Michigan Tech Smart Grid

Education and Laboratories

Bruce A. Mork

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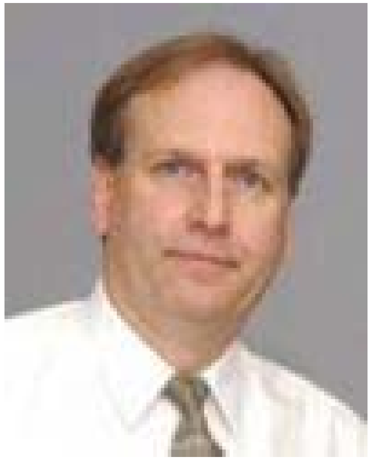
Professor, Electrical Power Systems
Director, Power & Energy Research Center



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

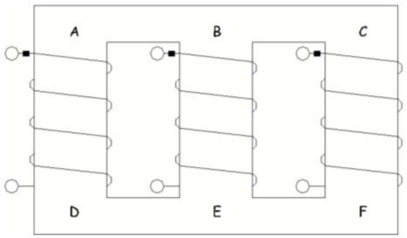
1989-90: **Statnett**, Husebybakken, Oslo, Norway
- Research Engineer: Relay Protection Group, Forensics, EMTP Studies

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

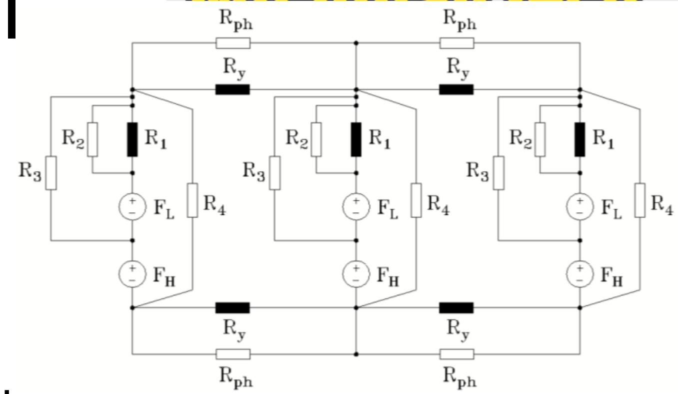
1979-80: **HDR** (formerly SSR), Bismarck, ND
- 69-kV and 115-kV Trans Lines: Surveying, design, construction management

