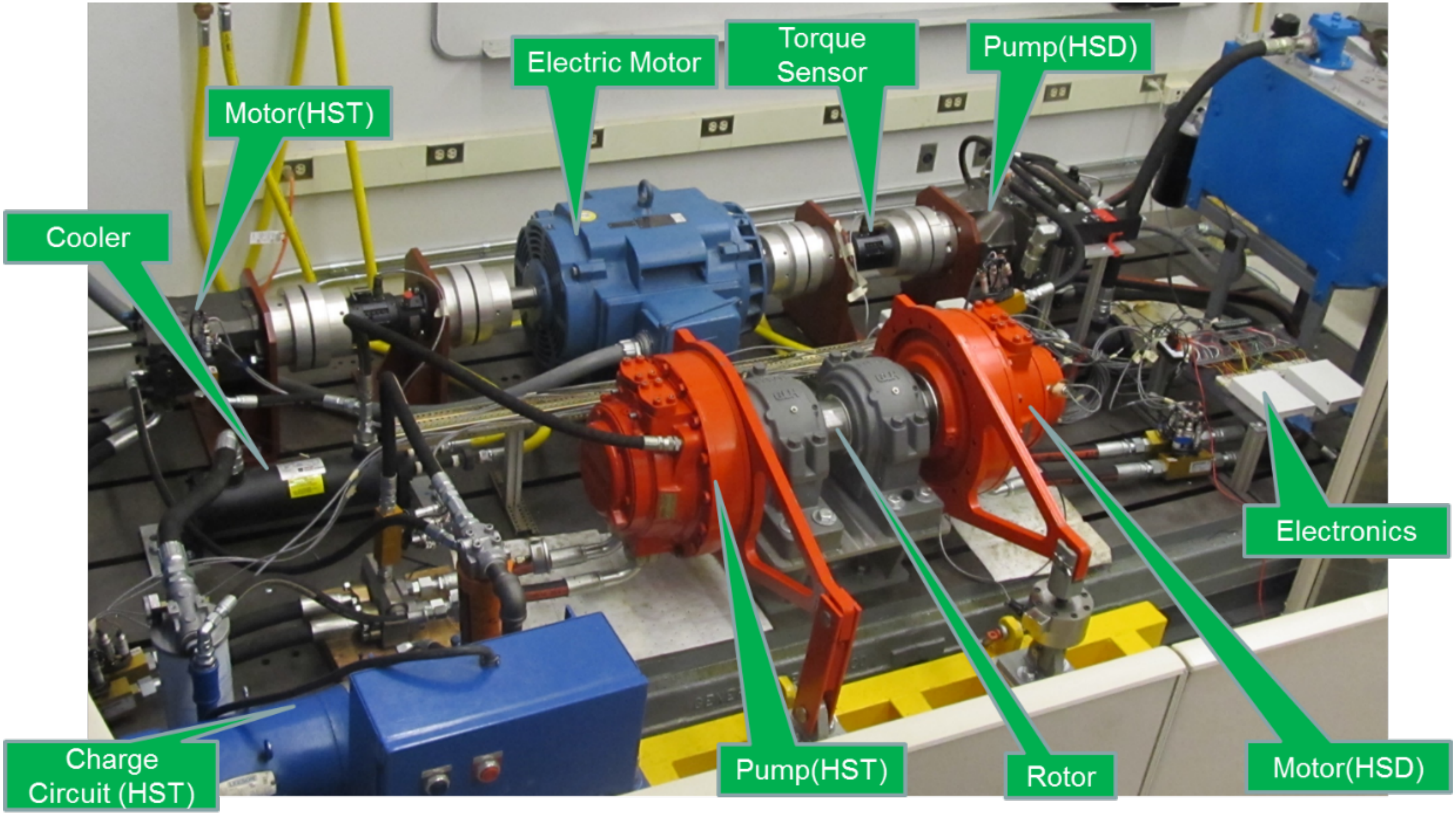
Power regenerative test platform



- **To Investigate the performance of hydrostatic transmission**
- **To test the advanced control algorithm**

1. Capable of simulating a turbine output power of 100 kW
2. Small electric motor (55kW) to compensate for losses in the components

Power regenerative test platform



Objective

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- **Sensor Calibration:**
  - Flow meter: Calibrated using advanced control valve and a calibrated flow sensor.
  - Pressure : Dead weight tester
  - Temperature: Water bath and calibrated temperature sensor.

