Introduction to Synchrophasors

ITP I-V

Synchrophasor Primer for the Electric Power Industry

An essential training course to for todays' Electric Power Industry personnel featuring:

- Synchrophasor Fundamentals
- Synchrophasor Metrics
- Phase Angle Differences
- Grid Event Signatures
- Oscillations

NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

INTRODUCTION TO SYNCHROPHASORS AND EPG_116487_ONLINE_INTRODUCTION_TO_SYNCHROPHASORS IS RECOGNIZED BY THE NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION AS AN APPROVED LEARNING ACTIVITY FOR WHICH 5.00 NERC CEHS CAN BE AWARDED, AND ELECTRIC POWER GROUP ADHERES TO CE PROGRAM CRITERIA.

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1 ABOUT THE COURSE

1.1 COURSE OVERVIEW

"Introduction to Synchrophasors" provides an essential primer on synchrophasor (or phasor) technology. The course covers essential aspects of this technology – what is measured, the various components, terminology, concepts, advantages and uses.

The course comprises 5 sessions that cover all foundational aspects of synchrophasors. Each session is of approximately 1 hr. of instruction.

Why is this course essential?
Synchrophasor technology is being rapidly deployed and implemented across the world by the electric power industry, not only to address challenges but also to enable next generation capabilities for planning, managing and operating the power grid. The potential of synchrophasors in improving situation awareness, preventing black-outs, monitoring power grid dynamics which cannot be delivered by traditional means like SCADA, are driving the universal implementation of phasors.

While the deployment of synchrophasors and implementation of solutions based on this technology has exploded, foundational awareness and knowledge amongst the potential users is seen as lagging.

Awareness and fundamental knowledge of this technology therefore is needed across-the-board among the personnel involved in any aspect of the electric power grid – operations, engineering, protection and planning.

1.2 NERC CONTINUING EDUCATION HOURS (CEH) CREDIT

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Introduction to Synchrophasors and EPG_116487_Online_Introduction_to_Synchrophasors is recognized by the North American Electric Reliability Corporation as an approved learning activity for which 5.00 NERC CEHs can be awarded, and Electric Power Group adheres to CE Program Criteria.

1.3 SYLLABUS: SESSIONS & TOPICS

The course provides a well-rounded understanding of synchrophasors. It comprises 5 sessions that cover the essential aspects of this technology and its use. Each of these sessions focuses on a key area of synchrophasors, and together, the 5 sessions form a strong foundational understanding and awareness of the domain. These sessions are:

1. Synchrophasor Fundamentals
2. Synchrophasor Metrics – Use in Real Time Operations

3. Phase Angle Differences – How can they be used in operations?
4. Grid Event Signatures – Use to detect and diagnose grid events
5. Power System Oscillations – Types, Causes, and Monitoring

Each session is described in more detail below.

1.4 TARGET AUDIENCE:

Deployment, implementation, management and utilization of synchrophasor technology involves personnel from several areas, responsibilities and departments. The target audience for this course includes:

(i) Real time control room operations personnel – dispatchers/operators, supervisors, etc.
(ii) Systems and operating engineers
(iii) Engineering and Planning personnel
(iv) Protection and Analysis
(v) Field personnel responsible for equipment installation, calibration, test and maintenance
(vi) IT personnel responsible for set-up and operation of phasor applications, data acquisition, networks and security.

1.5 PRE-REQUISITES

This course assumes a basic understanding of the following fundamental power grid concepts at a high level:

- Voltage
- Current
- Substation Components and Operation
- Potential (Voltage) Transformer (PT)
- Current Transformer (CT)
- Control Room Operation

1.6 FACULTY

The course instruction is provided by experienced practitioners who are also acknowledged subject matter experts. The blend of real world experience, subject matter expertise and training experience of the instructors makes this course and its respective sessions truly unique, balanced and comprehensive. The faculty includes:

- Ken Martin is an internationally recognized pioneer of synchrophasors.
- Jim Dyer, has managed and operated one of the world's largest systems at SCE
- Wayne Schmus, has over 4 decades of expertise in Engineering and Planning
- Kevin Chen, has led the development of real time solutions and is an experienced trainer
- Prashant Palayam, lead research & analysis projects for all N. American Interconnections & DoE

1.7 INSTRUCTION METHODOLOGY

Each session is a video based instruction simulating a classroom session. The instructor conducts the session using presentation aides. Sessions include:

- Concepts
- Terminology
- Case Studies & Real World Examples

1.8 PROFICIENCY EVALUATION

Each of the 5 sessions include a multiple choice proficiency test, comprising of questions that probe the trainee's understanding of the subject matter of the session.

Additionally, the sessions feature informal pop-quizzes and questions.

2 INCLUDED COURSE SESSIONS

The course comprises of 5 sessions, each of which cover a key area of synchrophasor technology foundational learning. The 5 sessions are:

(i) Synchrophasor Fundamentals
Preview at: https://youtu.be/r4lg7-dlj_c

(ii) Synchrophasor Metrics – Use in Real Time Operations
Preview at: https://youtu.be/CO9yyI-aCzA

(iii) Phase Angle Differences – How can they be used in operations
Preview at: https://youtu.be/nZAd9lPz7KA

(iv) Grid Event Signatures – Use to detect and diagnose grid events
Preview at: https://youtu.be/h-hyQxacQpU

(v) Power System Oscillations – Types, Causes and Monitoring
Preview at: https://youtu.be/WOUp1HeHHUE

The details of each session are provided below along with a link to a video preview of each session:

2.1 ITP-I: SYNCHROPHASOR FUNDAMENTALS

2.1.1 Session Description – Synchrophasor Fundamentals

Synchrophasor Fundamentals is the first session in the "Introduction to Synchrophasors" course. This session provides an introduction to synchrophasors and covers the following topics:

- Phasors - Fundamentals

  This section defines phasors and explains the concept of magnitude and angles. It describes voltage and current phasors in AC power systems.

- Synchrophasors - Definition and Description

  This section defines synchrophasors and describes their properties. It explains how synchrophasors are calculated and provides examples. It also describes how synchrophasor are obtained from power system measurements and why they are important for real-time operations and control.

- Synchrophasor Attributes – Essential Properties

  This section describes the characteristics of synchrophasors and how metrics like power flows and frequency are derived from synchrophasor measurements. It talks about how synchrophasors can be used to study power system dynamics and the importance of synchrophasors for obtaining a wide-area system view.

- Applying Synchrophasors – Measurement Principles and Examples

  This section gives an overview of how synchrophasors can be applied to the power grid and provides high-level examples on the use of synchrophasors for wide area visualization using

phase angle differences, voltage stability assessment, oscillation detection and stability assessment, power system model validation etc.

- Synchrophasor Technology Infrastructure – Components and Data Flow

  This section describes the data flow in a synchrophasor system from measurement devices in the substations to control centers and data concentrators and then to the operators & engineers for the use in real-time operations and analysis. This section also provides an overview of the devices and components in a synchrophasor system.

  A preview of this session is available here: https://youtu.be/r4lg7-dlj_c

2.1.2 Instructor (s)

The instructor for this session is **Ken Martin**.

Kenneth Martin is a principal engineer with the Electric Power Group (EPG). He has over 35 years of experience in the electric utility industry, starting at the Bonneville Power Administration (BPA) and including work in communication, precise timing, instrumentation, and testing. He started working with synchrophasor measurement with the original PMUs in 1987. He developed the phasor measurement system at BPA including building the first phasor data concentrator, and supported similar developments at many utilities. Mr. Martin chaired the development of the IEEE C37.118 Synchrophasor Standards from 2000 through the current 60255-118-1 IEC-IEEE standard under development. Mr. Martin is a Fellow of the IEEE and a registered Professional Engineer. Ken is internationally recognized authority on synchrophasors and regularly provides consultation to DoE, NIST and actively participates in industry forums including IEEE, NASPI, JSIS and others.