The hybrid transformer model

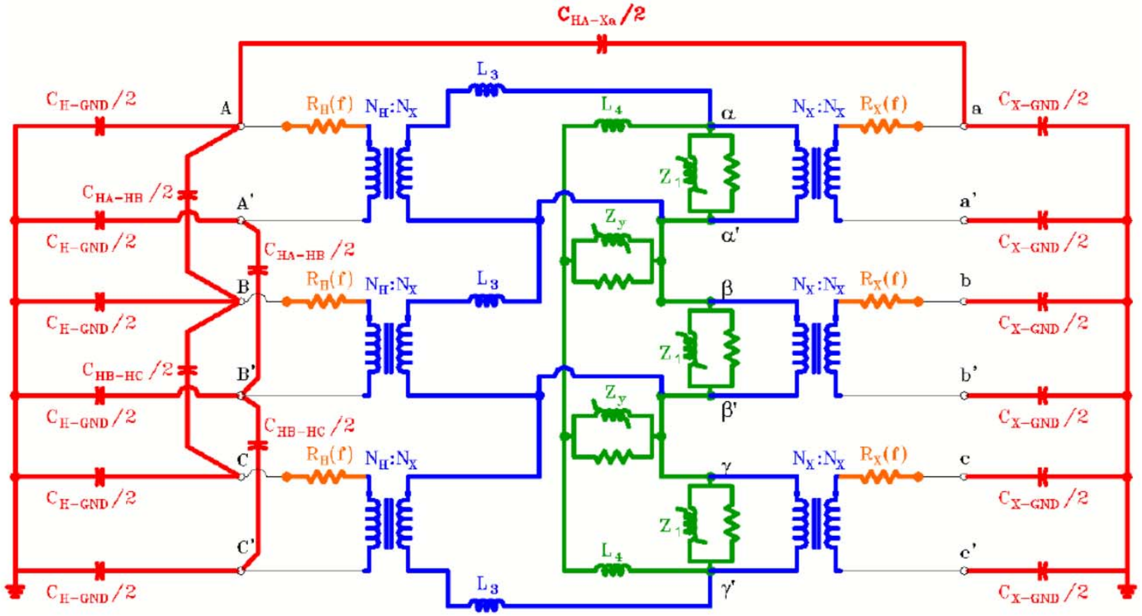
1. Physical structure

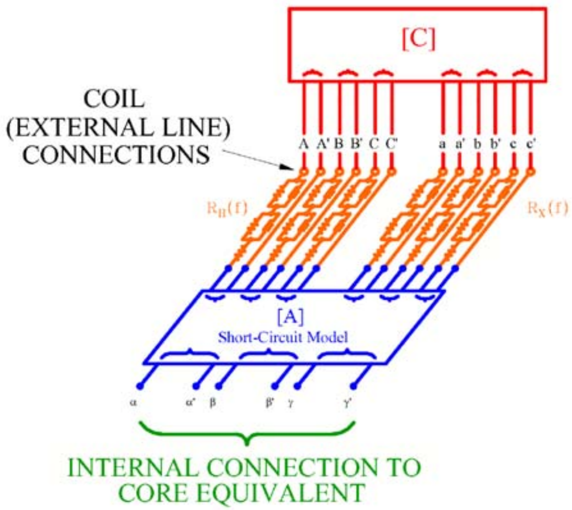


2. Magnetic circuit



3. Dual electrical circuit, Hybrid Model



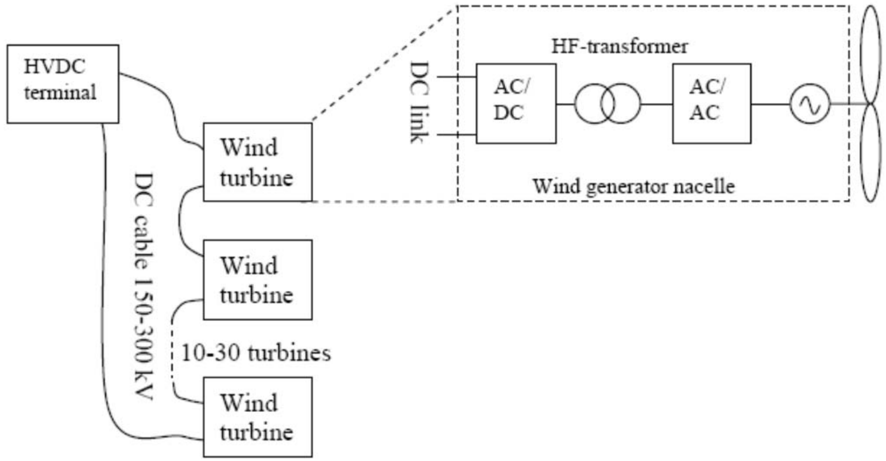


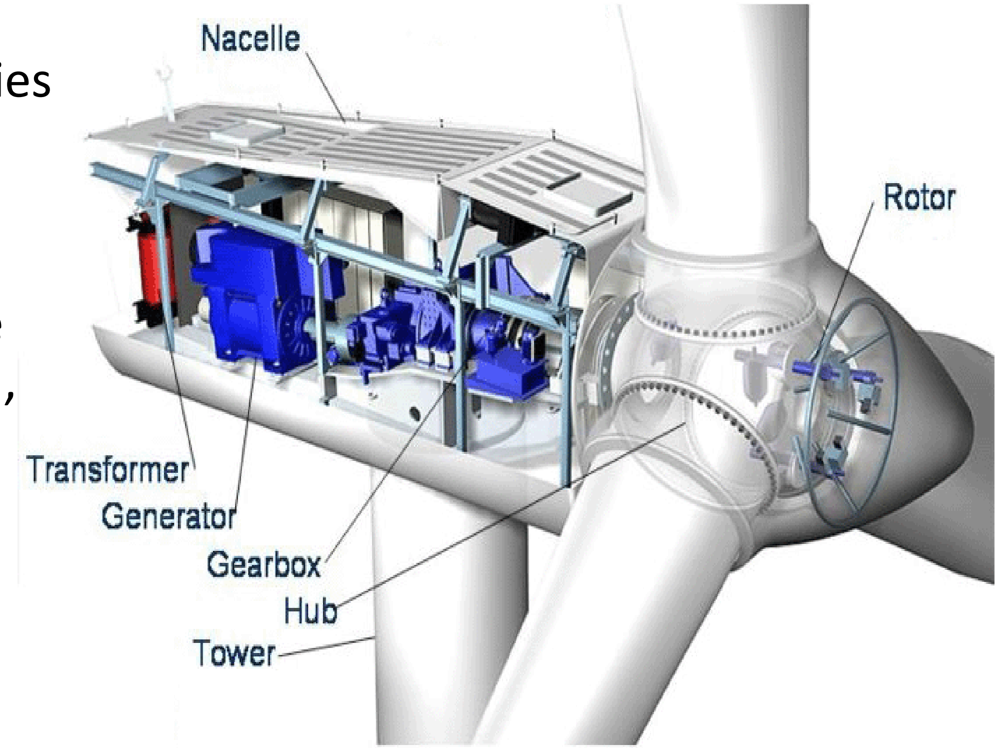
– Core representation
– Leakage representation