- **Characterization of components**
  - A variable displacement pump and a fixed displacement motor for HSD.
  - A fixed displacement pump and a variable displacement motor for HST.
  - Requires large power supply to characterize each unit independently.
  - Advanced control valve is used to characterize each unit within the power regenerative test platform.

Advanced Control Valve

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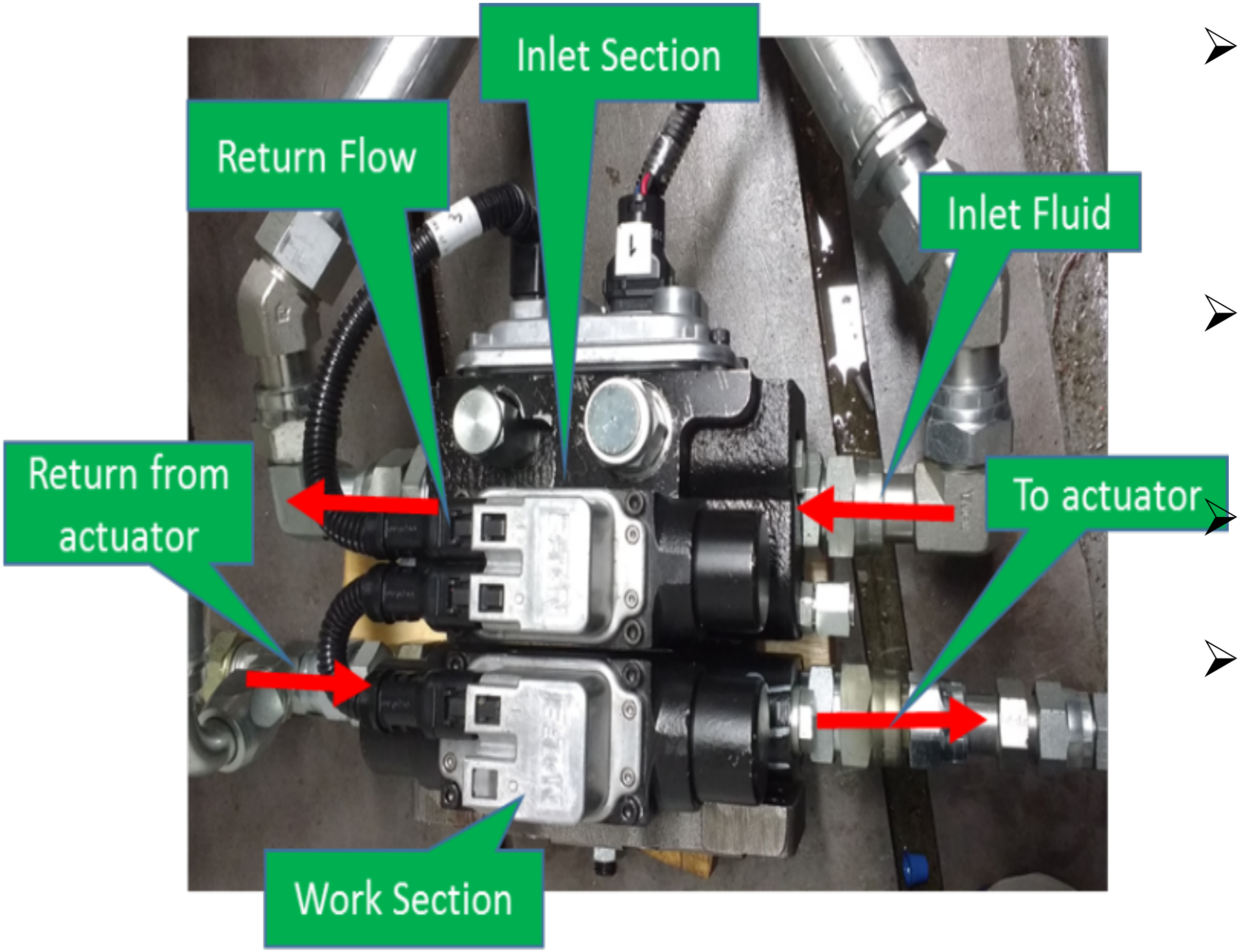
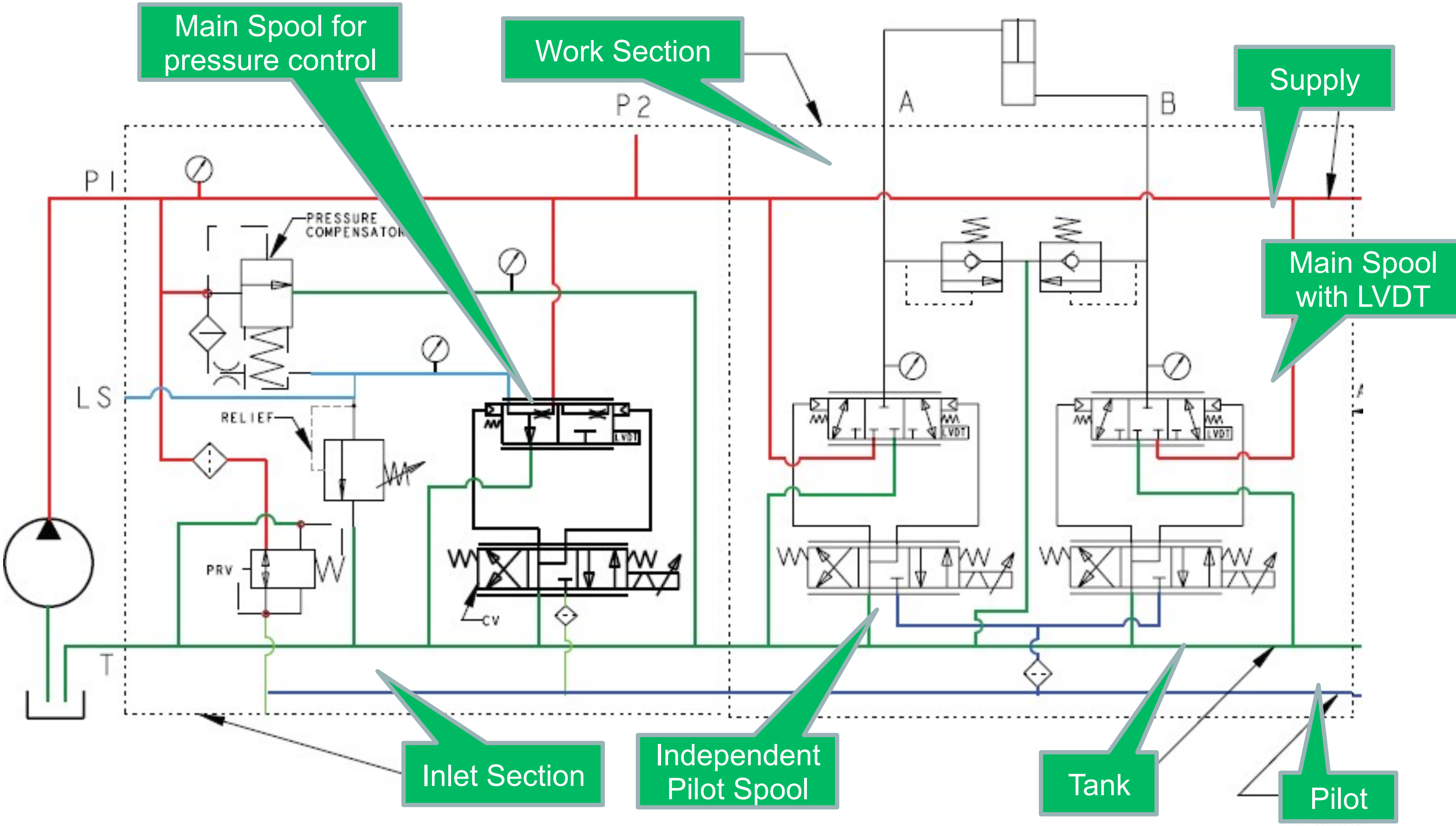


- Electrohydraulic sectional valve with independent metering spools.
- Integrated with pressure sensors, and spool position sensors.
- Capable of controlling either flow or pressure.
- For 15 cSt hydraulic oil, the valve has a bandwidth of 17.5 Hz and a rise time of 24 ms.

