Workshop on AFDD for RTUs
Moving from R&D to Commercialization
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Virtual Sensing to Enable Integrated RTU Diagnostics

Jim Braun
Ray W. Herrick Laboratories
Purdue University
West Lafayette, IN 47907

Virtual Sensors

Low-Cost Measurements

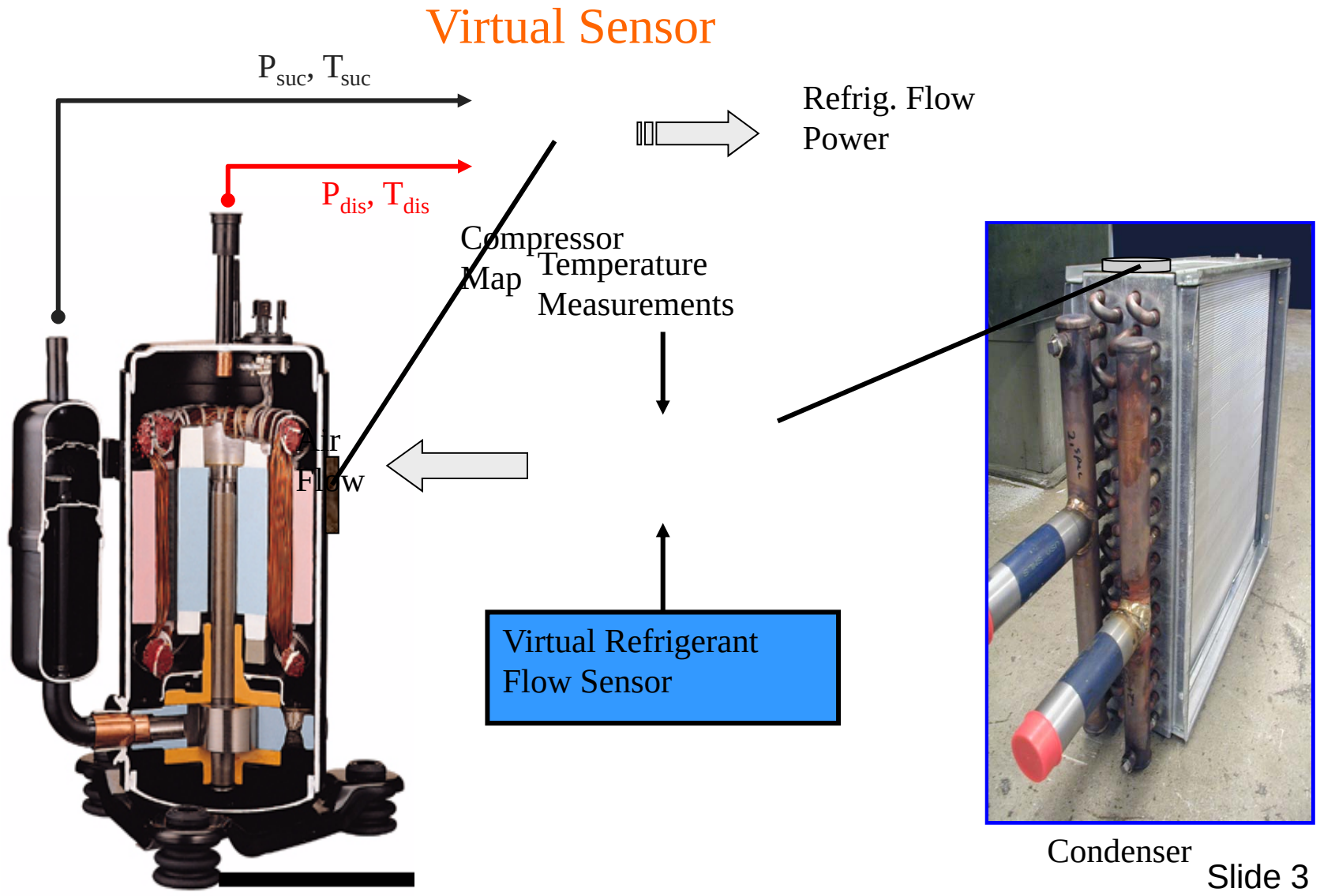
Mathematical Models

Estimations of quantities that are