– Resistance
– Capacitive effects

High frequency wind power

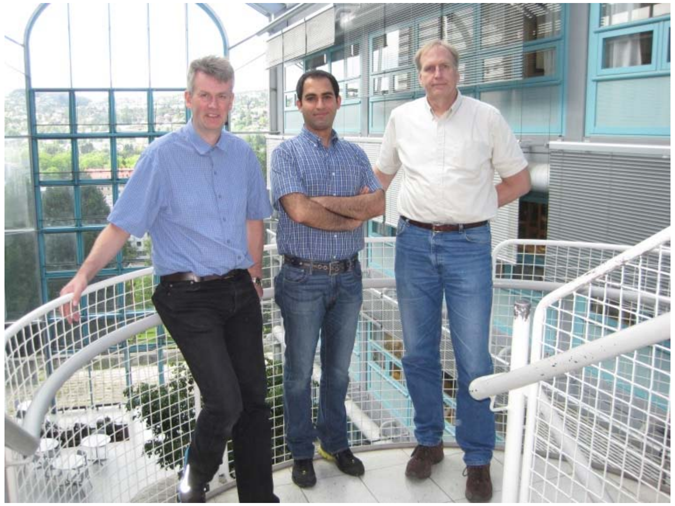
- NFR FP project
- 3 PhD students
  - Nathalie Holsmark: Design and control of matrix converters with reverse-blocking IGBT (Prof. Marta Molinas, NTNU)
  - Himanshu Bahirat: DC collection systems, reliability and fault studies (Prof. Bruce Mork, MTU)
  - Edris Agheb: High frequency transformer, design and loss calculations with nano-crystalline materials (Prof. Hans Kr. Høidalen, NTNU)
- Weight and volume reductions





SIU Project

- Smart Grid Education & Research
- January 2015 through June 2015
- MTU assists NTNU to develop relay lab
  - PhD student Zagros Shahooei at NTNU Feb-June 2014.
  - Initially for research and masters projects
  - Plan for overall instructional lab
- NTNU develops first online delivery of a masters course (High Voltage Equipment).
- MTU/NTNU cooperate on development of relay protection coursework and lab materials.
- Collaboration to write proposals.



TET4195 – EE5290
High-Voltage Equipment Course

Spring Semester 2016

- SIU Project – pilot course
- Investigate online delivery of a popular/complementary course
- TET4195 – High Voltage Equipment
  - Offer to a group of 10 MTU students as EE5290 "Special Topics" 3 credits.
    - Provides great flexibility for first-time or pilot.
    - View TET4195 lectures via It's Learning
    - Complete same TET4195 exercises, graded by same vitas.
    - Take TET4195 final exam using MTU online proctoring system. Graded by NTNU faculty and sensor.
    - Arrive at grade as a combination of exercises, participation/contribution to course, project report, and final exam.
  - "Lessons learned" are useful as we go forward.

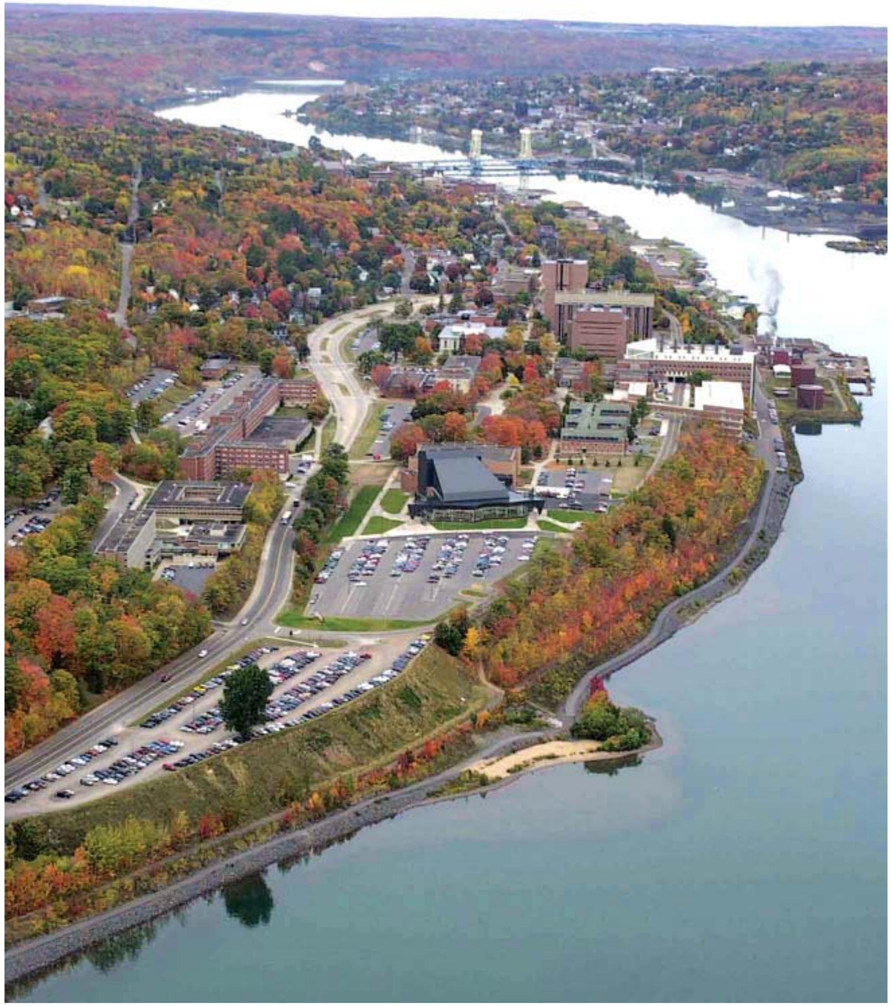
- Logistical challenges
  - Multiple points of contact
    - NTNU
      - Hans Kr. Høidalen – initiate
      - Halsten Aastebøl
      - Kristoffer Halseth
      - Sigrid Hauge – Int'l Office
      - Dag Nummedal - IT support
      - Kaveh Niayesh – instructor/coord.
      - Arne Nysveen - instructor
      - Erling Ildstad – instructor
      - Henning Taxt – course grader
    - MTU
      - Glen Archer, course creation
      - Kathleen Pintar – registration
      - Bruce Mork