Advanced Control Valve



Calibration of Flow Sensor

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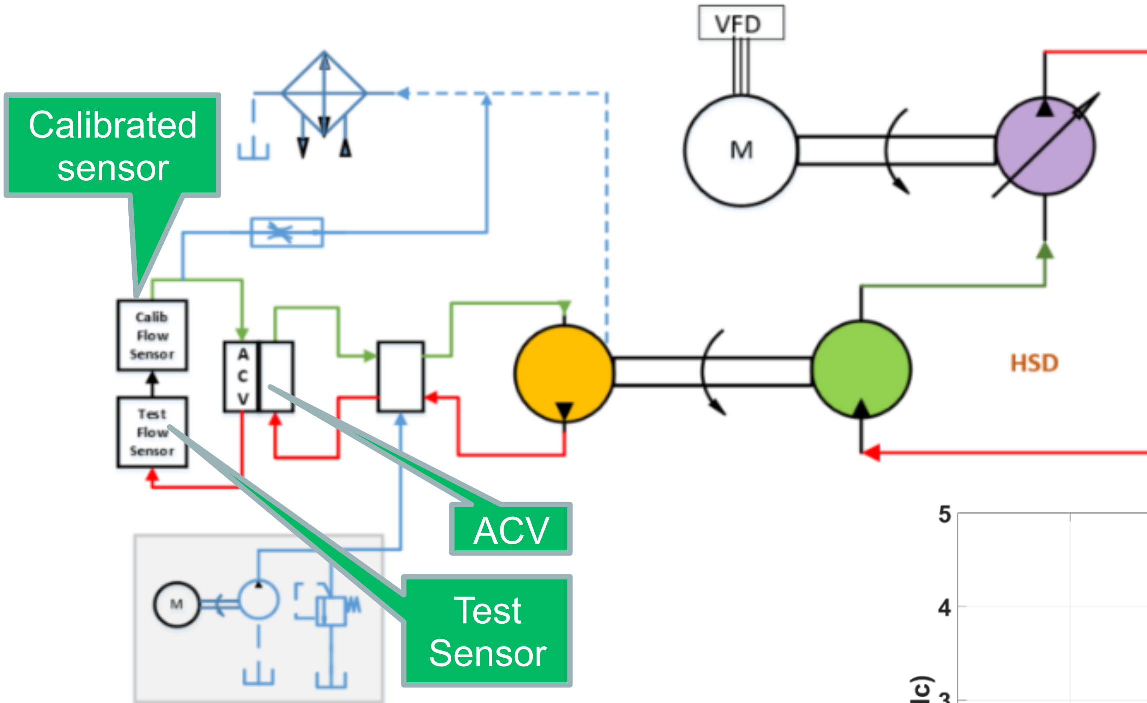
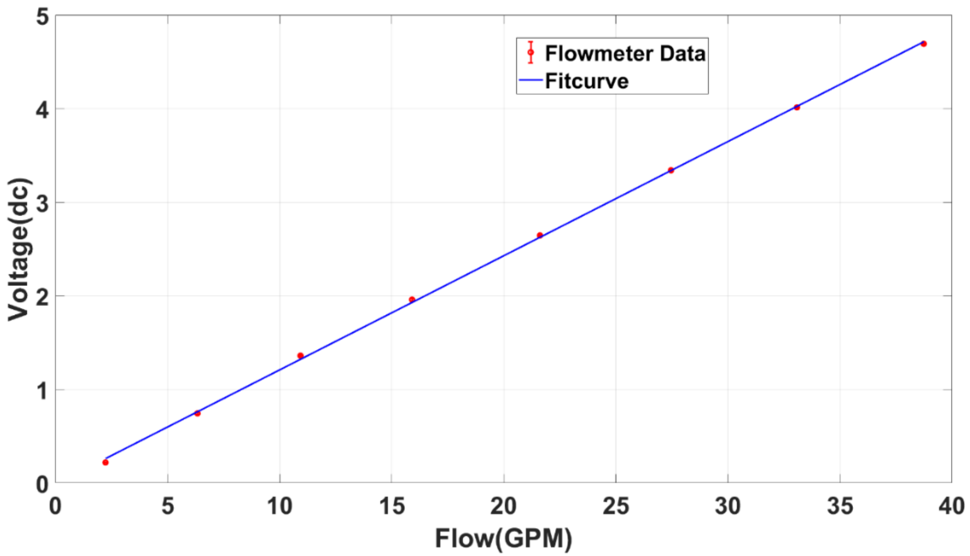


