UNIVERSITY of WISCONSIN
UWMILWAUKEE
School of Continuing Education

POWER SYSTEM / ELECTRICAL ENGINEERING SERIES:

***Electrical Substation Design Fundamentals (3 days)**

***Protective Relaying Principles & Applications (3 days)**

***Understanding Power System Design & Operation (3 days)**

***Transmission Line Design (2.5 or 3 days)**

***Generator Protection (3 days)**

***Motor Applications (2 or 3 days)**

Prepared by
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INSTRUCTOR PROFILES

Dan Chaply
UWM Adjunct Faculty

Dan Chaply has been a lead substation design engineer for substation projects for more than 25 years. He has developed designs for a wide variety of voltages, capacities, and end-user categories, including dedicated single-use industrial substations, large transmission substations, bulk power/intertie substations and switchyards, IPP interconnects, and power system distribution substations. He received his BSEE and MSEE from Lehigh University, and is a member of the IEEE.

Anthony F. Sleva, P.E.
UWM SCE Adjunct Faculty

Mr. Sleva is President of Sleva Associates, an electrical consulting and training company founded in 1995.

He is a registered Professional Engineer with a BSEE degree from Pennsylvania State University. During his career, he has designed electrical systems for nuclear generating stations; designed 500-230 KV, 230-69 KV, 138-12 KV and 69-12 KV substations; provided technical support to power dispatchers, system operators and plant operators; and developed technical training programs for technicians, drafters, designers and technical clerks. Presently, Mr. Sleva specializes in the analysis of power system events that cause the loss of customer load and/or the initiation of emergency load control procedures as well as events that may have been caused by incorrect protective relay actuations.

Doug Proctor
UWM SCE Adjunct Faculty

Mr. Proctor, president of D. Proctor Engineering, Inc. has over 40 years of engineering, project management, and construction management experience on transmission, substation, and distribution projects throughout the United States and overseas.

Doug has been responsible for initial project planning and layout, preliminary design, routing alignment, substation site selection, right-of-way acquisition, project evaluation and development, environmental coordination, transmission/substation design, microwave and fiber optic communication systems, and construction management services.

He is experienced in all aspects of transmission and substation projects at voltages ranging from 7.2-kV to 500-kV including environmental services, land acquisition services, engineering, contract administration, construction management, and project management. Mr. Proctor is a registered professional engineer in California. His area of expertise is project engineering on overhead transmission projects encompassing engineering and design, environmental support associated with transmission line routing and substation site selection, preengineering studies to assess feasibility of options, structure design and selection, right of way acquisition , clearance requirements, cost estimates, preparation of contracts, contract administration, scheduling, establishing budgets and work plans, and construction management.

Donald Reimert
UWM SCE Adjunct Faculty

Don Reimert has been involved with the application of motors and generators for more than 40 years. He has worked with motor applications at nuclear power plants, coal, oil and gas fired power plants, dredging operations and mining operations. Mr. Reimert authored the textbook "Protective Relaying for Power Generation Systems" published by Taylor and Francis.

He is a graduate of The Pennsylvania State University and a registered Professional Engineer. Currently, Mr. Reimert is employed by PPL Electric Utilities in Allentown, PA.

COURSE TOPICS / OUTLINES

Electrical Substation Design (3 days)
-Mr. Dan Chaply

Overview
This program is presented as an introductory course on the fundamentals for the electrical, civil, structural design issues of electric power substations. Topics will cover safety, standards, site development, grounding practices, bus configurations, AC and DC ancillary systems, and major equipment.

The course will address a complete variety of substation design subjects at a level appropriate to those relatively new to the area of substation design. It will introduce technical requirements, configuration philosophies, design practices, information sources, and work processes. Issues related to reliability, safety, security and maintainability will be underscored. Emphasis is placed on practical issues important in developing an engineered solution. After this course, one will have a broad foundation upon which one can base the development of new, and the upgrade of existing, substation facilities.

This course will also provide an introduction to electrical substation engineering for non-electrical engineers, as well as a civil and structural introduction for non-civil / structural engineers.

