Practical, in-depth information for electric utility engineers, senior technicians, managers, consultants, researchers, and others…

Modern Power System Protection: Applications and Performance Analysis

June 16–20, 2014

Madison, Wisconsin

Communications for Power System Protection, Automation, and Smart Grid Technology

June 23–27, 2014

Madison, Wisconsin

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Department of Engineering Professional Development
432 North Lake Street Madison, Wisconsin 53706

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Why You Need These Courses

The addition of new power system facilities, including large power plants and high-voltage transmission lines, is becoming more difficult as economic and environmental constraints increase. Factors resulting from utility restructuring, including transmission open access and energy from independent power producers, and legislation affecting air quality and electromagnetic effects are combining to cause existing equipment to work harder and longer under conditions that were not involved in its original design or its protection.

The flurry of activity accompanying the arrival of the Smart Grid provides opportunities for improved performance of the network's protection system while placing additional burdens on the communication and information processing system.

As a producer and user of electrical energy, you must increase your awareness of present and future power system protection. You must realize that system integrity depends on a well-conceived and properly implemented protection philosophy. You should learn how to design a system where equipment or line removal and system restoration occur quickly and reliably. To do this, you need to understand:

- How present mechanical and microprocessor-based relaying systems function and communicate
- How to analyze their performance
- How to attain electronic security (cybersecurity)
- The impact of international standard IEC 61850 and how to apply it
- What is on the horizon to meet new challenges, and especially
- The demands placed by the Smart Grid

Attend and Benefit

Taught by instructors with broad knowledge, these courses will be valuable to electric utility engineers involved in applying, simulating, and testing protective relaying devices. Since equipment and system protection affects all aspects of the power system, engineers, senior technicians, managers, educators, consultants, and researchers involved in electric power systems and interfacing with relaying and substation communications and automation will also benefit. You are expected to have a good understanding of the principles of operation of electric power systems and the major equipment that constitutes those systems.

Enrollees in the *Modern Power System Protection* course will receive a free textbook. Enrollees in the *Communications* course can bring their laptops and participate in an exercise to configure a local area network in a substation.

Your Instructors for These Courses

Arun G. Phadke
Course Coordinator
Distinguished University Research Professor
Virginia Polytechnic Institute and State University
Blacksburg, Virginia

John R. Boyle
Principal Engineer
PSA/Power System Analysts
Signal Mountain, Tennessee

Charles Henville
President
Henville Consulting, Inc.
Delta, British Columbia, Canada

James K. Niemira
Principal Engineer
Power System Services
S&C Electric Company
Chicago, Illinois

Mark G. Adamiak
Chief Application Architect
GE Multilin
King of Prussia, Pennsylvania

Kenneth Fodero
Senior Communication Consulting
Schweitzer Engineering Laboratories
Orlando, Florida

Gary L. Michel
President
Power System Consulting
Hialeah, Florida

Miriam Sanders
Senior Instructor
SEL University
Asheville, North Carolina

Careful observers will note the absence of Stan Horowitz from our faculty. Stan joined us in 1990; his years of industry experience have been much appreciated by our students. We wish him well in his retirement and welcome the return of Charlie Henville to our campus.

Modern Power System Protection: Applications and Performance Analysis

June 16–20, 2014 in Madison, Wisconsin

What You Will Learn

During this intensive course you will study:

- Transmission line relaying, working toward an understanding of the algorithms used in computer relaying
- Principles behind the protection of rotating machines, transformers, and other power system components, leading to an understanding of overall system protection considerations
- The concept of adaptive relaying, a real-time feedback system whereby the protection philosophy changes in response to changing system conditions
- Dependability vs. security considerations: system protection is biased toward dependability since the system must be able to withstand an outage but cannot withstand a delayed trip; adaptive relaying properly applied can enable increased security of the system
- The response of protection systems to transient phenomena (special emphasis)

The course instructors will supplement the lectures on protection practices with presentations of field oscillograms illustrating disturbances that trigger protective action and an analysis of the resulting responses.

The course includes a discussion of operating problems affecting human safety. This is a reminder that you are responsible not only for the protection of your company's electrical equipment but also for the safety of your co-workers and customers.

Special Session on Protection of Wind and Solar Plants

We include a presentation this year on special protection practices applied to wind and solar energy plants. Featured are collector station protection zones, turbine tower protection, and protection coordination topics.

Protection and the Smart Grid

Any discussion of modern power system protection would be remiss if the implications of the Smart Grid were not addressed. Intelligence derived from the Smart Grid enables rapid protection responses to unexpected disturbances. In addition, Friday's lecture on Phasor Estimating will illustrate how synchronized phasor measurements become the backbone of Smart Grid protection.