- ➢ HSD together with hydraulic pump supply flow to inlet section of the AVC
- ➢ The desired amount of flow is send to test flow sensor from work section of the ACV

- ❑ The ACV does not measure the flow but rather it controls the flow by controlling the position of the spool.
- ❑ The test flow sensor is calibrated with a calibrated flow sensor.



Characterization of Components

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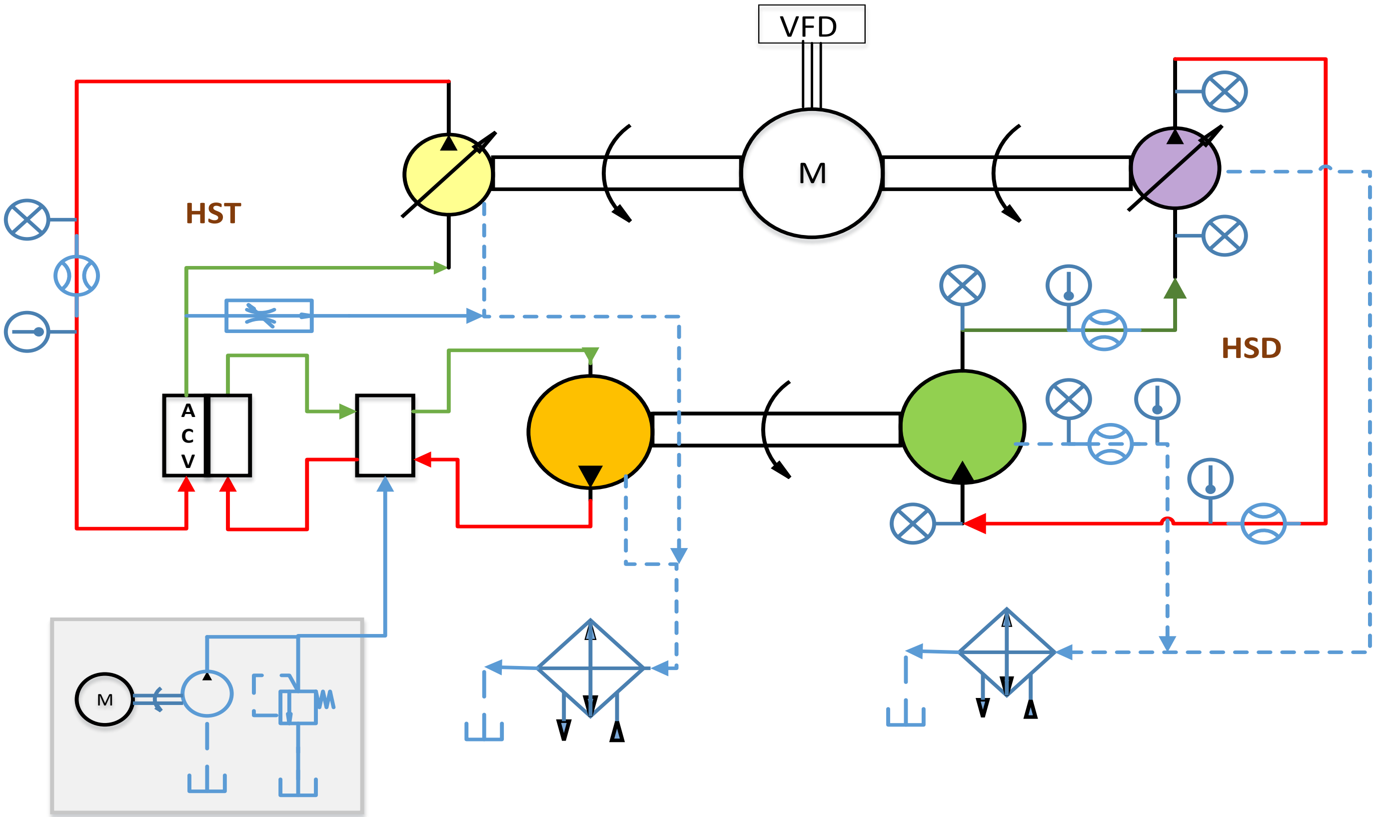