Course Outline

Day One

Electrical Substations, Power Systems, and Deregulation
- Structure of the Electric Power System - Overview
- Power Distribution Systems
- Classifications
- Equipment Definitions
- Design Principles

Substation Project Chronology
- Workflow and Project Sequence Planning

- Site Identification and Acquisition
- Engineering Design, Drawings and Documentation
- Procurement and Contracts Administration
- Construction, Testing and Commissioning
- Developing the Scope/Identifying the Constraints for the Overall Project
- Safety
- Power Requirements
- Site Constraints
- Weather
- Atmospheric
- Environmental Community and Societal Influences
- Electrical Effects
- Construction Related
- Operation and Maintenance O&M

Costs and Schedules

- Costs and Financial Analysis
- Schedules and Impacts

Site Grading Design

- Substation Grade Types
- Drainage and Erosion Protection
- Oil Spill Containment

Day Two:

Foundations

- Slab on Grade
- Pier
- Piles
- Access Roads
- Fence

Design Techniques

- Open Air
- Metal Clad Switchgear
- Gas Insulated Subs/SF6

Bus Configurations

- Types of Common Configurations
- Reliability Criteria
- Single Bus
- Segmented Bus
- Breaker and Half
- Ring Bus
- Double Bus/Double Breaker

Insulation and Insulation Protection

- Insulation
- Insulation Protection
- Clearance
- Surge Arresters

Bus Conductor

- Electrical Power Bus
- Rigid Bus
- Strain Bus

Grounding

- Need for Grounding
- Personnel Safety
- Hazardous Potentials During Faults
- Ground Grid
- Earth Resistivity
- Design Considerations
- Testing
- Soil and Electrode Enhancement Materials

Structures

- Materials
- Design Options and Considerations
- Finishes

Day Three:

Principle Equipment

- General Specifications and Ratings

Transformers

- Core, Winding Configuration
- Tap Changers
- Specifications

Circuit Breakers

- Design and Purpose
- Operating Mechanism
- Interrupters
- Relayed Operation
- Specifications

Switches

- Operational Types
- Interrupters
- Specifications

Ancillary Equipment

- Potential Transformers
- Current Transformers

Substation Auxiliary Systems

- Necessity
- AC Station Power
- DC Station Power

Protective Relaying Principles and Applications (3 days)

-Mr. Tony Sleva

Overview

This program presents fundamental concepts of protective relaying. It covers basic concepts, important setting considerations and short circuit current calculations. You also learn how overcurrent, phase distance and differential relay settings are determined.

You gain the ability to determine setpoints for protective relays commonly encountered in substations, switchyards and industrial plants for protection of feeders, lines, transformers, buses and motors.

Course Outline

Day One

Basic Concepts

- Protective relay functions
- Relay technology
- Relay inputs - CT & VT
- Protection and control schemes

Zones of Protection

Short Circuit Calculations

- Typical System Impedances
- Per unit quantities
- Symmetrical components
- Sequence diagrams
- Sample short circuit calculations

Distribution Line and Motor Feeder Protection

This segment of the course discusses protection of radial lines and feeders

- Power system configuration
- CT and VT location and characteristics
- Load current considerations
- Overcurrent relay pickup setting considerations
- Overcurrent relay time delay considerations
- Downstream coordination example
- Upstream coordination example

Day Two

Transmission Line and Networked Distribution Line Protection

This segment of the course discusses protection of networked lines

- Power system configuration
- CT and VT location and characteristics
- Load current and voltage considerations
- Overcurrent relay pickup setting considerations
- Overcurrent relay time delay considerations
- Phase distance relay setting considerations
- Pilot (communication aided) schemes

Power Line Carrier relaying (Blocking)

Audio-Tone relaying (Permissive Overreaching)

Fiber Optic relaying

- Phase distance relay setting example
- Overcurrent ground relay setting example

Transformer Protection

- CT location and characteristics
- Transformer considerations
- Differential relay setting considerations
- Overcurrent (thermal) relay pickup setting considerations

- Overcurrent relay time delay considerations
- Differential relay setting example

Day Three

Bus Protection
- CT location and characteristics
- Bus considerations
- Differential relay setting considerations
- Differential relay setting example

Breaker Failure Protection
- Bus configuration considerations
- CT location and characteristics
- Differential relay setting considerations
- Differential relay setting example

Capacitor Protection
Motor Protection
Under/Over Voltage Protection
Under/Over Frequency Protection

Understanding Power System Design & Operation (3 days)

-Mr. Tony Sleva

Overview

This program presents fundamental concepts of power system design and operation for non-electrical engineers involved in the electric power industry. This course gives you a working knowledge of electrical power system basics and the ability to comfortably discuss electrical system issues with utility personnel who rely on your input and advice.

The course is for analysts, designers, drafters, engineers, project managers, supervisors, technicians, and others who need to know the fundamental concepts for designing or operating power systems. This course introduces terminology and components of power system transmission and distribution systems.