Location

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

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

Michigan Tech

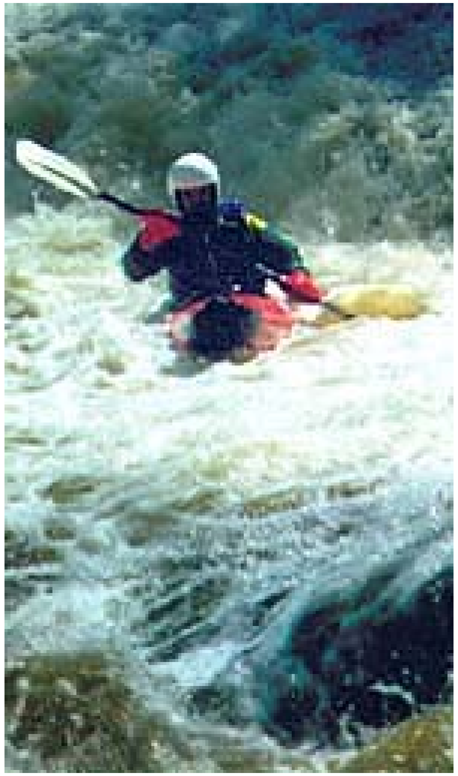


- Enrollment – approx 7,000 Students.
- About 10% are international, about 10% are graduate students.
- About 3,800 enrolled in engineering, math, sciences.
- Electrical Engineering has over 600 BS students, about 50 PhD students, and 130 masters students.
- Online MSEE program in Power Systems.

Spring & Summer

Michigan Tech
Create the Future

There are many clean sand beaches, making for refreshing getaways on the weekends. Other activities are sailing, swimming, water skiing, fishing, mountain biking, golfing (Michigan Tech operates a golf course), kayaking, etc.



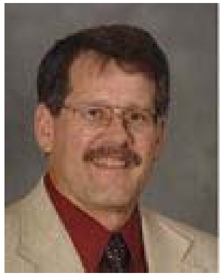
MichiganTech

Central ECE/PERC Power Faculty

Michigan Tech
Create the Future

- **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

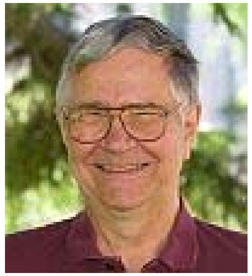


- **Dr. Lucia Gauchia**
  - Energy Storage Systems
  - State estimation for batteries and supercapacitors

- **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

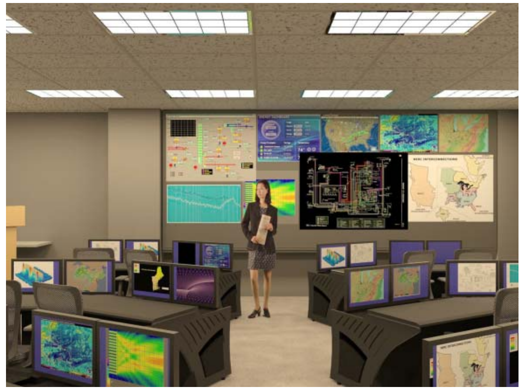
Online Energy Education

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 4223/5223 – Power System Protection	✓	✓	✓
EE 5230 – System Operation		✓	✓
EE 5240 – Computer Methods		✓	✓
EE 4225/5250 – Distribution Systems	✓	✓	✓
EE 5260 – Wind Power & Grid Integration		✓	✓
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