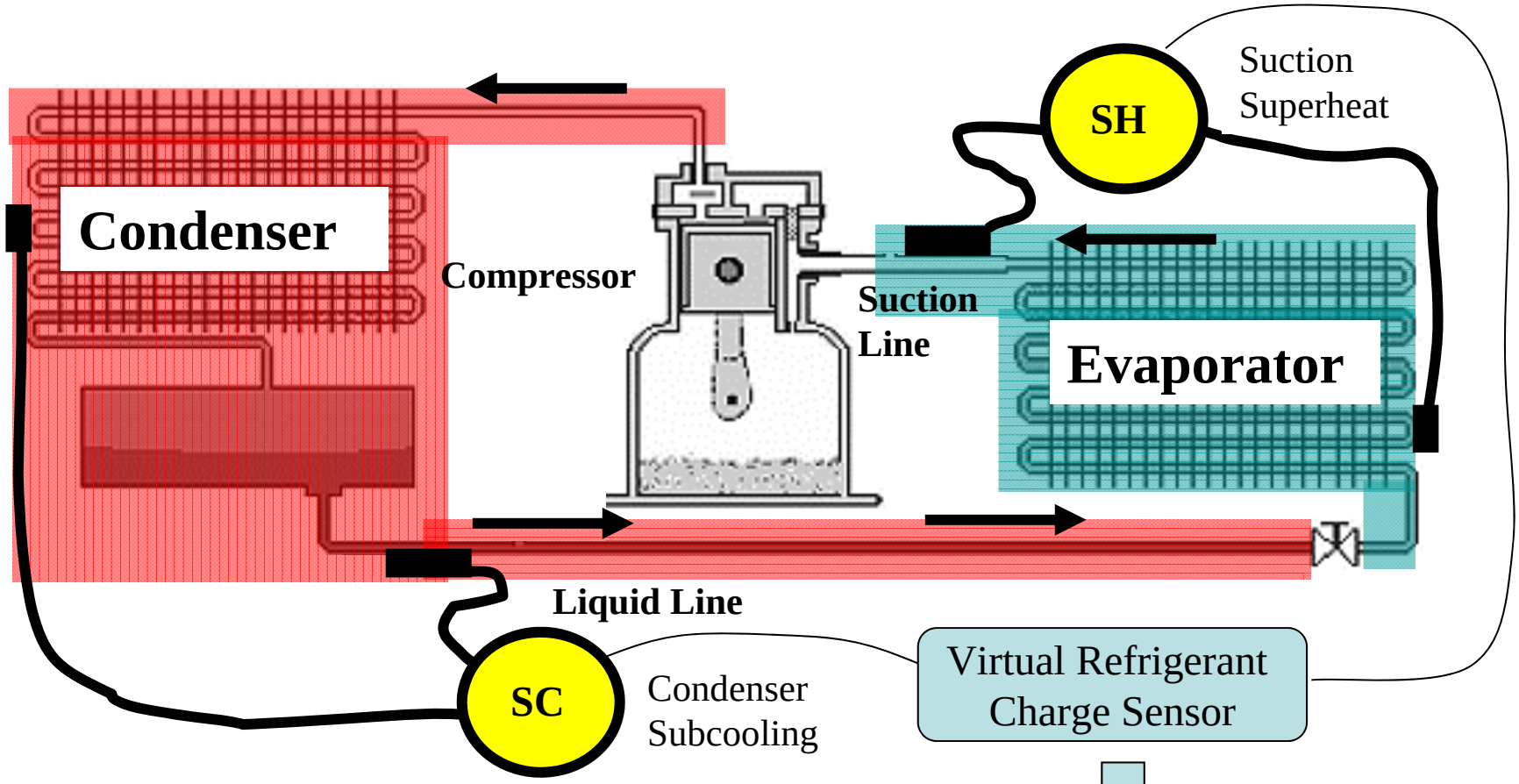
- Difficult to measure
- Expensive to measure

but that are needed as decoupling features for AFDD that can handle multiple-simultaneous faults

Virtual Sensor Example



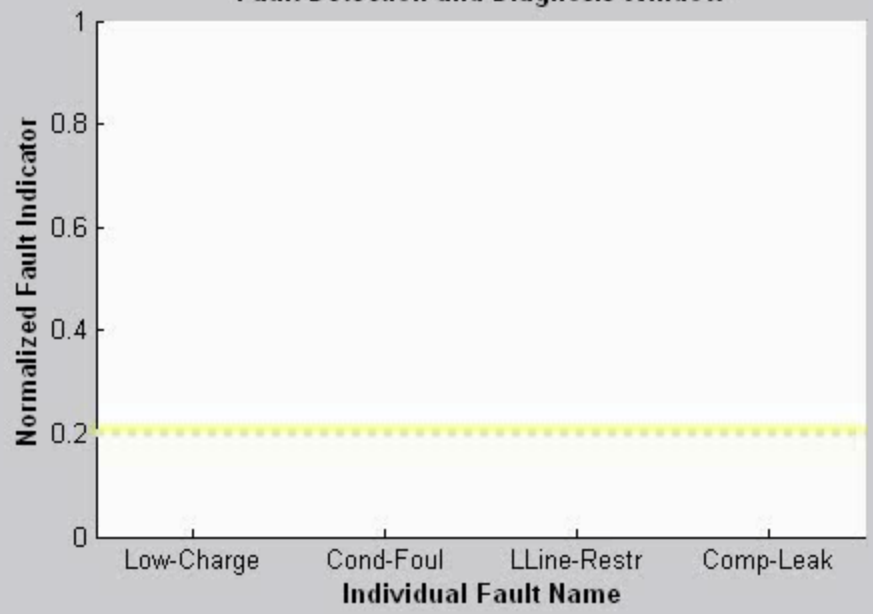
Virtual Refrigerant Charge (VRC) Sensor



VRC Sensor Demo

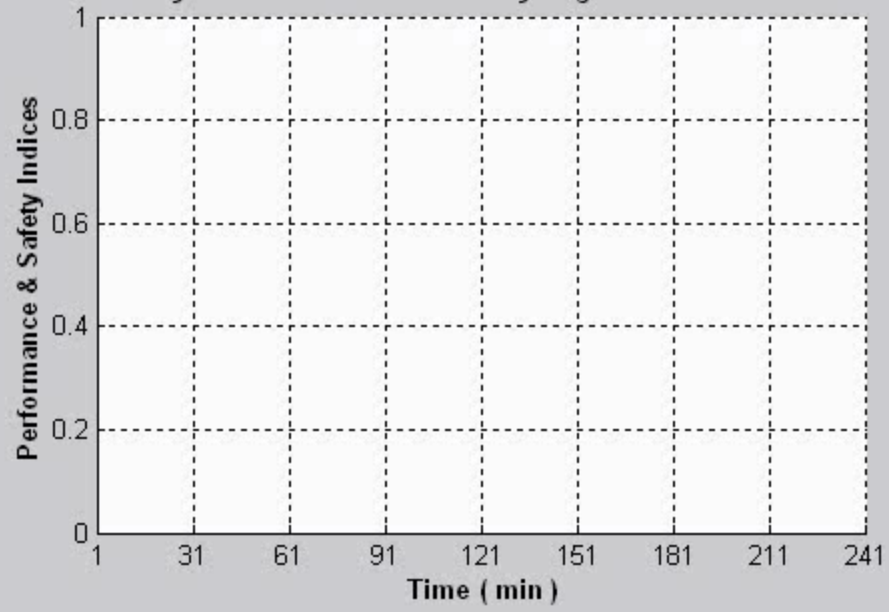
FDD Demo for Multiple-Simultaneous Faults

