Michigan Tech Smart Grid

Education and Laboratories

Bruce A. Mork

Sumit Paudyal

Bruce A. Mork, PhD, PE

Professor, Electrical Power Systems
Director, Power & Energy Research Center

Education:
- BS Mechanical Engineering, NDSU, 1979
- MS Electrical Engineering, NDSU, 1981
- Doctoral Researcher, NTNU, 1990-91
- PhD, Electrical Engineering, NDSU, 1992

Experience:

1992-date: **Michigan Technological University**

2013-14: Sabbatical at **NTNU**, research development.

2001-02: **SINTEF Energy Research/NTNU**, Trondheim, Norway
- Fulbright Senior Scientist; Research Council of Norway Visiting Researcher

1990-91: **NTNU**, PhD Exchange Student, Visiting Researcher

1989-90: **Statnett**, Husebybakken, Releavdelingen, Oslo, Norway
- Research Engineer: Relay Protection Group, Forensics, EMTP Studies

1982-86: **Burns & McDonnell Engineering**, Kansas City, MO
- Substation Design Engineer: 12.47-kV to 345-kV

  Station layout, high-voltage equipment, grounding, rigid bus, raceways, protection, relay control panels, SCADA, communications

1979-80: **HDR** (formerly SSR), Bismarck, ND
- 69-kV and 115-kV Trans Lines: Surveying, design, construction management

MTU Personnel

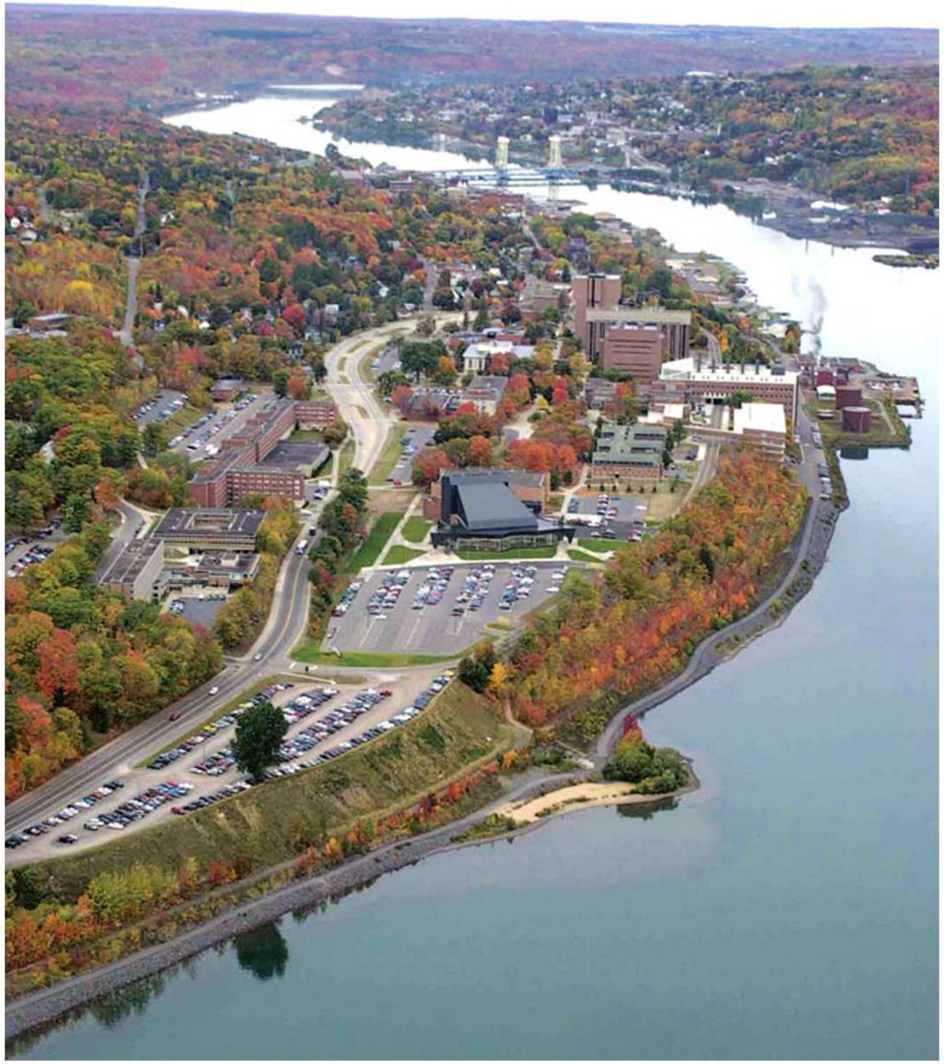
- Prof. Bruce Mork
- Prof. Sumit Paudyal
- Dr. Zagros Shahooei – at NTNU Spring 2014, defended May 2017
- Ph.D. Student Jaya Yellajosula – estimated completion Spring 2019
- Ph.D. Student Maciej Grebla – Exchange Fall 2018

Location

Michigan Tech -
Houghton, Michigan.
In the Upper Peninsula.

Travel: via SAS/United to Chicago. Two flights per day to Houghton.

Michigan Tech



- Enrollment – approx 7,000 Students.
- About 10% are international, about 10% are graduate students.
- About 3,800 enrolled in engineering, math, sciences.
- Electrical Engineering has over 600 BS students, about 80 PhD students, and 250 masters students.
- Online MSEE program in Power Systems. 20 Courses offered.