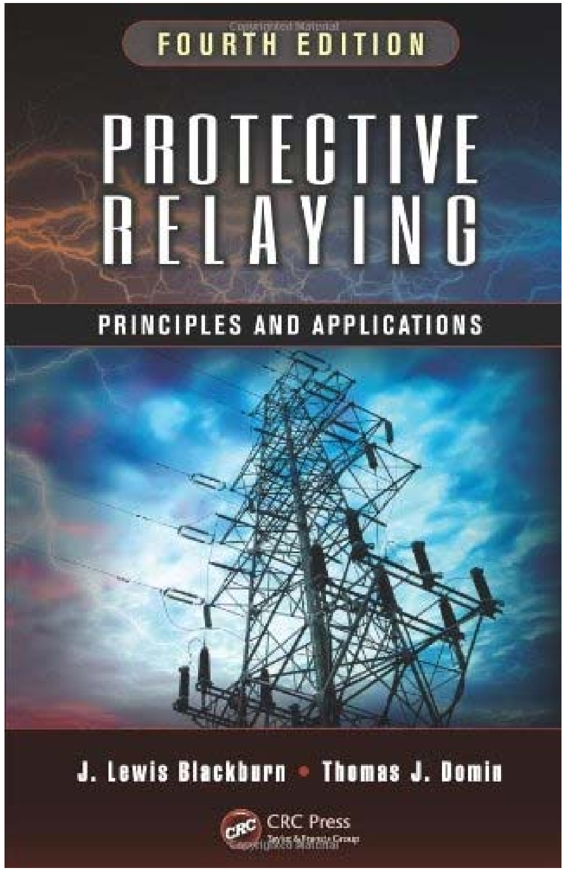
- Smart Grid Operations Center
  - ➢ Energy Management: EMS, DMS, SCADA
  - ➢ Synchrophasors, Wide Area Control & Protection
  - ➢ IEC 61850, Network Communications



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

EE 5223 Course - 102 Students

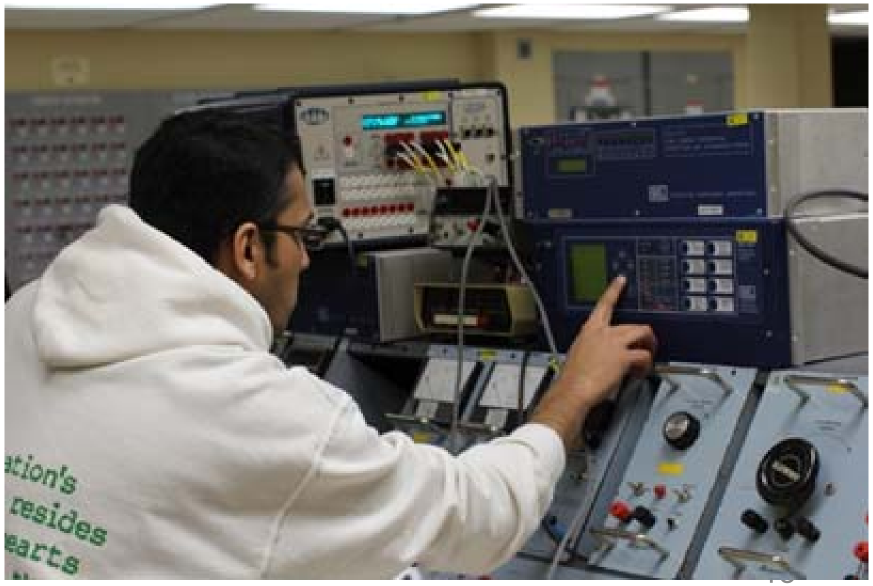
- http://www.ece.mtu.edu/faculty/bamork/EE5223/
- Software for short circuit, coordination, waveforms:
  - ASPEN, Doble, ATP, Cyme. Also have PSS/E, CAPE.
- Software usage integrated throughout
- Complete "protection chain"
  - CTs, VTs, relays, control, comm, CBs.
- Understanding of system, interactions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



Protection Lab – 68 students



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

Relays at MTU

Goal: Interoperability!

- Westinghouse/ABB
  - Electromechanical (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 – line impedance (G3/G4)
- Siemens – obtaining SV merging unit