Fault Detection and Diagnosis Window



Field Fault Simulation Window

System Performance & Safety Degradation Window



FDD Report Window

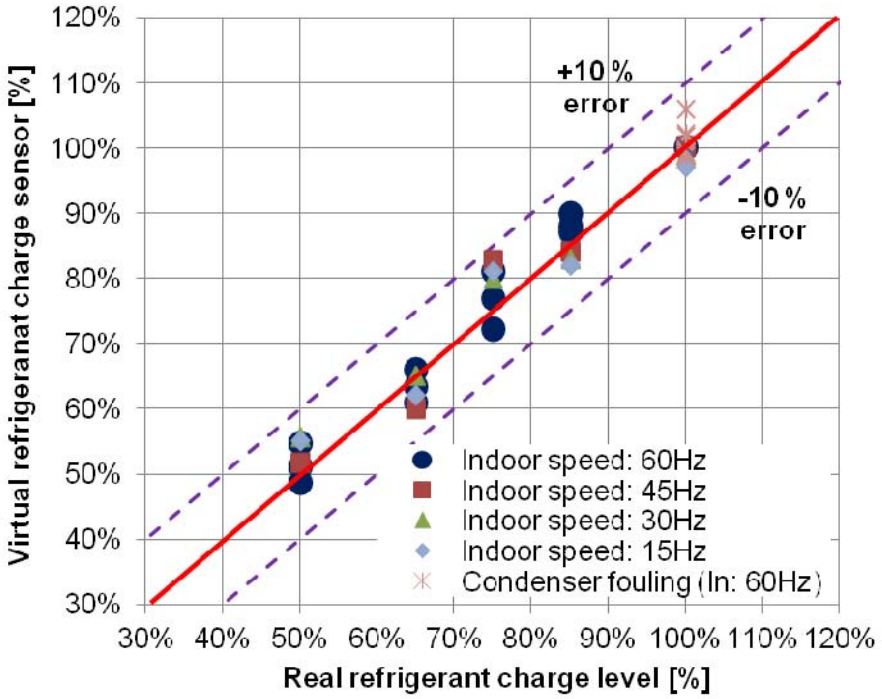
Other Virtual Sensor Examples

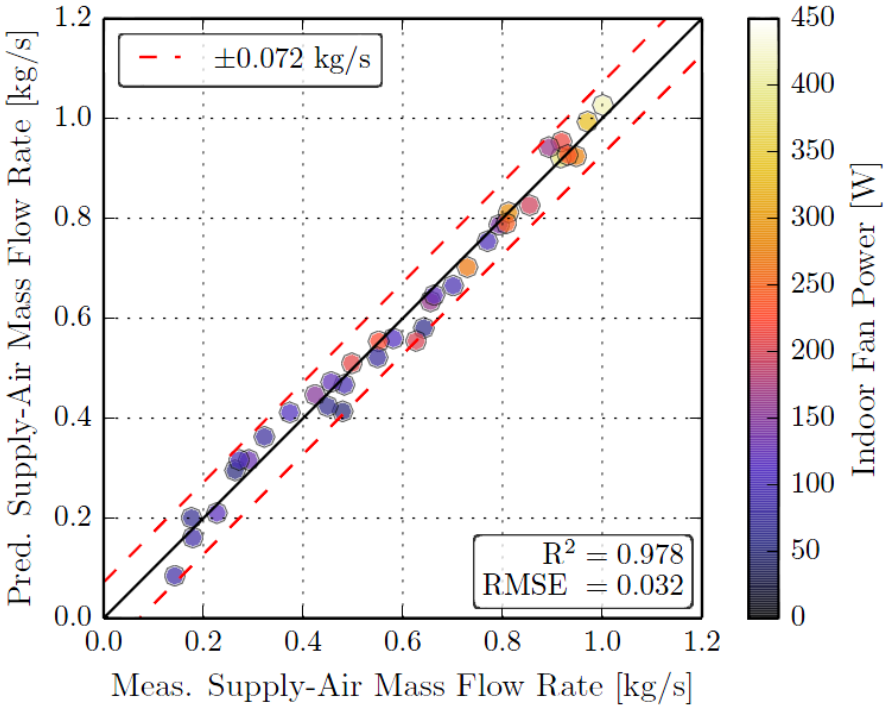
- RTU capacity
- Refrigerant mass flow rate (3 ways)
- Refrigerant charge
- Compressor power
- Evaporator air-flow rate
- Condenser air-flow rate
- Supply fan air flow rate
- Supply fan power
- Outdoor-air fraction

Some Virtual Sensor Inputs/Outputs

		Input	Output
Virtual refrigerant charge (VRC) sensor		1) **Evaporating / 2) Condensing 3) Suction / 4) Liquid line Temperatures**	Refrigerant Charge
Virtual Refrigerant Mass Flow (VRMF) Sensor	Compressor Map	**1) Evaporating / 2) Condensing Temperatures**	Refrigerant Mass Flow Rates (Compare 3 VRMF sensors to isolate faults)
	Energy Balance	**1) Evaporating / 2) Condensing 3) Suction / 5) Discharging Temperatures + VCP Output**	
	Expansion device	1) **Evaporating / 2) Condensing 3) Suction / 4) Liquid line Temperatures**	
Virtual Air Flow (VAF) Sensor	Indoor or Outdoor	**Fan Differential Pressure or Air Inlet/Output Conditions and VRMF Output**	Air Mass Flow Rate
Virtual compressor power (VCP) sensor		**1) Evaporating / 2) Condensing Temperatures**	Compressor Power