Receive Valuable Text

You will receive a copy of the text, *Power System Relaying*, newly released Fourth Edition, by Stanley H. Horowitz and Arun G. Phadke with contributions from James K. Niemira, John Wiley and Sons, Ltd., 2014.

Course Outline

Day 1

Welcoming Remarks: Long

1. Introduction to the Course: Phadke
- Course organization
- Role of relaying theory
- Field experiences

2. Relaying Fundamentals: Henville
- The nature of relaying
- Relay terminology
- Relay design

3. Transducers: Phadke
- Current transformers
- Voltage transformers
- Capacitive potential devices

4. Transient Phenomena: Phadke
- DC offset in fault currents
- CT and CVT transients
- Restrike
- Ferroresonance

5. Interpreting Oscillograms I: Boyle
- Understanding oscillographic traces
- Transient events

6a. Non-Pilot Line Protection of Transmission Lines I: Henville
- Relay coordination
- Time delay, instantaneous overcurrent, distance relays
- Relay setting philosophy

Day 2

6b. Non-Pilot Line Protection of Transmission Lines II: Henville
- 3-terminal lines
- Series capacitors, reactors
- Setting examples

7. Pilot Line Protection of Transmission Lines: Henville
- Communication channels
- Directional comparison
- Transfer trip
- Phase comparison
- Wire pilot
- Settings

8a,b. Transformer Protection: Boyle
- Fuse coordination
- Overcurrent coordination
- Differential protection
- Magnetizing inrush
- Application examples

9. Bus Configurations and Protection: Boyle
- Typical bus arrangements
- Main and transfer bus
- Breaker-and-a-half schemes
- Bus differential

10. Capacitor and Reactor Protection, Grounding Banks: Boyle
- Capacitor bank connections
- Unbalanced protection
- Dry-type and oil-immersed reactors
- Reactor differential protection
- Grounding banks

Day 3

11a,b. Rotating Machinery Protection: Henville
- Phase and ground protection
- Unbalanced voltage and current
- Loss of field
- Motor protection
- Plant auxiliary systems
- Start-up, inadvertent energization

12. Response of Distance Relays: Phadke
- Phasor diagrams
- Distance relay response
- Loading and fault conditions

13. Fault Location: Phadke
- Digital relays and digital fault recorders
- Limit to the accuracy of fault location
- Complexity of data input requirements
- GPS signals for record synchronization

14a,b. Power System Protection: Phadke
- Loss-of-field relaying
- Phasor diagrams during stability swings
- Out-of-step relaying
- Frequency dynamics (catastrophic changes)
- Under-frequency load shedding

Day 4

15. Interpreting Oscillograms II: Boyle
- CT saturation
- Bus differential protection

16. Introduction to Computer Relaying: Phadke
- Historical overview
- Computer relay architecture
- Hierarchical systems
- Input-output systems
- Sampling processes
- Anti-aliasing filtering

17. Distribution System Protection: Boyle
- Small tapped substations
- High and low set ground relays
- High side circuit switchers
- Pole-top recloser coordination

18. Distribution Transformer Excitation: Boyle
- Lightning-induced disturbances
- Distortion from re-energization
- Corrective actions

19a,b.Protection Practices for Wind and Solar Plants: Niemira
- Review of fault detection and discrimination
- Windplant fault current sources
- Collector station protection zones
- Turbine tower protection
- Protection coordination
- Applications to solar plants

Day 5

20. Operating Problems Affecting Human Safety: Boyle
- Miscoordination of relays
- Misapplied operating procedures
- Equipment failures
- Failures of backup protection

21. Blackouts: Causes and Countermeasures: Phadke
- Rare events
- NERC statistics
- More intelligent controls
- Remedial action schemes
- Effects of open access and deregulation

22. Phasor Estimating and the Smart Grid: Phadke
- Motivation for GPS synchronized measurements
- State estimation with synchronized phasors
- Improved control with synchronized phasors
- Applications to adaptive protection

Course Schedule

Registration and course will be held at
The Pyle Center
702 Langdon Street
Madison, WI

Day 1

8:00 a.m. to 8:20 a.m. Registration

8:20 a.m. to 5:00 p.m. Class

Days 2–4

7:45 a.m. to 8: 00 a.m. Coffee and Conversation

8:00 a.m. to 5:00 p.m. Class

Day 5

7:45 a.m. to 8: 00 a.m. Coffee and Conversation

8:00 a.m. to 12:00 p.m. Class

Midmorning and midafternoon refreshments will be provided. Lunch will be provided on days 1–4.