Central ECE/PERC Power Faculty

- **Dr. Bruce Mork, Center Director**
  – Power System Transients, EMTP
  – Power System Protection, Smart Grid, WAMPAC, wind power
  – Nonlinearities, Chaos Theory
  -- BPL - Broadband over Powerline

- **Dr. Leonard Bohmann, Assist. Director**
  – FACTS (Flexible AC Transmission Systems)
  – Motor Drives
  – Power Quality
  – Power System Transients, Operation

- **Dr. Lucia Gauchia**
  - Energy Storage Systems
  - State estimation for batteries and supercapacitors

- **John Lukowski**
  – Electronics, Energy Conversion, Renewable Energy
  – Automotive Electronics, Hybrid and Electric Vehicles
  – Smart Meters, Home Energy Management

- **Dr. Wayne Weaver**
  – Power Electronics -
  – Micro-Grids
  – Alternate Energy – Wind and Solar
  – Motor Drives

- **Dr. Dennis Wiitanen, Emeritus**
  – High Voltage Engineering, Dielectrics
  – Reliability Analysis
  – Electric Machines (Motors, Generators, Transformers)

- **Dr. Chee-Wooi Ten**
  – Smart Grid Technologies
  – Cybersecurity
  -- Emergency Control
  -- Self-Healing systems
  -- DMS

- **Dr. Sumit Pudyal**
  - Power System Operations
  - Real-time digital and analog control.
  - Power System Protection

Workforce Needed

- In US: 30% of utility technical workforce will retire in the next 5 years.
- NERC Summit, Washington DC, March 2017
  - What is the state of the EE Power Programs at US universities?
  - How many students are you producing?
  - What competencies are they being educated for?
- What has MTU been doing about this? See next slide…

Online Energy Education

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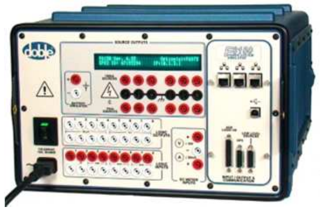
Courses	Certificate	Adv Cert	MSEE
EE 3010 – Circuit Analysis	✓		
EE 3120 – Energy Conversion, Renewables	✓		
EE 4219 – Intro to Motor Drives	✓		✓
EE 4221 – Power Systems I	✓	✓	✓
EE 4222 – Power Systems II	✓		✓
EE 4227 – Power Electronics	✓	✓	✓
EE 5200 – Advanced Analysis of Pwr Syst		✓	✓
EE 5220 – Transient Simulation (EMTP)		✓	✓
EE 5221 – Advanced Machines & Drives		✓	✓
EE 5223 – Power System Protection	✓	✓	✓
EE 5230 – System Operation		✓	✓
EE 5240 – Computer Methods		✓	✓
EE 5250 – Distribution Systems	✓	✓	✓
EE 5260 – Wind Power & Grid Integration		✓	✓
EE 5275 – Energy Storage		✓	✓
EE 5295 – Advanced Propulsion Systems for HEDV		✓	✓
EE 5750 – Distributed Embedded Control Systems		✓	✓
EE 6210 – Power System Stability		✓	✓

On Campus Laboratory Facilities

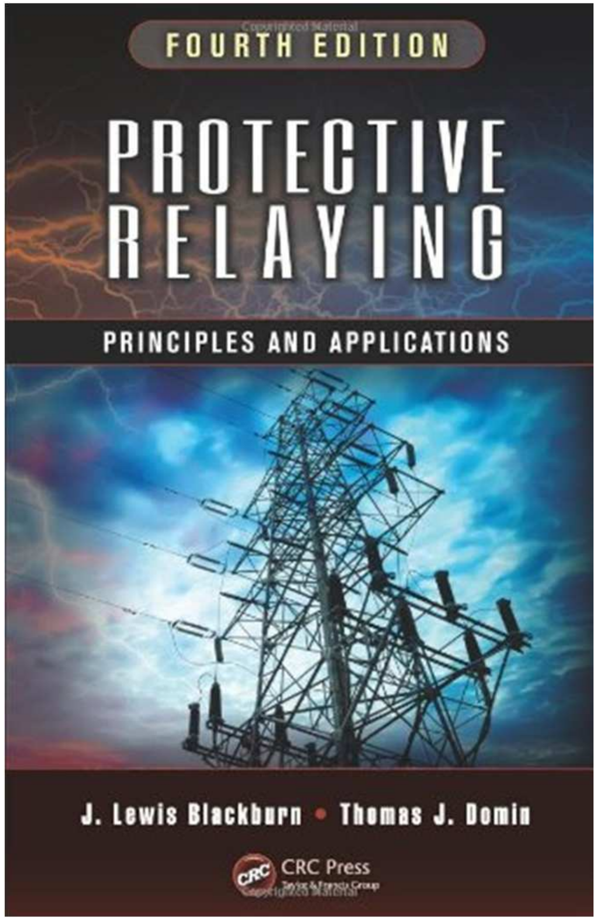


- Relay Protection Lab
- Power Systems Lab
  - Transformers, Ferroresonance, Relay testing, HIL
  - EMTP, Power Quality, Power Line Communications
- Smart Grid Operations Center
  - Energy Management: EMS, DMS, SCADA
  - Synchrophasors, Wide Area Control & Protection
  - IEC 61850, Network Communications