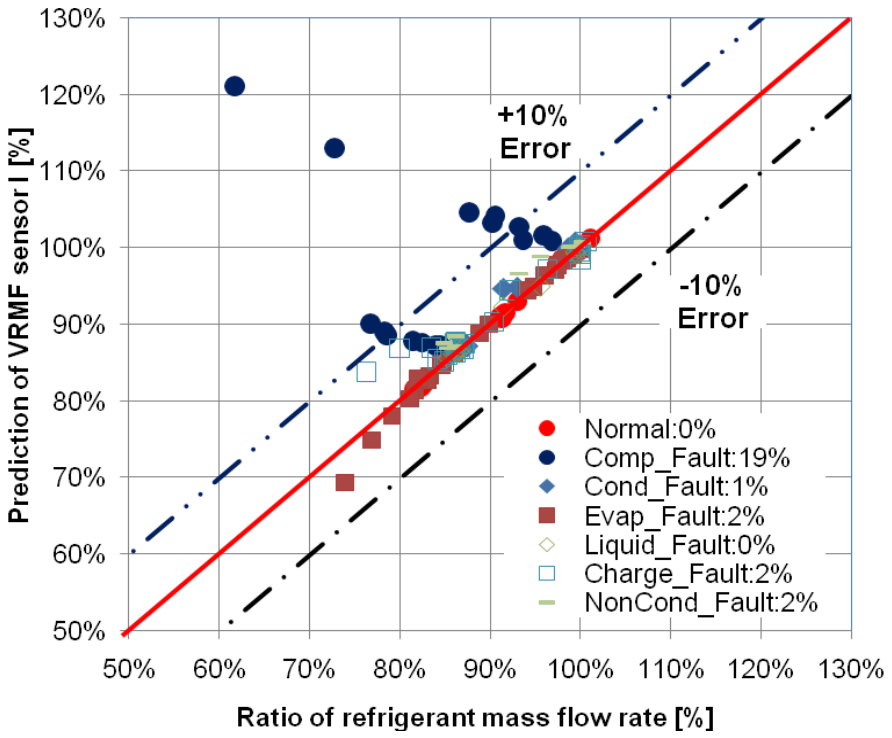
Example Validation Results



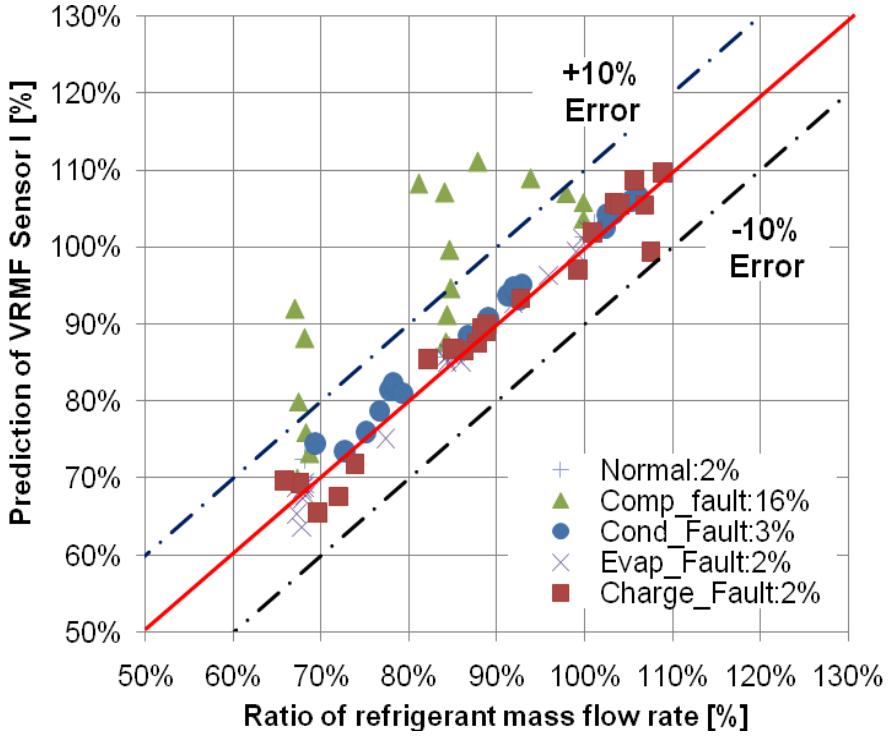


VRMF I (Compressor Map)