2.2 ITP-II: Synchrophasor Metrics – Use in Real Time Operations

2.2.1 Session Description –Synchrophasor Metrics

This is the second session in the "Introduction to Synchrophasors" course. This session describes synchrophasor metrics and explains how these metrics can be used in real time operations. The topics covered in this session are given below:

- Introduction to Synchrophasor Metrics

  This section lists the important synchrophasors metrics and gives an overview of how can these metrics be used in operations. This section also compares synchrophasor data to SCADA data and explains the differences between them.

- Phase Angle Differences – How to use phase angle differences to assess grid stress?

  This section defines phase angles and phase angle differences and explains their significance. It describes how phase angles are related to power flows and how phase angle differences can be used to assess grid stress. It explains the concepts of phase angle differences across a line vs phase angle differences across a wide area. This section provides use case examples to illustrate how phase angle differences can be used in control rooms to assess grid stress.

- Voltage Sensitivity- How to use voltage sensitivities to assess voltage stability

This section explains what voltage sensitivity means and how it is calculated. It describes different types of visualization displays that can be used to assess voltage stability using voltage sensitivities. Use case examples are provided to explain why voltage sensitivity is important and how it can be used in control rooms.

- Frequency Deviations - How to use frequency deviations to assess grid disturbances and instability?

  This section explains what frequency deviations are and how they can be used to diagnose grid events, identify root cause and also detect instability in the grid.

- Oscillations – How to use synchrophasors to assess the risk posed by oscillations?

  This section introduces the concept of power system oscillations and explains characteristics of oscillations like Damping and Frequency. It explains how to identify the source of oscillations and provides examples to illustrate how to detect, diagnose, mitigate and monitor oscillations in the power systems.

A preview of the session "Synchrophasor Metrics – Use in Real Time Operations" is available here: https://youtu.be/CO9yyI-aCzA

2.2.2 Instructor (s)

The instructor for this session is **Wayne Schmus**.

Mr. Schmus earned a BS in Engineering at Harvey Mudd College in Claremont, CA. His 34-year career at Southern California Edison Company included 25 years in transmission and generation planning attaining the position of Manager of Transmission Planning. His specialties were stability, interconnections and reliability. He also held the positions of Chief Engineer Distribution Automation, Manager Distribution Maintenance, and Manager System Protection. For two years, he chaired the NERC Subcommittee on Reliability Assessment. At EPG, Wayne is responsible for research initiatives, project management and special projects. Wayne is leading the EPG team on a DoE funded project on Development of a Direct Non-Iterative State Estimator that utilizes Synchrophasor and SCADA data. Mr. Schmus is a Registered Professional Electrical Engineer in California.

2.3 ITP-III: Phase Angle Differences – How Can They Be Used in Operations?

2.3.1 Session Description – Phase Angle Differences

This is the third session in the "Introduction to Synchrophasors" course. This session describes phase angle differences and explains how they can be used in real time operations. The topics covered in this session are given below:

- Definition & Importance of Phase Angle Differences for Operations

  This section explains what phase angles and phase angle differences are and why they are important. It gives an overview of some of the major blackouts and the lessons learnt from them.

- Phase Angle Differences – What are safe values?

This section explains the difference between phase angle differences across a line and phase angle differences across a wide area. It also describes using examples the safe values and limits for phase angle differences across short distances and across a wide area.

- Importance of PMU Location

  This section explains the importance of PMU location and its impact on phase angle monitoring. It compares PMU location on lines vs buses and discusses how to avoid loss of phase angle information.

- Use of Phase Angles in Control Rooms - Line Closing

  This section explains the key things to focus on during loss of transmission lines and discusses steps to take before closing lines.

- Case Study – 8 Bus System

  This section includes a case study using an 8 bus system to illustrate and explain how to use phase angle differences in control rooms to monitor the power system, diagnose events and stressed grid conditions and take remedial actions to reduce the impact on the grid. This section covers 4 different event scenarios and discusses the best remedial action to be taken in each scenario based on phase angle information.