- Power Electronics Research Lab
  - Power Converters, Power Quality
  - Microgrid Lab
  - Control System Design, Prototype and Testing

EE 5223 Course - 102 Students

- http://www.ece.mtu.edu/faculty/bamork/EE5223/
- Software for short circuit, coordination, waveforms:
  - ASPEN, Doble, ATP, Cyme. Also have PSS/E, CAPE.
- Software usage integrated throughout
- Complete “protection chain”
  - CTs, VTs, relays, control, comm, CBs.
- Understanding of system, interactions
- Protection philosophies
- Knowledge of equipment protected
- Relay inputs, polarization, outputs
- Relay functionalities, applications



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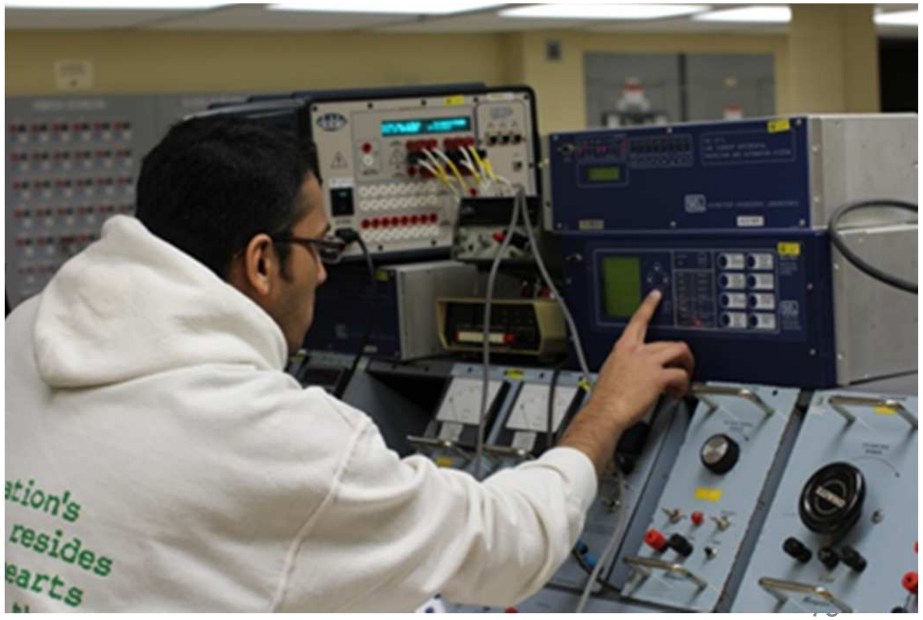
Protection Lab – 68 students

G1: Electromechanical – G2: Electronic -- G3: Microprocessor -- G4: Networked!



Relays at MTU

Goal: Interoperability!

- Westinghouse/ABB
  - Electromechanical CO-9 (G1)
  - RET670 Transformer Differential Relay – BPA project
  - In contact with ABB re. SDH optical system for process bus, SAM600.
- Basler
  - Electronic Relays (G2)
- General Electric UR, “brick MU”
- SEL (EE5224 teaching lab)
  - 751 overcurrent/reclosing
  - 411L – line differential, trav wave
  - 387, 787 – Transformer Differential
  - 487Z – bus differential
  - 421-7 – SV line impedance
- Siemens – obtaining SV merging unit

Note: To date, only systems-level research, no research for relay companies.