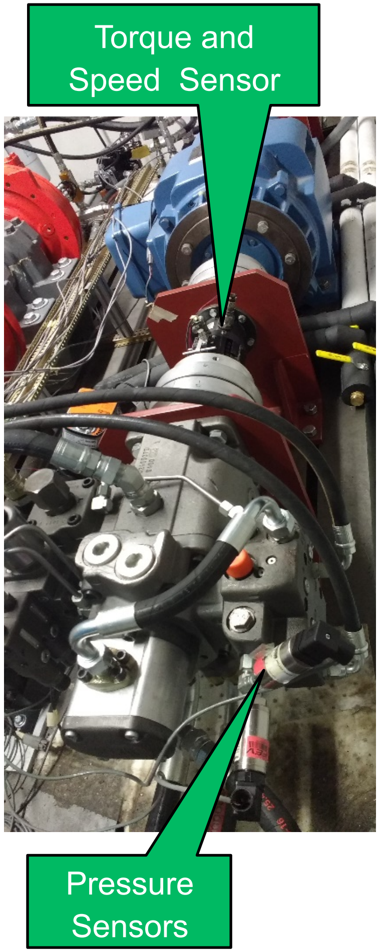

- **Hydraulic line:** Pressure, flow and temperature sensors.
- **Mechanical line:** Torque and speed sensors.
- The ACV is used to load the circuit

Characterization of HSD pump

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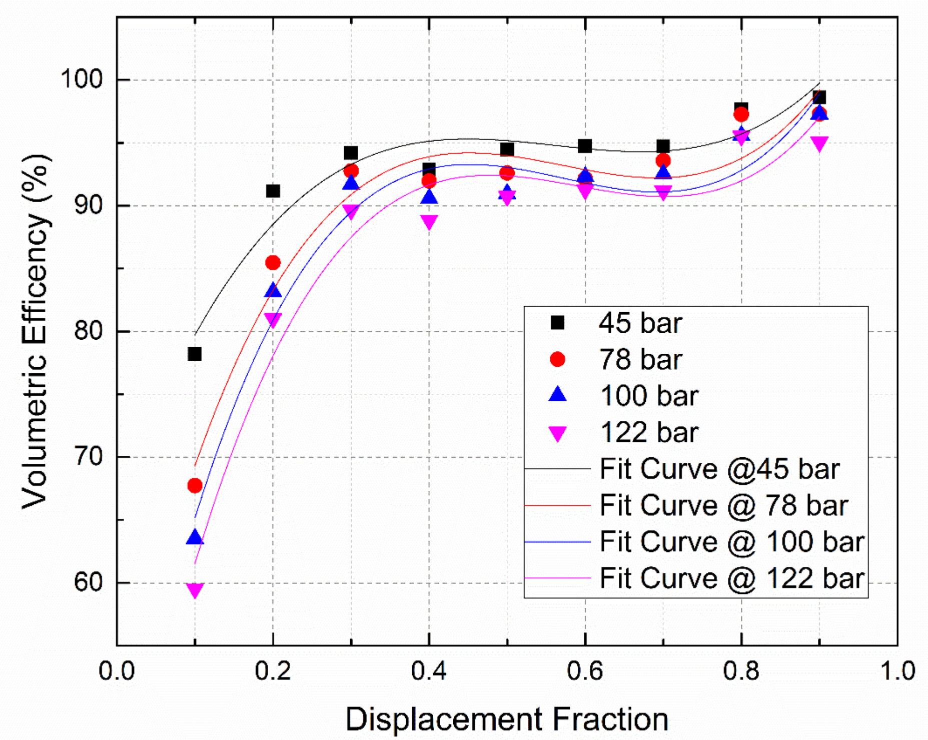