Both faulted and unfaulted conditions



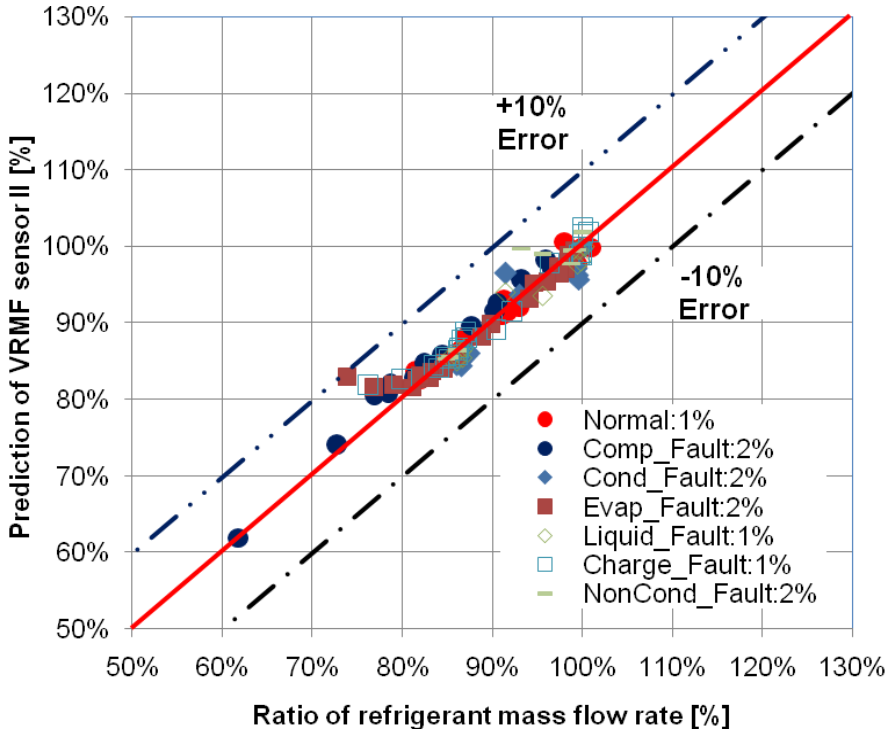
System w/ fixed speed compressor

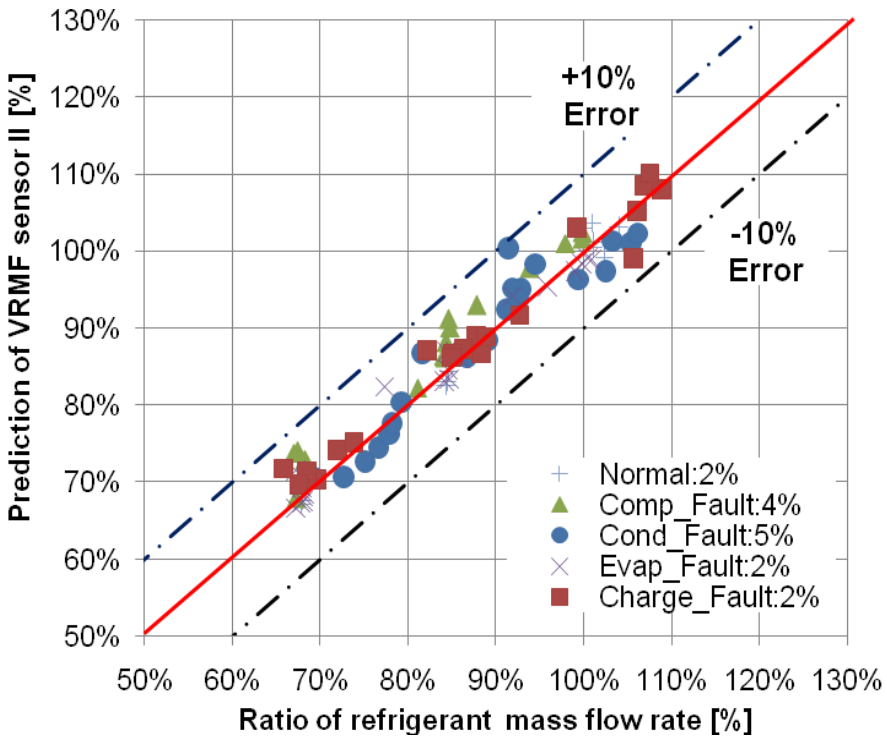


System w/ variable speed compressor

VRMF II (Compressor Energy Balance)