Course Outline

Day 1*

Customer Equipment and Service Requirements
- Single phase 120 and 240 volt equipment
- Three phase 120/208 and 277/480 volt equipment
- Voltage requirements
- Current demand
- Power quality
- Reliability expectations

Distribution System Design and Operation
- Voltage and current ratings
- Overhead lines and components
    - Wire, cable and support structures

    - Electrical clearance considerations
    - Circuit breakers and protective relays
    - Circuit reclosers and fuses
    - Air break switches
    - Surge and lightning protection
- Underground lines and components
    - Cable and duct banks
    - Circuit breakers and protective relays
    - Fuses and sectionalizers
    - Air break switches
    - Surge and lightning protection
- Distribution system operation
    - Short circuit detection and isolation
    - Load and voltage control
    - Power factor correction capacitors
    - Voltage regulators
    - Distribution system efficiency

Day 2

Transmission System Design and Operation

- Voltage and current ratings
- Overhead lines and components
- Underground lines and components
- Transmission system operation
    - Short circuit detection and isolation
    - Load and voltage control
    - Economic dispatch of generators
    - Power factor correction
    - Voltage control with generators
    - Transmission system efficiency
    - System stability considerations
    - Reactive Power Requirements

Day 3

Substation Design and Operation

- Voltage and current ratings
- Outdoor substations
    - Electrical clearance considerations
    - Transformer connections and ratings
    - Control houses
    - Circuit breakers and ratings
    - Circuit switchers and circuit interrupters
    - Protective relaying
    - Air break switches
    - Zones of protection
    - Surge and lightning protection
- Indoor substations
    - Switchgear designs
    - Phase bus designs and ratings
    - Electrical clearance considerations
- Substation operation
    - Bus configurations
    - Transformer and bus redundancy
    - Single failure analysis

- o Circuit breaker failure considerations
- o Short circuit detection and isolation

System Design Considerations

- Load characteristics
- Nominal versus actual voltage
- Power factor correction
- Daily and seasonal load fluctuations
- Voltage reductions
- Rotating blackouts
- Under frequency load shedding

*Special note: Course notes include numerous photographs of many power system components. Small transformers, insulators, surge arrestors, fuses, wire, cable, cable terminators and other items are utilized during class discussions.

Transmission Line Design (2.5 or 3 days)

-Mr. Douglas Proctor

Day One

1. Basic Overview **1 hour**

Discussion of Overhead Transmission Line Design considerations

- Transmission Lines as a System
  - o Electrical Fundamentals for Transmission Lines
  - o Towers, Poles, and Conductors
  - o Insulation
  - o Line Protection
- Structural Loading
- Codes and Clearances
- Standard Transmission Voltage Levels
- Environmental Impacts

2. Required Conductor Clearances **2 hours**

Discussion of National Electrical Safety Code and its impact on Line Design.

- Vertical Clearances
- Horizontal Clearances
- Minimum Clearances
- Structure Clearances
- ROW Clearances
- Joint Use Clearances
- Navigable Waterway Clearances
- FAA Height Restrictions
- Sag Charts

3. Mechanical Loads on Structures **2 hours**

Discussion of weather data and how lines are designed to withstand loads placed upon them from the wind, ice accretion (buildup), and in combination.

- Conductor Tension
- Wind Speed
- Ice Loading
- Construction Loads

- Potential for Uplift
- Air Break Switches
- Wireless Communication Antennas

4. Insulators **1 hour**

Discussion of ceramic, glass and polymer insulators and the advantages of each.

- Suspension Type
- Post Type
- V Strings
- Switching Surges
- Lightning Surges
- Leakage Distance
- Contamination Considerations
- Insulation Coordination
- Mechanical Design Considerations

5. Conductors **2 hours**

Discussion of the types of conductors (ACSR, ACAR, high strength steel, etc.) and their electrical and mechanical characteristics including ampacity, sag, allowable tensions, vibration and vibration damping.

- Conductor Selection
  - Ampere Rating
  - Evaluation of Losses
  - Corona Levels/EMF
  - Physical Loading
- Bundled Conductors
- Conductor Movement
  - Insulator Swing
  - Blowout
  - Aeolian Vibration
  - Galloping
  - Ice Shedding
- Accessories
  - Fittings
  - Aerial Markers
  - Spacers
  - Dampers
- Standardization

<u>Day Two</u>

6. Overhead Ground Wires **1 hour**

Discussion of the types of overhead ground wire (EHS, EHSS, Alumoweld, OPGW, etc.) and their effectiveness for lightning protection.