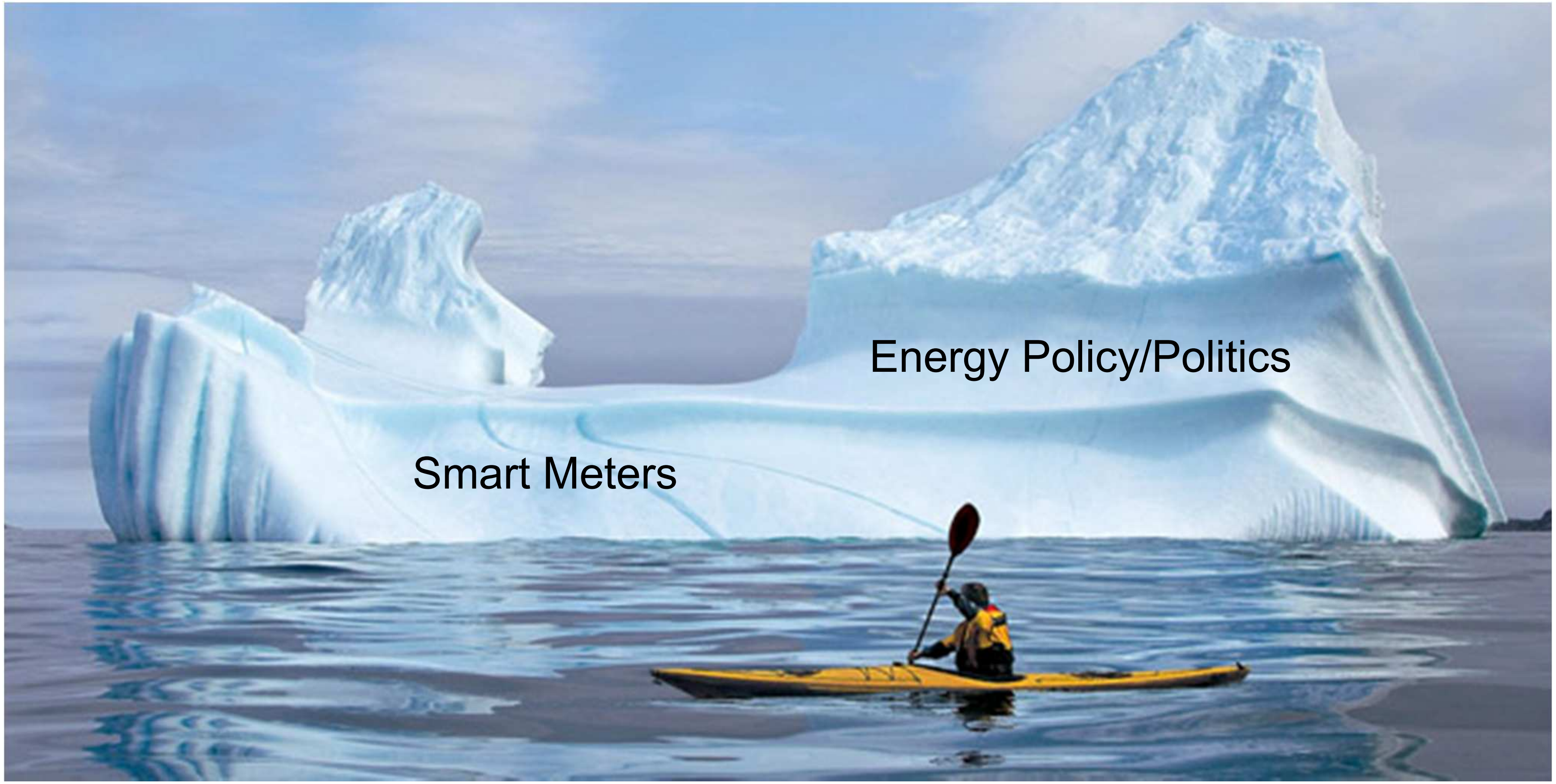
Lab – DOBLE 6150SV

- Simulate three streams of IEC618509-2LE sampled values through one fiber-optic port and one copper (RJ45) port.
- Simulates (publishes) and subscribes to IEC61850 GOOSE messages involving multiple IEDs, station or process bus.
- Performs standard relay calibration and verification testing of high-burden (electromechanical), solid-state, and microprocessor-based relays
- Delivers full VA power with resistive, inductive and capacitive load maximum current rating. The following ranges available with the F6005 Enhanced Rating Option: (6 x 35, 3 x 70, 1 x 210 A).
- Performs state simulation and transient testing
- Interface between Opal-RT and DOBLE can be established for both measurements and communications.
- AI measurements option in DOBLE will enable Opal-RT to send V&I measurements to the simulators (merging unit functionality).
- DOBLE can also be used as power amplifier to Opal-RT.
- Remote control via network is possible.

Protection Lab Exercises

- Introduction, safety, relay tester, software, basic relay settings, testing, time overcurrent.
- SEL (Interoperability: GE, ABB, Siemens & Beckwith)
- Radial coordination
- Directional overcurrent
- Differential protection – bus and transformers
- Distance protection, coordination
- Communications, permissive or blocking.
- Introduction to PMUs, synchrophasors.
- Next: advanced lab on DSP, 61850, WAMPAC.

Smart Grid Technologies



In order to have a smart grid:

1) Need “smart” devices (IEDs), i.e. embedded processors with an IP address.
2) Increased use of advanced sensors, GPS-time-tagged data.
3) Wide-area communications, peer-peer communications, “interoperability.”

A More Complete View of Smart Grid Challenges and Research Opportunities...

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- GPS, Real-time data for real-time protection & control
- SCADA, interoperability, communications protocols
- Communications speed & bandwidth
- Wide area relaying and Control: WAM, WAMAC, WAMPAC
- High-performance real-time distributed algorithms, computing
- Cyber Security, Information security, Privacy
- Big Data, optimization of collection, use, storage
- Complexity, reliability of smart grid technolgies themselves.
- Fall-back modes when fancy technologies fail.

EE5225 – Advanced Protection

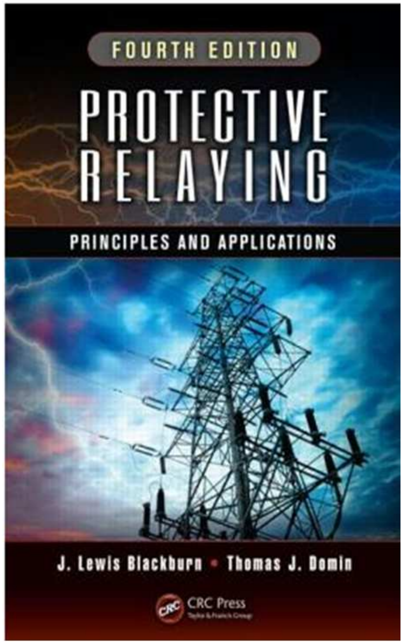
- One of the goals: start to bridge the Engineer-IT gap from the Electrical Power Engineering Side.
- Pilot Course – Fall 2017 (22 students)
- Startup from EE 5240 – Online videos, lectures
  - Network servers
  - Setting up a network, Switches, Routers, Managed Routers
  - Packet Data flows, Wireshark
  - IEC 61850, GOOSE, Synchrophasors, SV
  - HIL (Hardware in the Loop, OPAL RT)