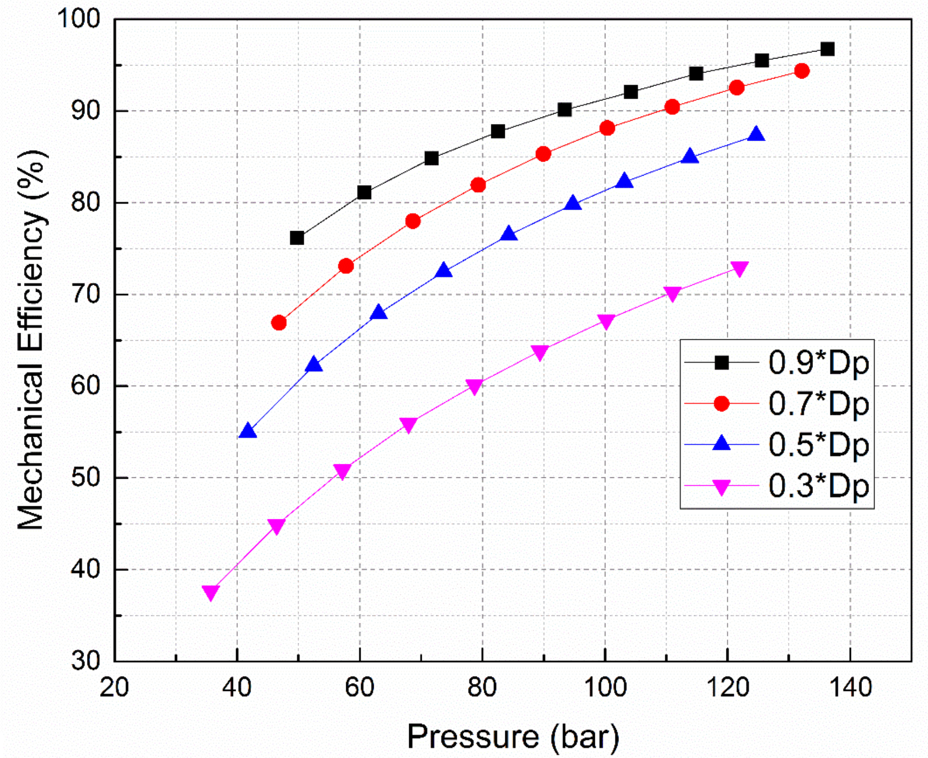

- **Specification:** 180 cc, Variable displacement axial piston @1000 rpm
- Sharp decrease in volumetric efficiency below 30% displacement fraction.
- Poor mechanical efficiency at low pressure and low displacement.

Characterization of HSD motor

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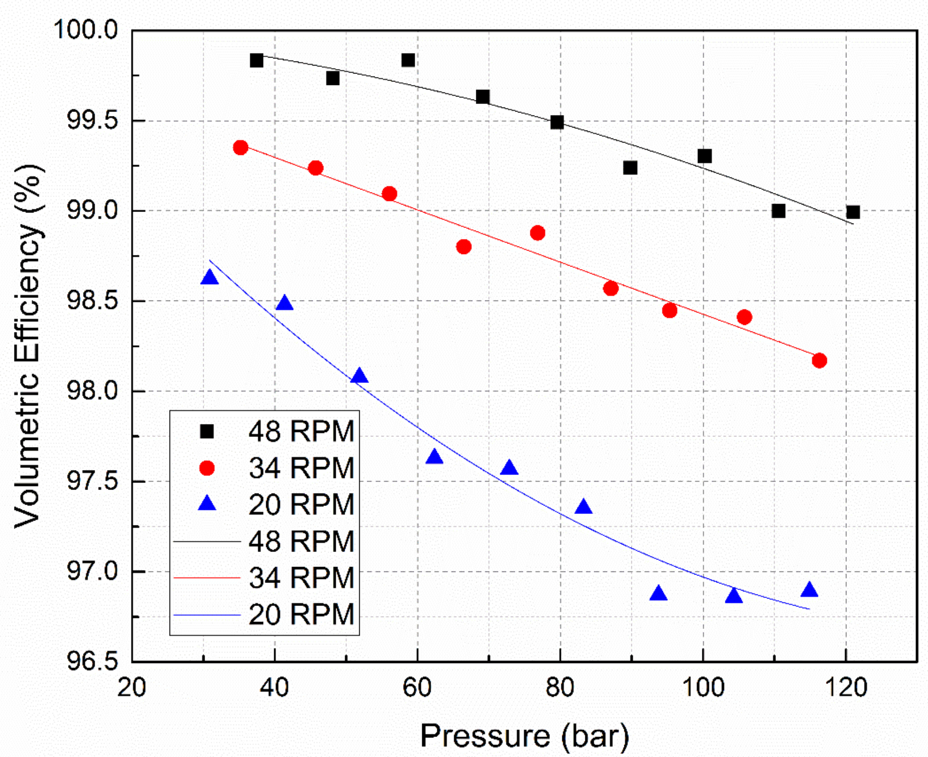