Both faulted and unfaulted conditions



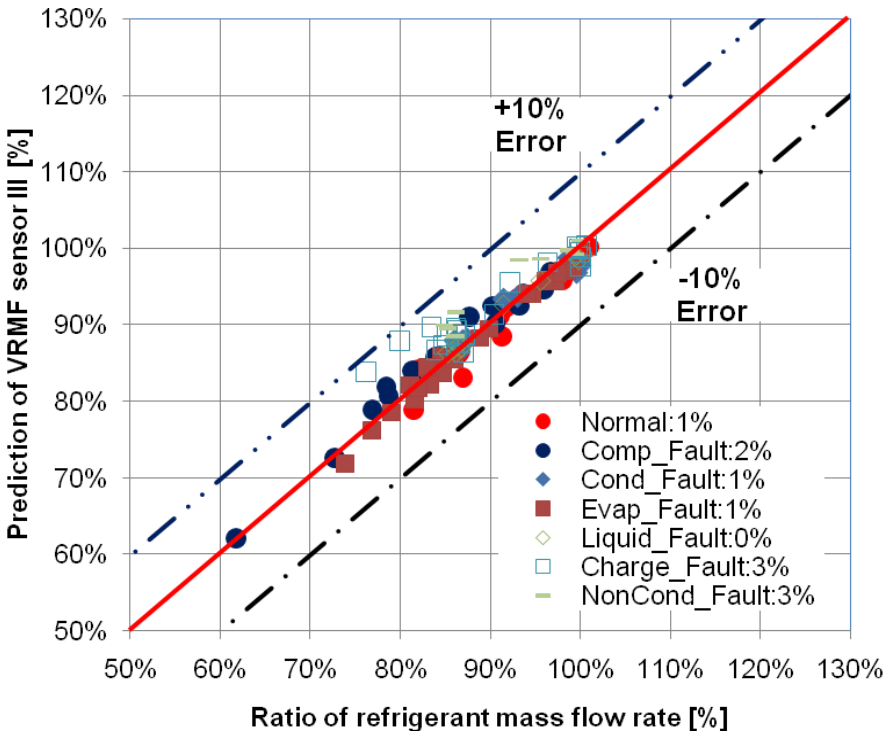


System w/ fixed speed compressor

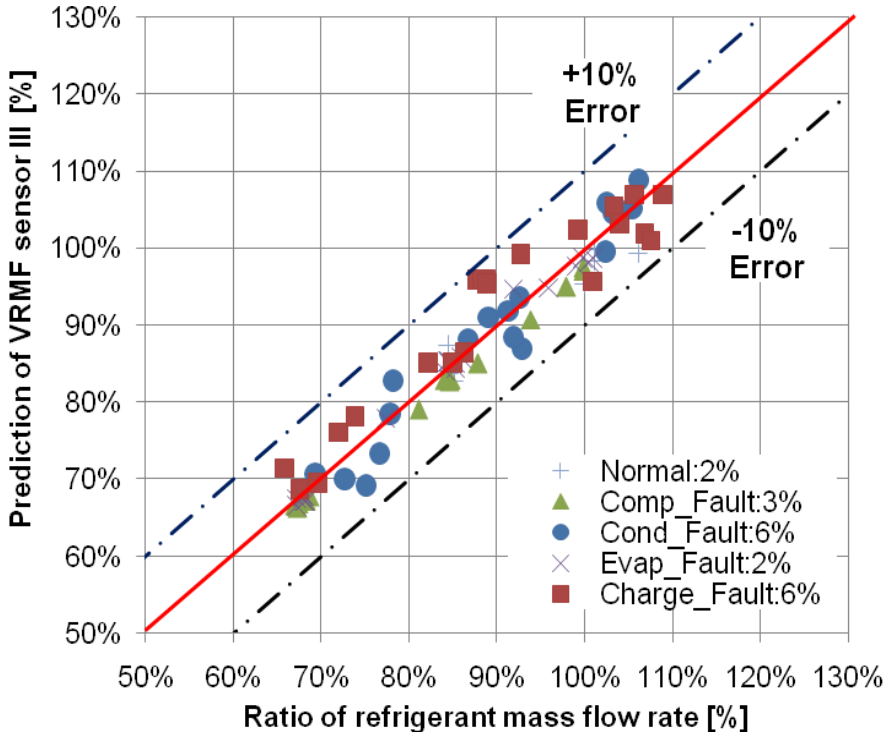
System w/ variable speed compressor

VRMF II (Expansion Device)