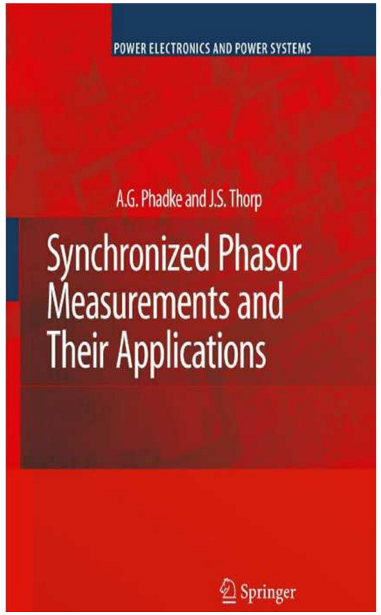
Course Content (42 lectures, with lab)

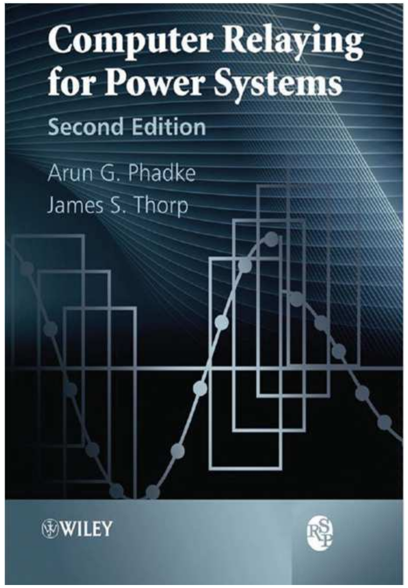
Microprocessor relays, DSP filters, PMUs, networks, synchrophasors, SV, advanced sensors, advanced relaying applications, wide-area protection

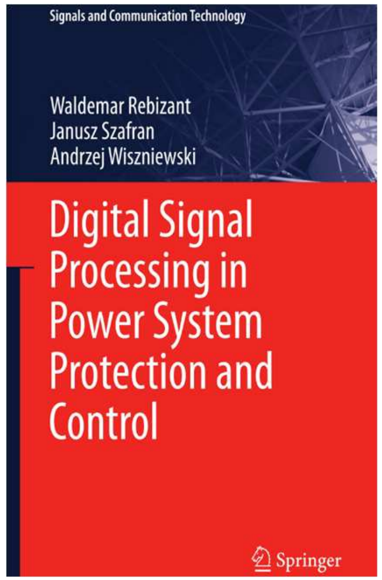
EE5225: Advanced Power System Protection
EE5226: Advanced Power System Protection Labs

- 22 students enrolled with background in power system protection, networking, and communication.
- Course includes:
  - Digital signal processing fundamentals for relay engineers
  - Networking essentials
  - Phasor Measurement Units (PMUs), Phasor Data Concentrators (PDCs), Phasor visualization.
  - Numerical protection fundamentals
  - Advanced protection schemes: advanced feeder, line differential, distance, out-of-step, bus differential, microgrid protection.
  - SCADA and Sample Values
  - Wide-area control and protection
  - Hardware-in-the-loop (HIL) validation