Communications for Power System Protection, Automation, and Smart Grid Technology

June 23–27, 2014 in Madison, Wisconsin

About This Course

We are sometimes asked if this is a communications course, a protection course, or a substations course. Our response is yes. The selected bullet points below illustrate the breadth of this course.

- Analog and digital communication fundamentals
- Communication requirements of protective relaying
- Communication networks in substations
- Integration of protection, communications, and control

What You Will Learn

This in-depth course is your opportunity to focus on:

- The impact of the Smart Grid on substation communication, protection, and automation
- Principles of analog communication techniques and how to compare the performance of various systems
- How to use different modulation schemes in power system communications
- Fundamentals of digital communications and pulse coded modulation (PCM) systems, including the important standards used in digital communications
- Fiber optic communications theory, system components and design considerations, utility applications and new technology–key topics since fiber optics is extremely important to modern power system communications
- Power line carrier and audio tones, a long-time faithful communications method in power systems
  - main applications of power line carrier and audio tones to protective relaying
  - effects of various communication systems and media on system dependability and security
- Various standards for serial data communications between computers and the intelligent devices connected to them
- Networking theory and how it applies to the substation and the power system as a whole
- Inter-substation digital communications as part of a utility enterprise that integrates protection, control, wide-area measurements, metering, on-line maintenance, and engineering
- Cybersecurity, especially as it relates to remotely accessible sensitive equipment
- Various communication protocols and standards important to the modern power system, with special emphasis on IEC 61850 and IEEE 1686

Substation design and operations engineers and senior technicians responsible for the integration of communications, control, and protection will find this course to be of particular value.

ACCEPTED 30 Professional Development Hours NATIONWIDE

Communications and the Smart Grid

The advent of the Smart Grid brings benefits and challenges to the utility industry. Notable is the impact on power system communications. In this course you will learn the requirements placed on the substation communication system to meet the concurrent demands for protection, automation, and Smart Grid implementation. Presentations will include a detailed review of ongoing work on the development of Smart Grid interface standards under the aegis of IEEE, NIST, and NERC.

Hands-on Networking Session

This course also includes a hands-on networking workshop connecting multi-vendor devices and YOUR laptop over a local area network (LAN) through the IEC 61850 protocol. You will learn how to:

- Set up a relay network
- Read values from standard IEC 61850 data objects
- Display the data in an Excel spreadsheet
- Implement Relay-to-Relay Communications via IEC GOOSE
- Capture and analyze network data packets

If you want to participate bring your own laptop with either XP or Windows 7 operating system. You should have ADMIN rights or have enough privilege to be able to load new applications. You MUST be able to configure the IP address on your laptop to a Fixed IP address for the hands-on session. Your laptop should have an Ethernet port. There should be at least 500MB of disk space available. Attendees will receive a demonstration copy of the SISCO IEC 61850 Browser and a copy of MMS-enabled Ethernet Network Analyzer Wireshark.

Case Studies Increase Understanding

You will learn the theory of hybrid system design, which integrates digital and electromechanical technology. To illustrate this topic, you will explore actual case studies of various substation projects.

We encourage you to bring examples of problems or unusual applications from your experience for review and discussion by the instructors and class.

Course Outline

Day 1

Introduction to the Program: Long Discussion—What Defines the Smart Grid: Sanders

1. Analog Communications Fundamentals: Sanders
- AM, FM, PM
- ASK, FSK, PSK, QAM
- Generation and detection
- Performance comparisons

2a,b. Digital Communications Fundamentals: Sanders
- Sampling theory
- Quantization
- Encoding
- Framing multi-channels
- Synchronous optical network (SONET)

3a,b. Fiber Optic Communication Theory and Application: Michel
- Fiber optic basics
- Fiber types (multi-mode, single mode)
- System components (sources, detectors, connectors)
- System design (architecture, loss calculations)
- Utility applications
- New technology and standards (WDM, PMD)

4. Problem Session: Staff

Day 2

5a,b. Fundamentals of Power Line Carrier: Sanders
- Basic system
- System components
- Coupling systems
- Modal analysis
- Performance calculations

6. Audio Tone Application: Fodero
- Basic system
- System components
- Relaying applications
- Audio tone to digital channels

7. Spread Spectrum Communications: Fodero
- Basic system
- System components
- Relaying considerations
- Control considerations

8. Special Communication Requirements of Protective Relaying: Sanders
- Dependability
- Security
- Channel delay effects
- Modes of operation
- Channel arrangements

9. Problem Session: Staff

Day 3

10. Serial Data Communication: Adamiak
- Basic concepts
- Data encoding formats
- RS-232
- RS-422
- RS-485
- RS-449
- G.703
- IRIG-B