- Shielding Angle
  - Positive
  - Negative
- Fault Current
- Fiber Optic Communication

7. Noise **1 hour**

Discussion of noise mitigation methods (Audible, RI, TVI, etc.)

- Causes and preventions
- Methods of Measurement

8. Structure Design **2 hours**

Discussion of structural design of wood and steel support structures

- Loading Tables
  - Vertical Loads
  - Horizontal Loads
  - Longitudinal Loads
- Overload Factors
- Structure Family
  - Tangent Structures
  - Angle Structures
  - Strain Structures
  - Terminal Structures

9. Foundation Design **2 hours**

Discussion of foundation installation techniques and types.

- Geotechnical Surveys
- Guys and Anchors
- Lattice Towers
- Tubular Steel Poles
  - Direct embedment
  - Anchor Bolt Type
- Soil Types

10. Grounding **1 hour**

Discussion of structure grounding methods.

- Ground Resistivity
- Ground Resistance
- Ground Rods
- Counterpoise
- Adjacent Facilities
  - Other Lines
  - Fences
  - Pipelines
- Safety Grounds for Personnel

<u>Day Three* (*1/2-day)</u>

11. Environmental Coordination **1 hour**

Discussion of the role of the engineers and designers in supporting environmental assessments of proposed transmission line projects.

- Construction Impacts
- Land Use
- Laydown Yards
- Access Roads
- Temporary and Permanent Impacts
- Visual Impacts
- EMF Considerations
- Plan of Development

12. Project Schedule **2 hours**

Discussion of key milestones for proposed transmission line projects.

- Notice of Intent
- Preliminary Corridor Selection
- Right of Way Acquisition
- Geotechnical Surveys
- Tower Spotting
- Detailed Design
- Procurement and Shop Fabrication
- Construction

Generator Protection (3 days)

-Mr. Donald Reimert

Overview

This three-day course provides basic concepts as well as in-depth discussion of schemes associated with the electrical protection of large generators.

Scheme discussions include hazards necessitating the protection, protection philosophy, setting criteria and example settings calculations.

This course is intended for, engineers, technicians, managers, supervisors and others who work with generators. This includes individuals involved with selection/application of protection for large generators, and those who operate or assess operational risks associated with generators.

Course Outline

This three-day course will use the instructor's text "Protective Relaying for Power Generation Systems" which will be provided to each attendee. The following will be discussed.

Generator Normal Operation

- Generator Capability
- Voltage Limitations
- System Limitation
- Capability Variations with Voltage
- Excitation Systems Overview

Generator Short Circuit Calculations

- Short Circuit Characteristics
- Generator Magnetic Structures
- Generator Constants
- Fault Calculation Methods
- Voltage Regulator Effects

Generator Differential Relay

- Idea Differential Relay

- CT Imposed Limitations
- Relay Characteristics
- Stabilizing Resistor Application
- Frequency Response

Backup Fault Protection

- Overcurrent Relay
- Voltage Control and Voltage Restraint Relays
- Distance Relay
  - – Characteristics and Setting Consideration
  - – Load Limits
  - – Influence of Wye-Delta

GSU Transformer

Generator Ground Fault Protection

- Grounding Methods and Considerations
  - – Ungrounded
  - – Solidly Grounded
  - – High-Impedance Grounding
  - – Low-Impedance Grounding
- Ground Fault Protection
  - – Alarm vs Tripping
  - – High Impedance Ground Protection
  - – Low Impedance Ground Protection
  - – 100% Stator Protection Schemes
    - – Harmonic Schemes
    - – Neutral Injection Schemes

Unbalance Current Protection

- Negative Sequence Current
- Effects of Negative Sequence Current on Generator
- Generator Negative Sequence Capability
- Sources of Negative Sequence Current

Motoring Protection

- Effects of Motoring
- Motoring Protection
- Sequential Trip Logic
- Backup Protection

Field Winding Protection

- Field Ground Protection
  - – Hazards and Detection
- Field Overcurrent Protection
  - – Full Load Field Current Values
  - – Maximum Field Current from Bridge-Rectifier

Overexcitation

- Causes and Damage
- Volts/Hertz Limits
- Protection
  - – Field Monitoring Relay
  - – V/Hz Limiters
  - – V/Hz Relay Application
    - – Settings for Transformer and Generator Protection
- Differential Relay Response to Overexcitation

Abnormal Frequency Protection

- Effects on Generator
  – Steam Turbines, Combustion Turbines, Hydro
- Effects on Excitation System
- Protection and Settings
  – Primary and Backup Protection