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

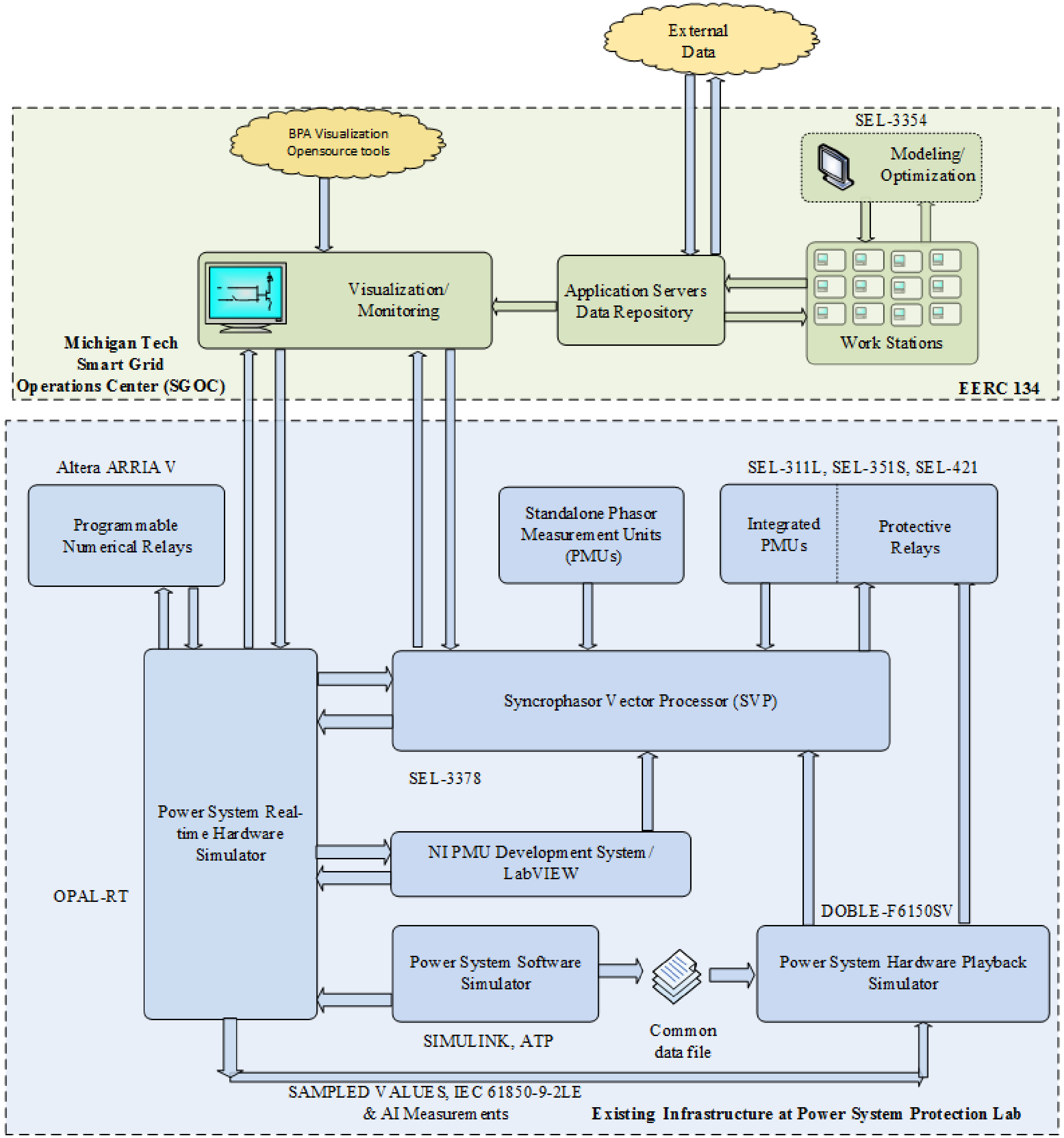
Protection Lab Exercises

- 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.

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."