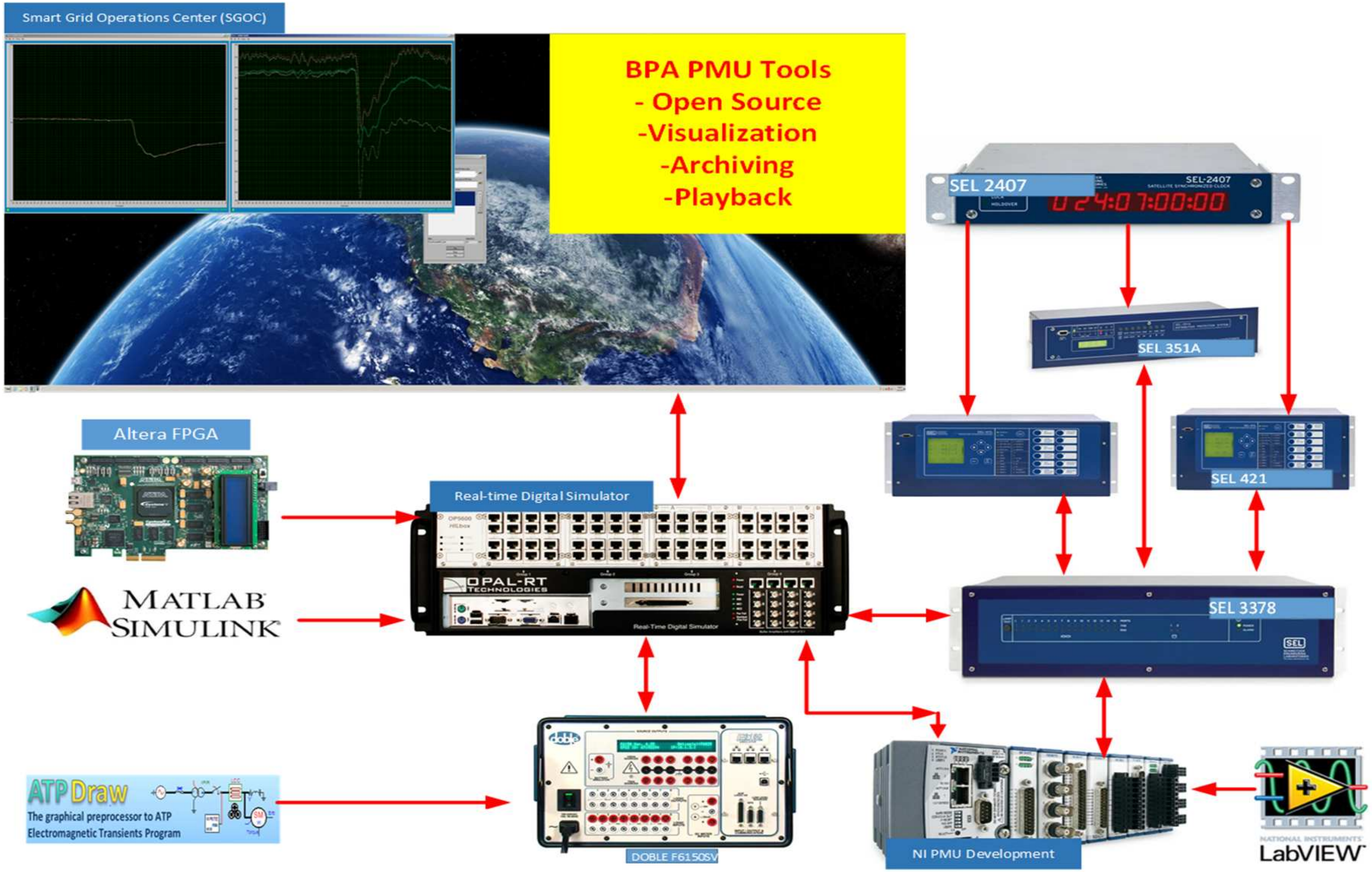






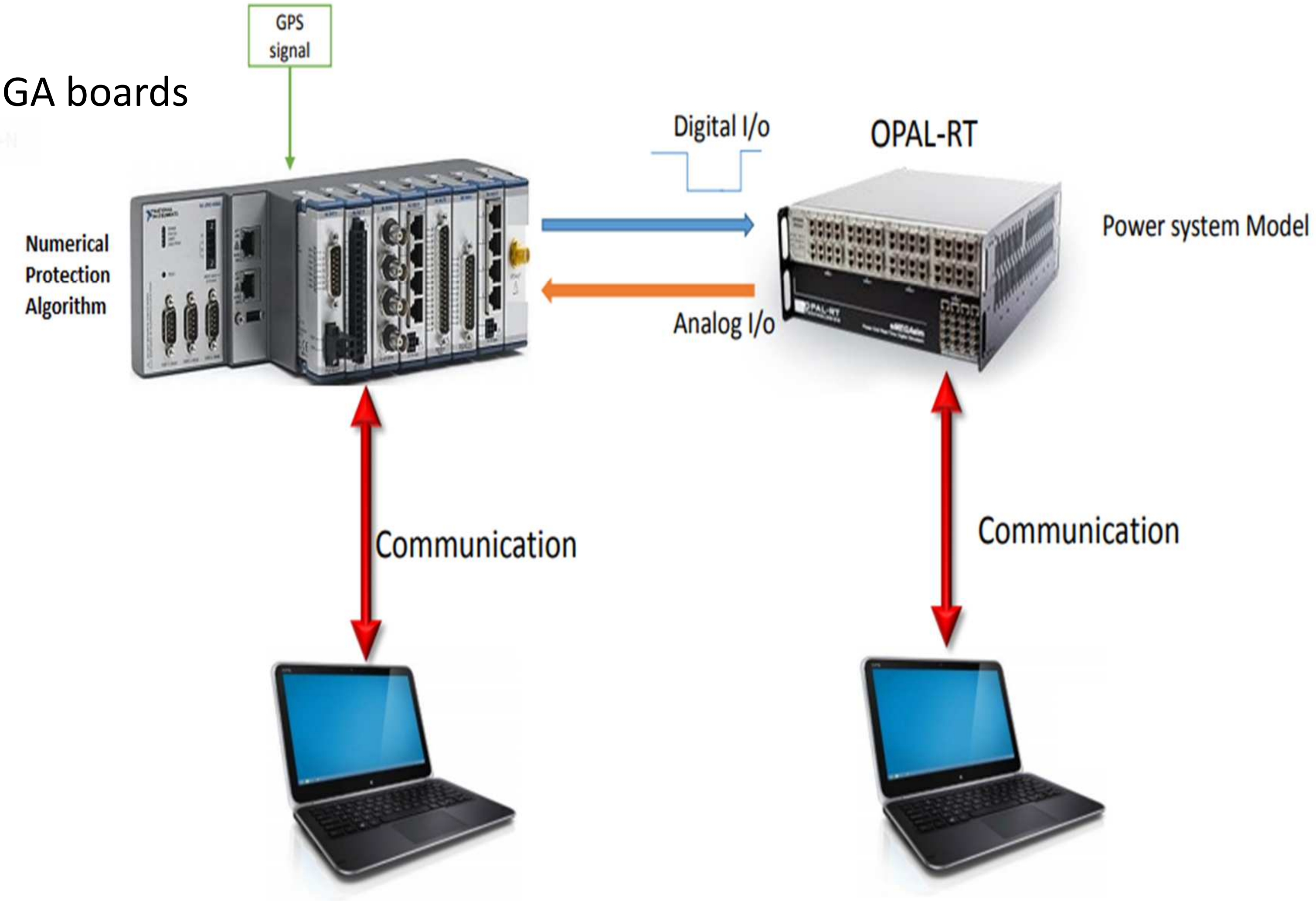
Lab and Course Project Activities

PMU and its applications in MTU's Smart Grid Operations Center (SGOC)