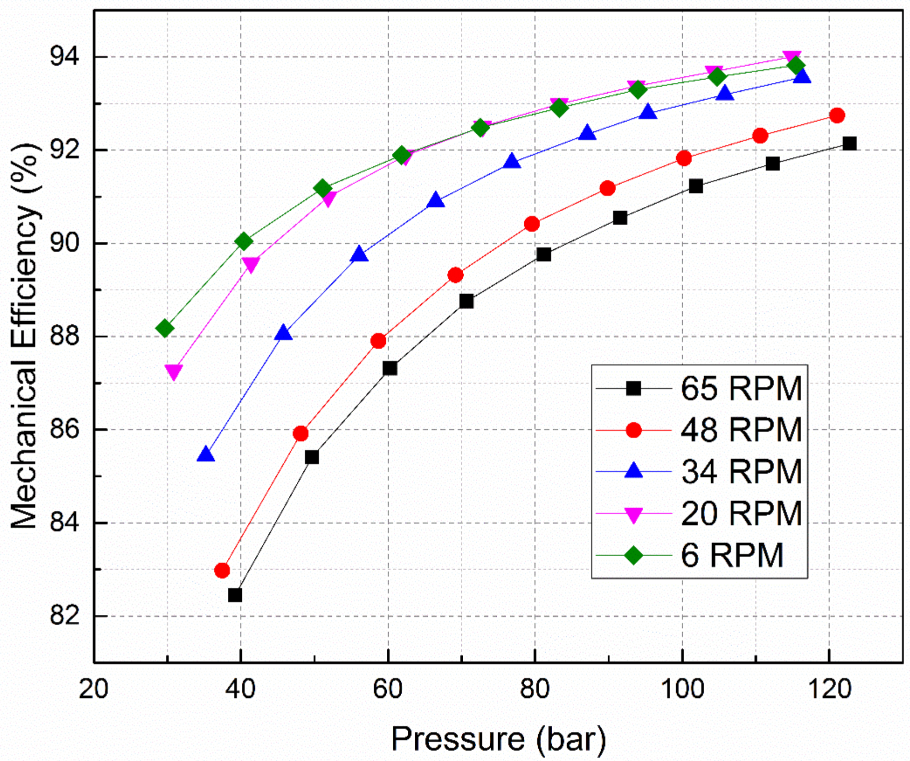

- ➢ **Specification:** 2512 cc, Radial piston fixed displacement motor
- ➢ High volumetric efficiency at high speed operation
- ➢ Better mechanical efficiency at high pressure operation, but poor performance at high speed and low pressure operation

Conclusions

- Midsize wind is a great opportunity to increase wind resources while preserving stability and reliability of the grid. An HST transmission is ideally suited to this size range.
- Electrohydraulic advanced control valve is equipped with multiple sensors, on-board electronics and an advanced control algorithm that delivers high precision and fast response.
- The ACV provides a flexible architecture to control pressure or flow on inlet and outlet ports to characterize hydraulic pumps and motors using the existing power of the testbed.
- Low speed pump and motor are identical units. It will be instructive to compare their volumetric and mechanical efficiencies.

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Thank you!

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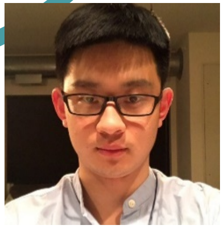

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