11. Data Networks: Michel
- Network concepts and devices
- OSI seven layer model
- Substation LAN architectures
- Network synchronization

12. Ethernet: Adamiak
- Physical connections
- Data frames
- Collision and retransmission mechanisms
- Bridging

13. Protocols: Adamiak
- TCP/IP
  - Internet protocol concepts
  - routing, routing tables
  - address discovery
  - loop issues
- Traditional Protocols
  - ModBus
  - IEC 870-5
  - DDE and OPC

14. Smart Grid Protocols and Standards: Adamiak
- Architecture development concepts
- Overview of new proposed Sequence of Events Standard - COMFEDE - IEEE PC37.239 - a proposed NIST Smart Grid Standard
- Overview of the IEEE Standard for Time Sequence Files - COMNAMES - I EEE C37.232
- Review of the proposed NERC Standard for Event, Fault, and Dynamic Recording - PRC-002-02

15. 61850 Network Communications Systems: Adamiak
- Abstract service models
- Logical node concept
- Internet-based communication
- The IEC 61850 security model
- Peer-to-peer communications (GOOSE)
- Substation Configuration Language-SCL
- Integration system examples
- Routable GOOSE/SV (sample values)
- Industry case studies

Day 4

16. User Considerations for IEC 61850: Sanders
- What does IEC 61850 do for the user
- Essential steps for the effective use of IEC 61850

17a,b. Configuring a Local Area Network in a Substation: Adamiak
- Bring your laptop (see the note under Hands-on Networking Session for details)

18a,b. Electronic Security of Remotely Accessible Control and Protection Equipment: Fodero, Sanders
- Threats
- Vulnerabilities
- Attack scenarios
- TCP/IP network scanner
- SCADA protocol reconnaissance
- Electronic attack barriers
- NERC Critical Infrastructure Protection Standards (CIPS)
- Requirements of IEEE 1686
- Substation IEDs' level of compliance

19. Network Security: Michel
- Security management (access, detection)
- Security building blocks (encryption, hash algorithms)
- Transport layer security (TLS/SSH)
- Internet protocol security (IPSec)
- Firewalls and gateways

Day 5

20.Communications Technologies Enabling a Smart Grid: Michel
- End user (Zigbee, BPL)
- Network access (modems, xDSL, FTTx, wireless)
- Substation access (IEEE C37.94)
- Wide area networks (IP, SONET, Ethernet, MPLS)
- Integration of communications systems

21. Impact of Phasor Measurements and COMTRADE on Power System Communications: Phadke
- History of COMTRADE (C37.111) development
- Elements of the COMTRADE standard
- Overview of new COMTRADE procedures
- Example files in the COMTRADE format

22. Synchrophasor as a Smart Grid Standard: Phadke
- Phasors and Synchrophasors
- Wide Area Measurement Systems
- IEEE Standard C37.118.1
- IEEE Standard C37.118.2

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What Students Say About Our Courses and Instructors

Modern Power System Protection: Applications and Performance Analysis

"Arun Phadke can explain all the topics very clearly. In his presentation I appreciated most the MATLAB animations, which are of great help in understanding the dynamic phenomena."

"Charlie Henville is a pleasure to listen to. His presentations are very detailed yet clearly delivered and easy to follow."

"John Boyle, with his real-life disturbance recordings, really helped me to see that theory (usually) matches with practical experience. Thanks to his enthusiasm, I might also start to analyze field recordings."

"An excellent overview of the various protection schemes."

"I will be able to communicate more intelligently with my cohorts having been introduced to several topics where my understanding was lacking."

"John Boyle has very good hands-on experience, which works great with the course material. His presentations using actual events and information were helpful, exactly what I needed."

"Jim Niemira's presentation on wind and solar plants was interesting and very informative."

"I've been to UW–Madison's EPD courses twice. I think you offer the best professional development experience I can find. This includes topics, instructors, facilities, technology, meals, etc. Thanks for a great effort. You have thought about a lot of extras and details. Well done."

Communications for Power System Protection, Automation, and Smart Grid Technology

"This is my third course with the University of Wisconsin–Madison, I am never disappointed. Keep on with your excellent work!"

"I came with very little communications knowledge and how it related to system control; I left with a much better understanding of the interrelationship."

"Gary Michel is very knowledgeable and makes a well-organized presentation."

"Arun Phadke is an excellent instructor with a superb knowledge of his subject matter. The content was very relevant."

"Mark Adamiak makes a very good presentation. He has a very good ability to transmit understanding of the topic."

"I am basically a relay person in an electric utility. Communication means have become very important in relaying and data acquisition. I came to learn more about the substance of communications and that is exactly what I learned."