Minimum Excitation Limiter

- MEL Application Overview
- Generator Leading Var Capability
- Coordination with Loss-of-Field
- System Stability Limitations
- MEL Characteristics
- MEL Dynamic Performance

Loss-of-Synchronism Protection

- Turbine-Generator Damage
- Transient Stability
- Out-of-Step Protection Schemes
- Classical Swing Impedance Characteristic
- Dynamic Swing Representation

Loss-of-Field Protection

- Factors Effecting Loss-of-Field Severity
- Potential Generator Damage
- Protection Schemes
- Other causes of LOF Tripping

Synchronizing Protection

- Potential damage to Generator and Stepup Transformer
- Breaker Considerations
- Synchronizing Methods
- Sync-Check Relay
- Auto Synchronizing
- Slow Close Protection

Accidental Energization Protection

- Generator State at Energization
- Inadvertent Energization at Standstill
  – Dynamic Analysis
- Breaker Flashover
- Generator and Turbine Damage
- Protection Provided by Other Schemes
- Dedicated Energization Protection Schemes

Motor Applications (2 or 3 days)

-Mr. Donald Reimert and Mr. Tony Sleva

This two-day course presents fundamental concepts needed for the application of AC and DC motors. Basic motor principles and definitions are reviewed and then related to low and medium voltage, induction and synchronous motors as well as series, shunt and compound DC motors. Motor starting and protection concepts are covered.

This course is intended for designers, engineers, technicians, managers, supervisors and others who work with motors. This includes individuals involved with selection, application and/or protection of motors.

Course Outline

This three-day course will use the instructor's text "Protective Relaying for Power Generation Systems" which will be provided to each attendee. The following will be discussed.

Induction Motors

- Nameplate Data
- Permissible Voltage Variations
- Voltage and Current Relationships
- Preferred Motor Ratings
- Inrush Current
- Locked Rotor Indicating Codes
- Equivalent Circuits
- Speed-Current Relationships
- Load-Current Relationships
- Speed-Power Factor Relationships
- Load-Power Factor Relationships
- Watts-Speed Relationships
- Vars-Speed Relationships
- Speed-Torque Relationships
- Load-Efficiency Relationships
- Rotating Magnetic Fields
- Basic Magnet Circuits

Design Considerations for Motor Selection

- Motor Speed
- Locked Rotor Torque
- Breakdown Torque
- Inertial Capability
- Starting Capability (Wk2)
- Occasional Excess Current
- Stall Time
- Insulation Classification
- Service Factor
- Efficiency

Induction Motor Applications

- Electrical Service
- Driven Load Requirements
- Required Horsepower Calculations
- Driven Load Characteristics
- Across the Line Starting
- Reduced Voltage Starting

Wound Rotor Motors

- Motor Characteristics
- External Rotor Resistance
- Driven Load Characteristics

- Two-Speed Motors

Motor Control Circuits

- Power Circuits
- Control Circuits
- Motor Starters
- Overload Detectors
- Voltage Drop

Motor Protection

- Overcurrent Protection
- Overload Protection
- Undervoltage Protection
- Overvoltage Protection
- Phase Unbalance Protection

Synchronous Motors

- Speed-Torque Characteristics
- Load Inertia and Maximum Slip for Pull In
- Out of Synchronism
- Amortisseur/Damper Windings
- Power Factor

DC Motors

- Series Motors
- Shunt Motors
- Compound Motors
- Inrush Current
- Starting Resistors

Why UWM SCE

Internationally Recognized University: When you choose the University of Wisconsin-Milwaukee School of Continuing Education, you partner with one of the nation's most respected university systems to gain the knowledge and skills your employees need to succeed.

Immediate Impact: Our courses are typically offered in an efficient, one-to-three-day format and are designed so knowledge gained can be immediately applied back on the job.

Top-Notch Instructors with Front-Line Experience: Our adjunct faculty is a team of practitioners who deal with real-world business challenges every day, so they are well equipped to help your employees bridge the gap between knowledge and implementation. Participants evaluate instructors after every program they teach. Instructor performance is monitored closely, and only the best are retained.

High Quality, Relevant Curriculum: Your employees learn from proven material; our courses are infused with best-in-industry examples and tools.

Rapid Response: We know the pace of business, and are committed to expedient program development and delivery.

Savings: Onsite programs are typically more cost effective on a per participant basis when compared to public programs for groups of eight or more.

Value: For all of these reasons, investment-savvy companies choose UWM SCE as their professional training partner because they know we have the most robust package of resources to offer them. As a result, they **get the best possible value for their education dollars.**