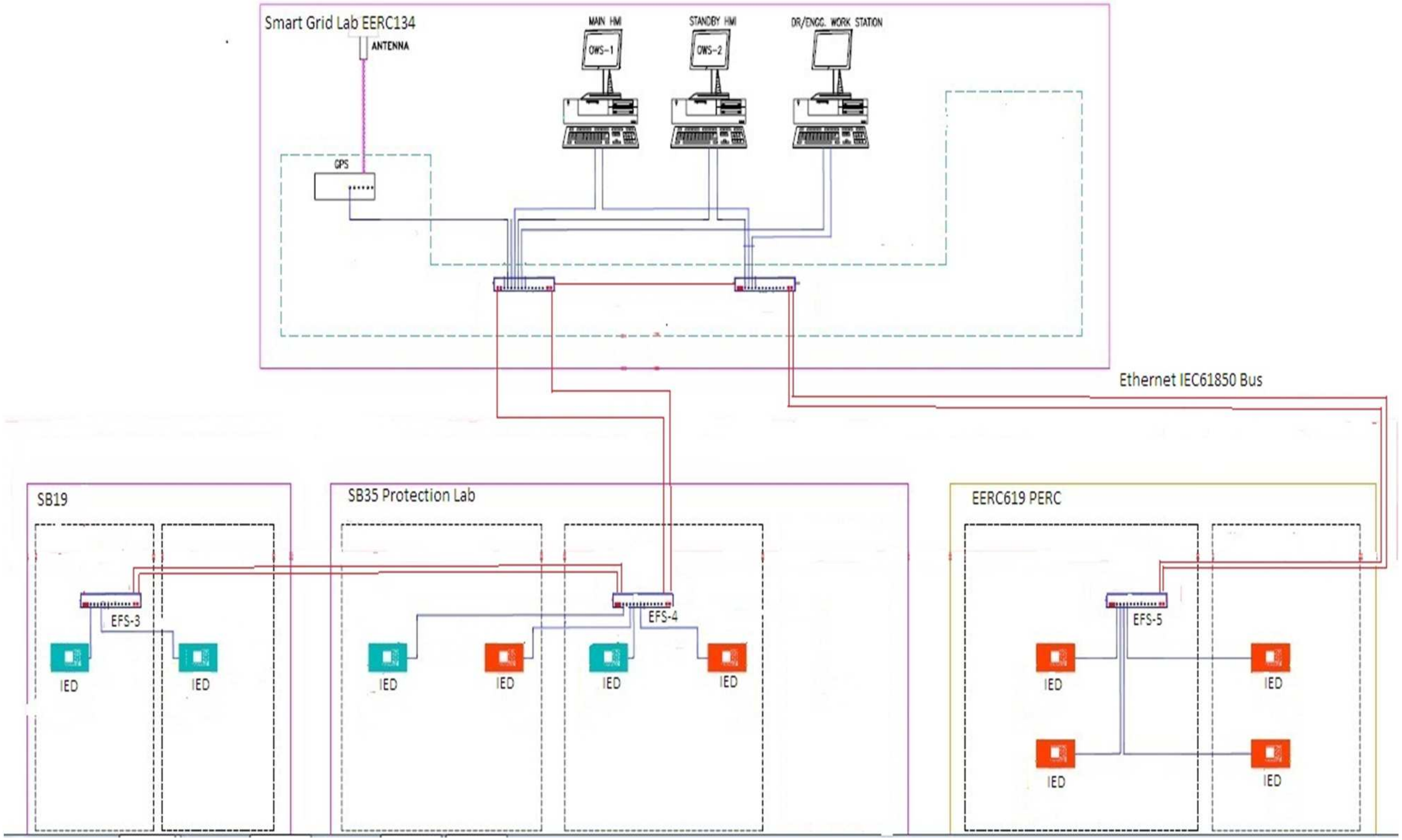


Hardware-in-the-loop Validation of Numerical Protection Schemes

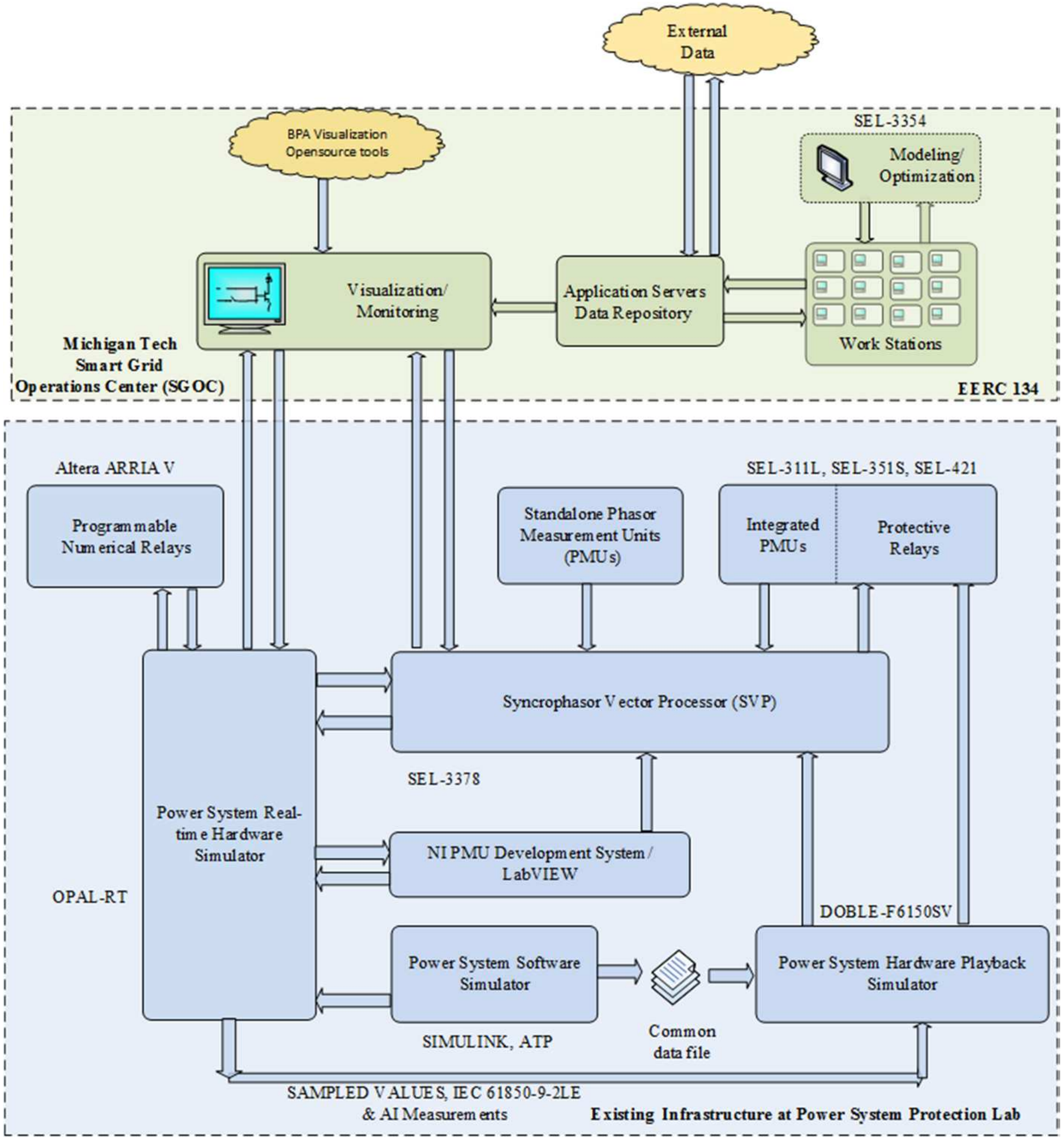
- OPAL's OP-5600
- NI's cRIO
- Altera FPGA boards



GOOSE based communication framework



Smart Grid Operations Center



Basis for development, priority ranking:

- SCADA
- Substation Automation (IEC 61850)
- Protection and control
- Distribution automation
- Demand response
- Smart metering

Commissioning of the video wall and operator consoles.

Smart Grid Operations Center

- Video Wall, six consoles, 15 seats. Teaching/research.
- SCADA, interoperability
- Energy Management (EMS and DMS)
- Dispatch training simulator
- Emergency Control
- Synchrophasors, SV, Wide Area Control & Protection
- System Protection, IEC 61850, interoperability
- Distributed microgrid and EV operations and monitoring
- Monitoring connection into MTU Energy Mgmt System
- Monitoring connection into regional grid.
- Remote lab connection for research, testing, teaching

Educational Challenges

- Tempting technologies should be tested..
  - The student is the customer, give the customer what they want, i.e. break into short bits? Clickers, multiple choice tests, info-tainment.
    Question: Does engineering still require a long attention span? Design? Synthesis/creativity?
  - Inverted classroom
    - Use class time for exercises and help sessions.
    - Professor records background lectures alone/boring.
- Priority in any case: teaching and learning!
  It needs to be interesting, stimulating, and fun. Outcomes: Design, creativity, synthesis.

Institutional Challenges

- University initiatives or movements to “consolidate computing” or extract it from the discipline areas. Risk: form a “super silo”
- A better solution may be to use a matrix organizational structure to connect applied and basic research:
  - Engineers have problems looking for solutions.
  - Scientists have solutions looking for problems.
- Connect with industry partners to solve their immediate problems and support them on path forward to new technologies. Show relevancies!

Big Data

- We have successfully used SVM (Support Vector Machine) for real-time data mining in our research.
- First law of holes:

"If you're in one, stop digging."

- Opportunity: reduce or optimize which data is collected and its sampling rate.

Challenges/Opportunities

- System Operations, energy markets, etc. can be in seconds, minutes, hours, days…
- Relay protection – must happen in milliseconds
  - Bad or missing data? No time for error correction or state estimation. Need to maintain two comm/sensor systems, quickly ID bad data, switch to other system.
  - AI, neural nets, agents, etc. may be too slow for high-speed real-time. Initial work with small proof of concept papers may not be practical for large system.
- Amount of power being controlled?
  - Microgrid vs. Distribution vs. Bulk transmission
- Time Scale? Days, hours, mins, seconds, milliseconds..