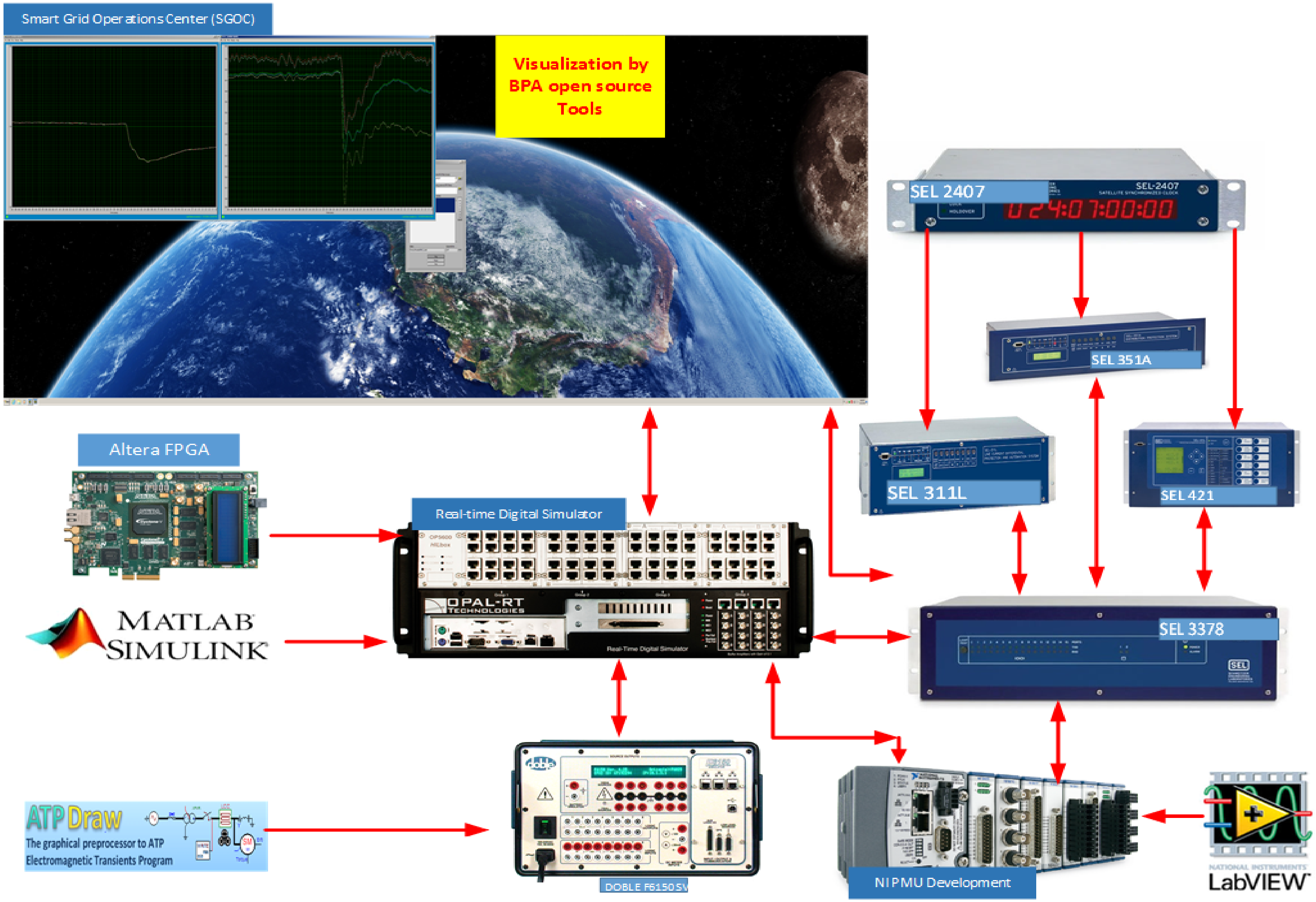
Smart Grid Operations Center



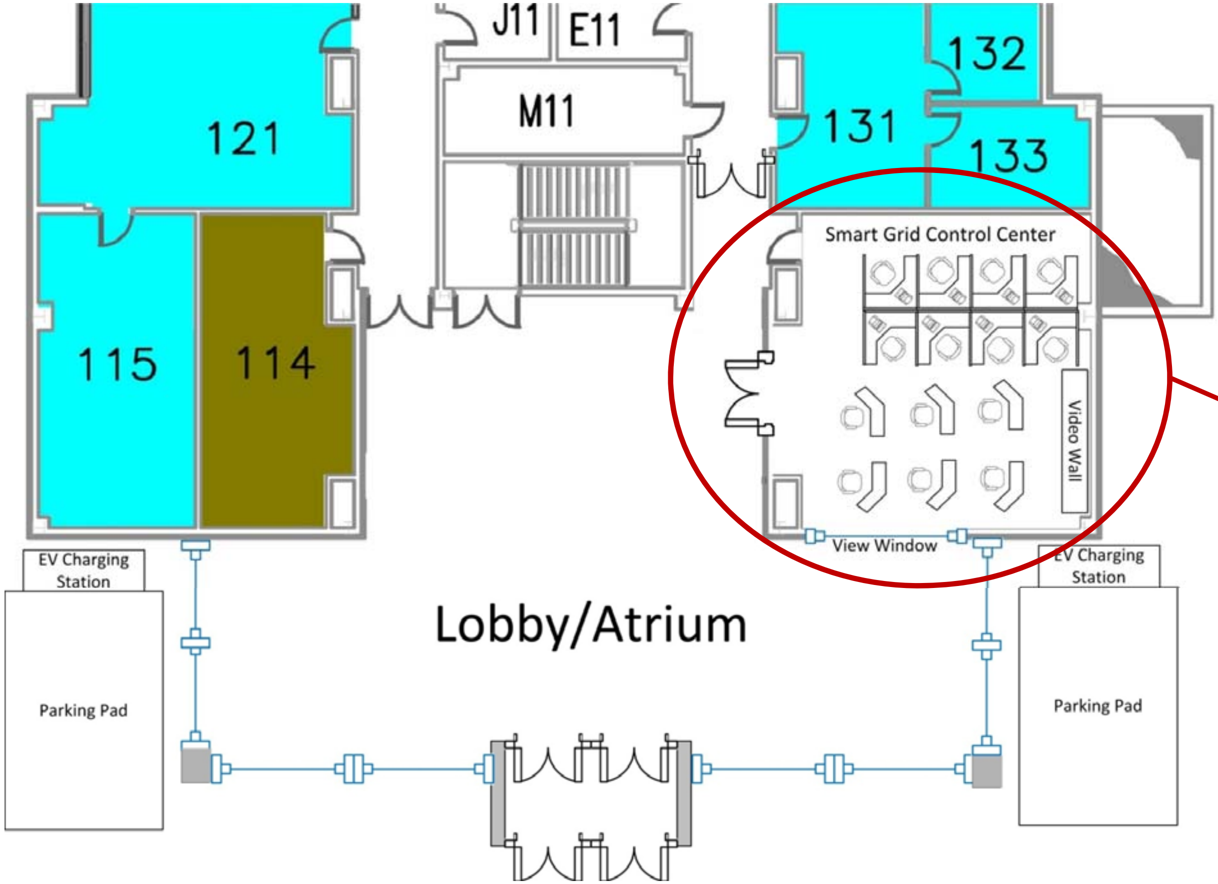
Basis for development, priority ranking:

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

Visual Representation

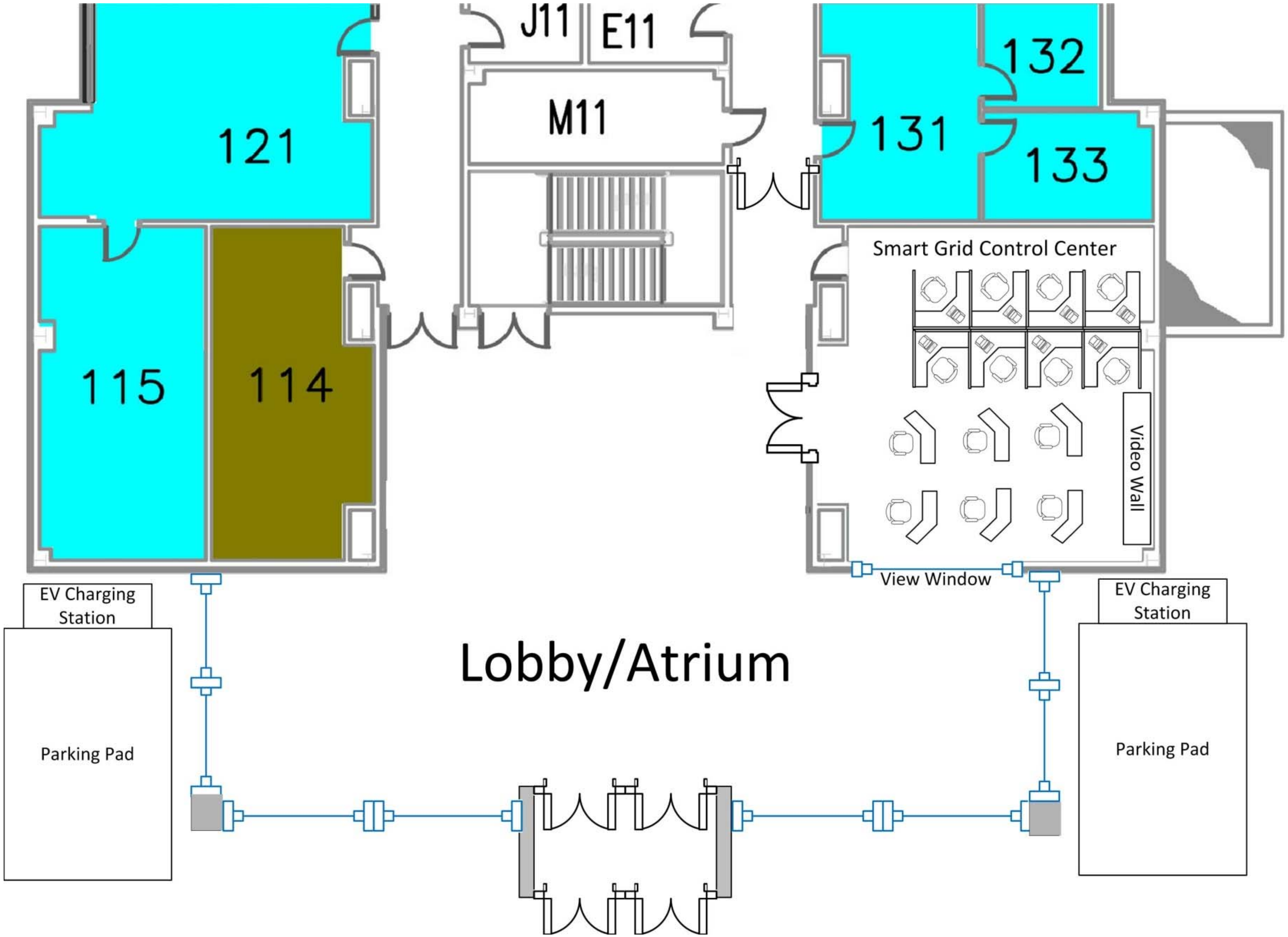


Smart Grid Operations Center - EERC 134



Stock photo – energy control center with video wall and operator consoles.

EV Charging Stations. Atrium expansion for departmental functions. Multi-purpose area.



Conceptual Plan for Smart Grid Operations Center housed in EERC 134. Also depicted are EV Charging Stations, atrium expansion for departmental functions and multi-purpose area.

Floor plan developed by Architect

Smart Grid Operations Center

- Video Wall, six consoles, 12 seats. Teaching/research.
- Cyber Security
- SCADA, interoperability
- Energy Management (EMS and DMS)
- Dispatch training simulator
- Emergency Control
- Synchrophasors and 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 ATC/MISO.

Commissioning of the video wall and operator consoles.