"I enjoyed Ken Fodero's part. It was interesting, not too short, not too long, and had good information. He provided solution possibilities, which is a good future resource."

"Miriam did a great job presenting her topics in particular, PLC (this is a very complicated subject that she made simple to understand)."

Related Courses

For information about the following courses, contact Willis Long, program director, 800-462-0876, or e-mail willis@engr.wisc.edu.

Analysis of Transients in Power Systems
May 5–9, 2014
Madison, Wisconsin
Course #P017

High-Voltage Direct-Current Power Transmission
May 13–15, 2014
Madison, Wisconsin
Course #P015

Power System Operation in the Age of Smart Grid
June 9–13, 2014
Madison, Wisconsin
Course #P020

Medium Voltage Cables in Nuclear and Fossil Power Plants: Characteristics, Performance, Condition Assessment
July 14–16, 2014
Charlotte, North Carolina
Course #P301

2014 EEI Transmission and Wholesale Markets School
August 4–8, 2014
Madison, Wisconsin
Course #P306

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Four Easy Ways to Enroll

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http://epd.engr.wisc.edu/

ENROLL ONLINE TODAY!

Phone:
800-462-0876 or
608-262-1299 (TDD 265-2370)

Mail to:
The Pyle Center
Attn: Engineering Registration
702 Langdon Street
Madison, Wisconsin 53706

Fax:
800-442-4214 or
608-265-3448

Course Information
Please enroll me in

- ❑ **Modern Power System Protection: Applications and Performance Analysis**
  Course #P018 June 16–20, 2014 in Madison, Wisconsin Fee: $2195
- ❑ **Communications for Power System Protection, Automation, and Smart Grid Technology**
  Course #P019 June 23–27, 2014 in Madison, Wisconsin Fee: $2195
- ❑ **Both courses (#P018/#P019)** in Madison, Wisconsin Reduced Fee: $3995
- ❑ I cannot attend at this time. Please send me brochures on future courses.

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Name _____

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Title _____

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Need to Know More?

Call toll free **800-462-0876** and ask for

Program Director: Willis F. Long
willis@engr.wisc.edu

Program Associate: Debbie Benell
benell@engr.wisc.edu

Or e-mail **custserv@epd.engr.wisc.edu**

General Information

Fee Covers Notebook, course materials, break refreshments, lunches, textbook for the Modern Power System Protection course, and certificate. We do not publish proceedings.

Cancellation If you cannot attend please notify us at least seven days prior to the course start, and we will refund your fee. Cancellations received after that date and no-shows are subject to a $150 administrative fee per course. You may enroll a substitute at any time before the course starts.

Location These courses will be held at The Pyle Center, 702 Langdon Street, Madison, WI. Phone messages: 608-262-1122.

Accommodations

For Course #P018

We have reserved a block of guest rooms (rates starting at $89, including continental breakfast) at The Lowell Center, 610 Langdon Street, Madison, WI. Reserve a room online at epd.engr.wisc.edu/lodgingP018 or call 866-301-1753 or 608-256-2621 and indicate that you will be attending this course under group code P018EPD. Room requests after May 9 will be subject to availability. Other fees and restrictions may apply.

We have reserved a second block of guest rooms (rates starting at $118, including shuttle) at The Madison Concourse Hotel and Governor's Club, One West Dayton Street, Madison, WI. Reserve a room online at epd.engr.wisc.edu/lodgingBP018 or call 800-356-8293 or 608-257-6000 and indicate that you will be attending this course under group code 330299. Room requests after May 24 will be subject to availability. Other fees and restrictions may apply.

For Course #P019

We have reserved a block of guest rooms (rates starting at $89, including expanded continental breakfast) at The Lowell Center, 610 Langdon Street, Madison, WI. Reserve a room online at epd.engr.wisc.edu/lodgingP019 or call 866-301-1753 or 608-256-2621 and indicate that you will be attending this course under group code P019EPD. Room requests after May 16 will be subject to availability. Other fees and restrictions may apply.

We have reserved a second block of guest rooms (rates starting at $118, including shuttle) at The Madison Concourse Hotel and Governor's Club, One West Dayton Street, Madison, WI. Reserve a room online at epd.engr.wisc.edu/lodgingBP019 or call 800-356-8293 or 608-257-6000 and indicate that you will be attending this course under group code 330300. Room requests after June 2 will be subject to availability. Other fees and restrictions may apply.

ACCEPTED 30 Professional Development Hours NATIONWIDE

Earn Continuing Education Credit
By participating in either course, you will earn 30 Professional Development Hours (PDH)