Both faulted and unfaulted conditions

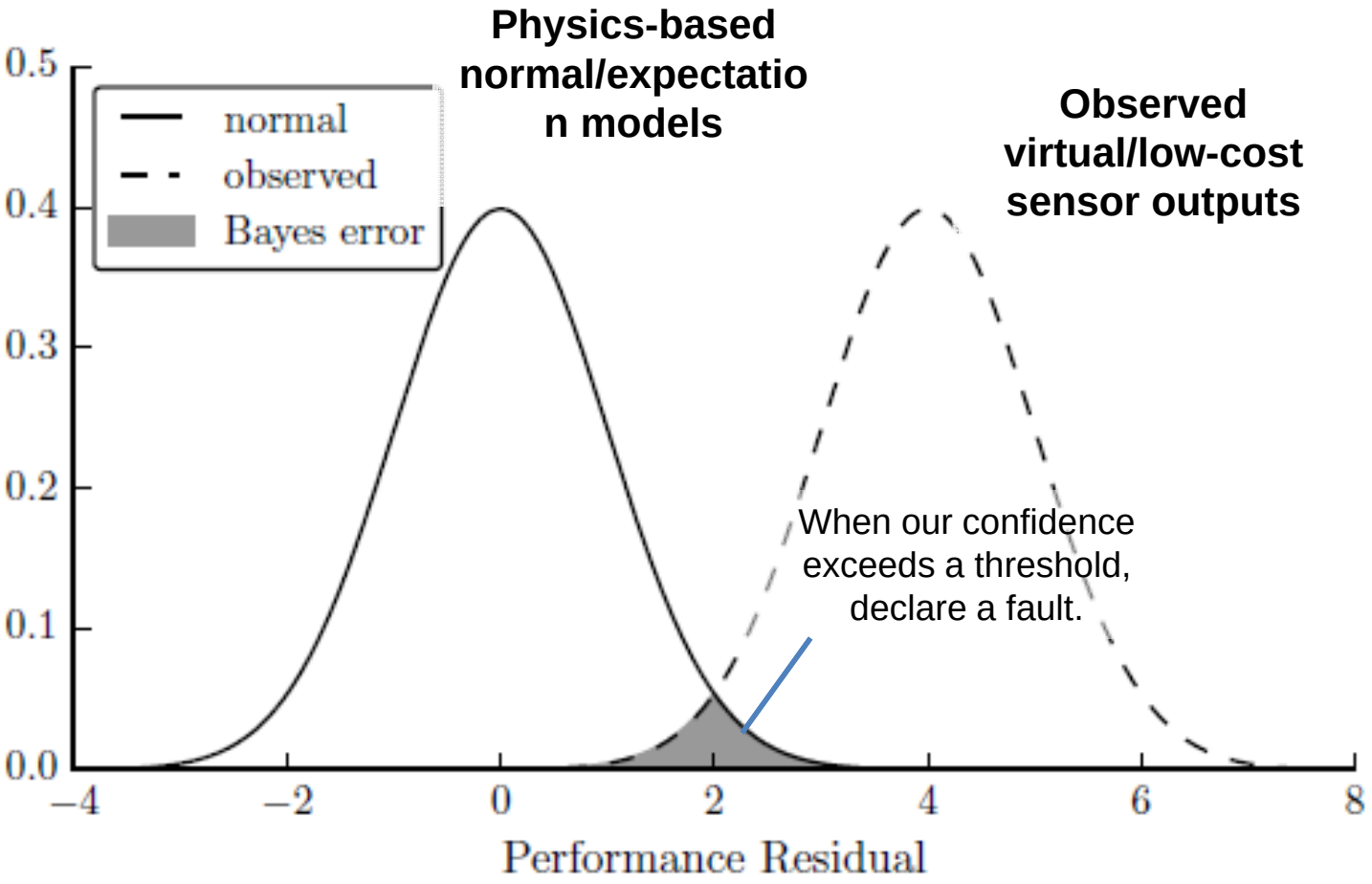


TXV w/ Fixed speed

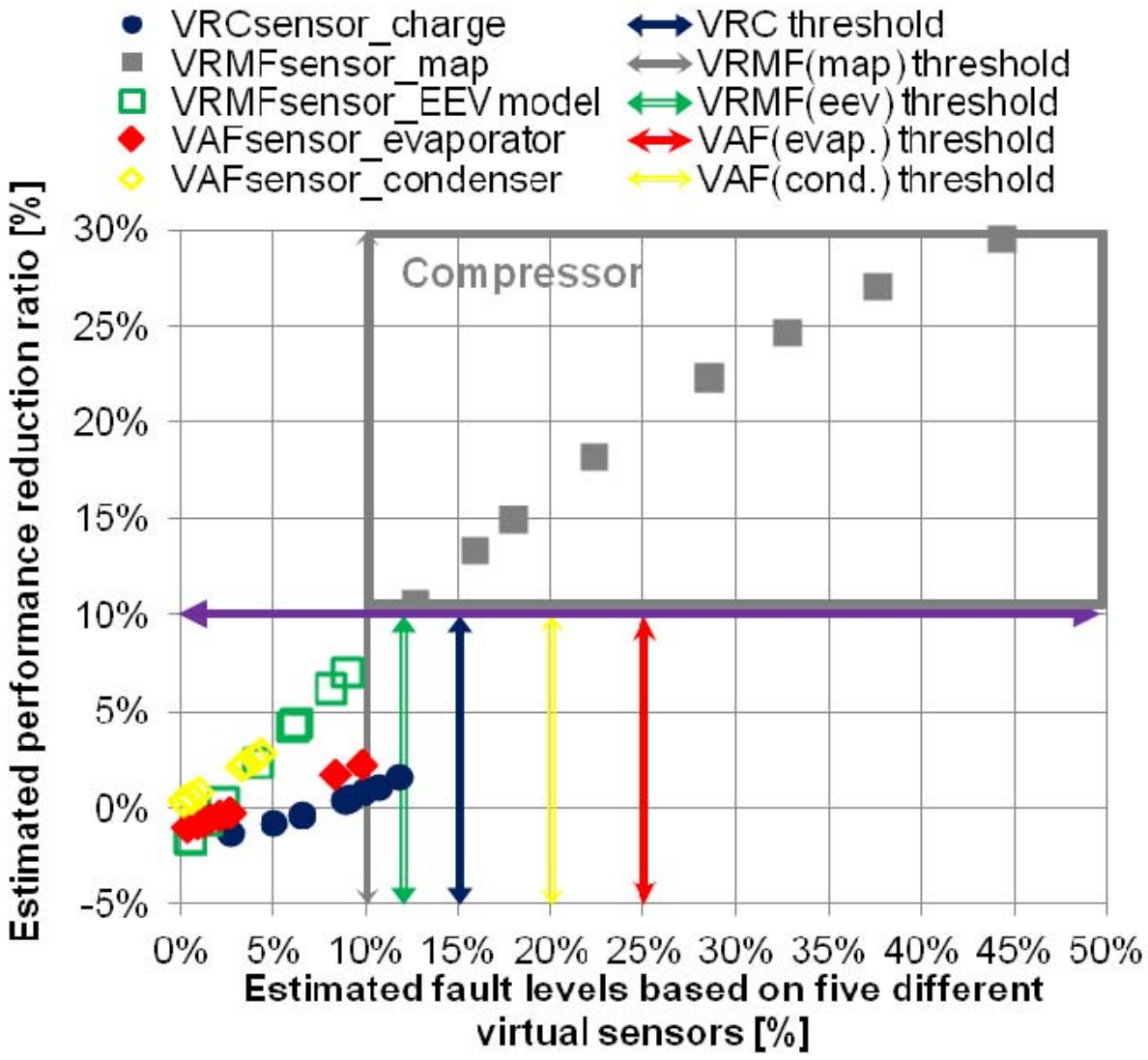


EEV w/ Variable speed

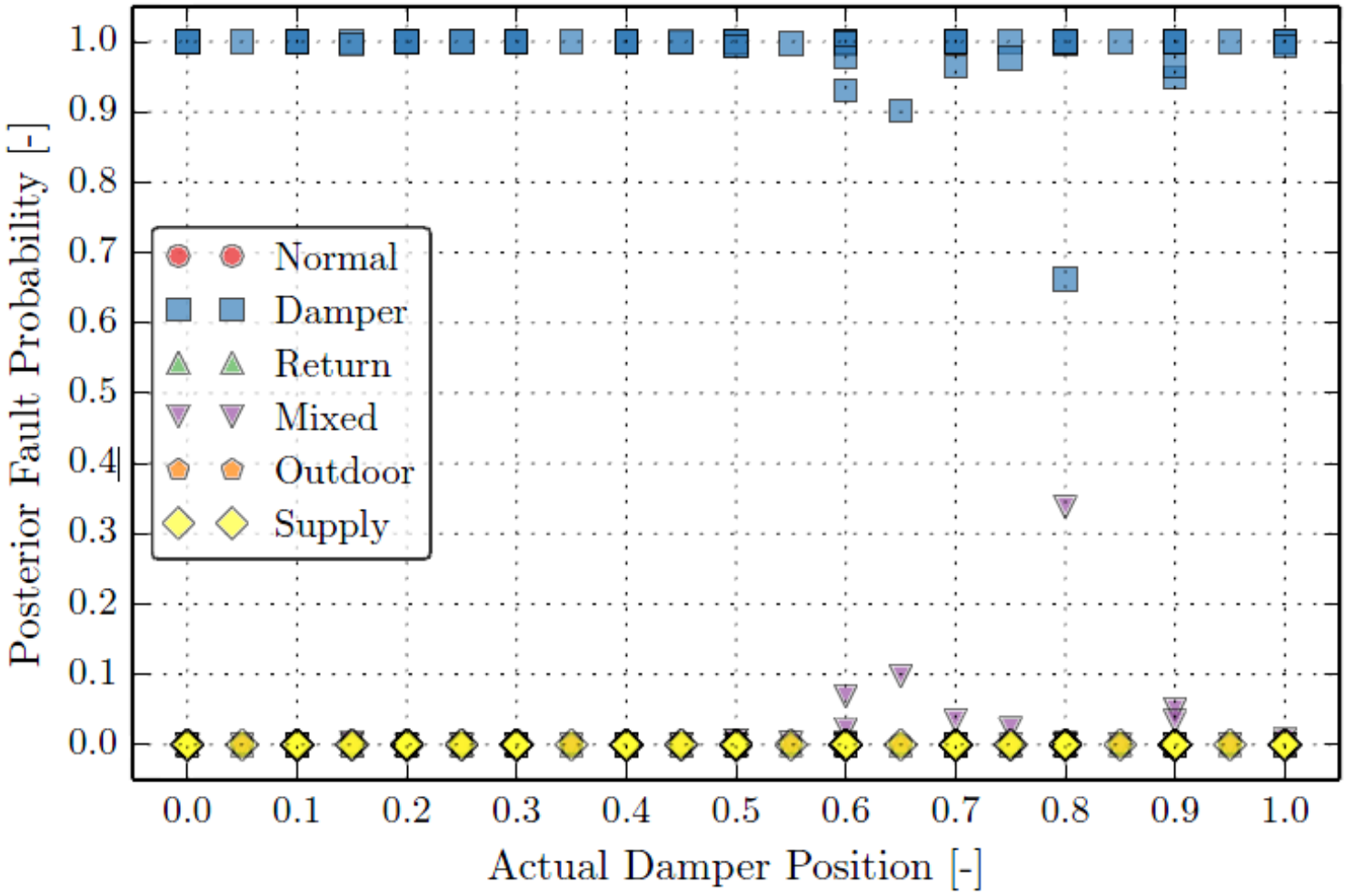
Statistical Thresholds for Faults



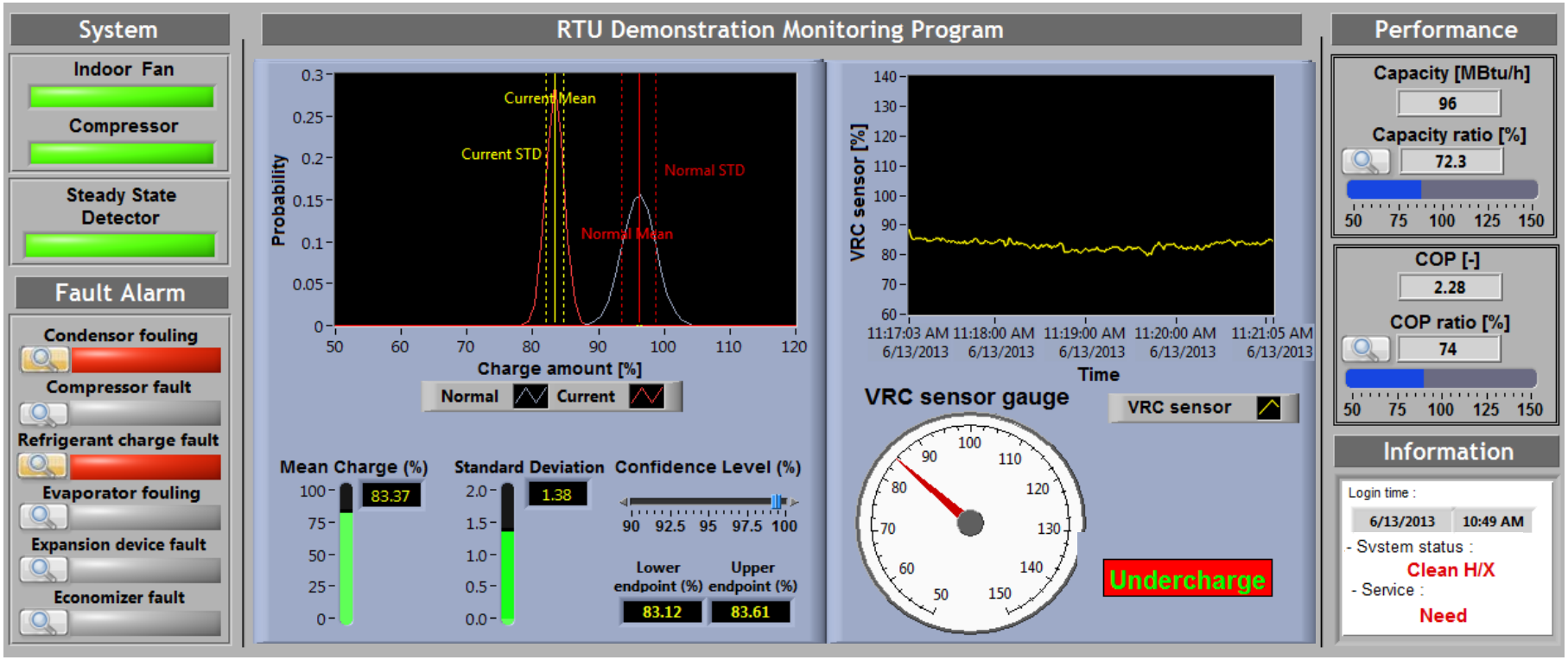
Example Outputs for Low Compressor Flow Fault



Example Outputs for Stuck Outdoor Air Damper



Example Diagnostics for Charge and Fouling



Thoughts

- Virtual sensors have the potential to enable relatively low-cost factory integrated diagnostics for RTUs
- Some integrated virtual sensors are starting to appear in high-end equipment
- Additional work needed to
  - extend virtual sensors to new equipment (units with variable-speed fans, tandem compressors, micro-channel heat exchangers)
  - reduce time to engineer/train virtual sensors for different models of equipment
  - develop optimal maintenance scheduling algorithms