- Use of Phase Angles in Control Rooms - Islanding & System Separation

  This section explains how phase angles can be used to detect islanding and system separation. It includes a video demonstration of how phase angles change after a system separation event and how they can be used to identify an islanding condition in the grid. It also shows different ways in which phase angle information can be visualized.

- Phasor Assisted Line Reclosing

  This section shows how phase angle differences can be used for line reclosing with examples of visualization displays that can be used by operators to determine whether it is safe to reclose lines.

A preview of this session: Phase Angle Differences – How Can They Be Used in Operations? Is available here: https://youtu.be/nZAd9lPz7KA

2.3.2 Instructor (s)

The instructor for this session is **Jim Dyer**.

Jim Dyer formerly a Manager of System Operation and Energy Control Center, Southern California Edison. Mr. Dyer has extensive experience in WECC and NERC on operations, transmission, reliability management and black-out investigations. Jim has been with EPG for 16 years and has been guiding the utilization of phasor technologies and development of phasor applications for use by real time operators, dispatchers and reliability coordinators at CAISO, ERCOT, SCE and by NASPI members and has been involved with NASPI since its inception.

Jim has delivered training programs on use of synchrophasors in real-time operations to industry bodies, control center staff, planners and engineers. His training programs combine his experience in operating one of the largest power systems in the United States and his expertise in synchrophasors.

2.4 ITP IV: Grid Event Signatures – Use in Operations To Detect & Diagnose Grid Events

2.4.1 Session Description – Grid Event Signatures

This is the fourth session in the "Introduction to Synchrophasors" course. This session describes different types of grid events and their signatures. The topics covered in this session are given below:

- Introduction to Grid Event Signatures

  This section explains what grid event signatures are and why they are important. It explains why synchrophasors can be used to leverage these event signatures to identify and diagnose events and also validate corrective actions.

- Types of Grid Event Signatures - Generation Trip, Line Fault, Line Trip, Load Trip, Islanding, Oscillations

  This section explains 7 different types of events (Generation trip, faults, line trips, islanding, oscillations etc.) and their signatures. It discusses how to identify the type of event based on its unique signature. It also explains the significance and meaning of these signatures for different type of events.

- Identify Event Type Using System Frequency Signature

  This section explains the process of detecting an event and identifying the event type in a synchrophasor system based on alarms and visualization available in synchrophasor system monitoring tools.

- Event Diagnosis - Using Synchrophasor Metrics

  This section explains how to use event signatures and the synchrophasor metrics to diagnose different power system events and assess the severity of the event. This section discusses 5 different types of events and uses metrics like voltages, frequency, power flow and phase angle differences to perform root cause diagnostics and assess severity of these events.

- Corrective Action and Validation Using Signatures

  This section explains how different corrective actions can be validated using the signature in the synchrophasor metrics and shows how these actions appear in a typical visualization display.

- Case Study – Generation Trip and Line Trip

  This section consists of two case studies. The first one is a generation trip event and the second is a line trip event. For both these events, this section describes the process of detecting an event, identifying event type using signatures, performing event diagnosis, assessing severity and confirming corrective action taken to mitigate the impact on the grid.

A preview of this session: Grid Event Signatures –Use in Operations to Detect and Diagnose Grid Events is available here: https://youtu.be/h-hyQxacQpU

2.4.2 Instructor (s)

The instructor for this session is **Prashant Palayam**.

Prashant Palayam has led research and analytics initiatives for ERCOT, NYISO, PJM, WECC, CAISO, as well as R&D projects from DOE, CCET, CERTS, etc. Prashant's expertise includes analyzing and characterizing grid dynamics involving oscillations, events, reactive zones, frequency response, data quality, data mining and baselining.

Prashant leads the EPG team as Product Manager for industry leading offline analytics software, the Phasor Grid Dynamics Analyzer (PGDA). He has led the research and development of event simulations and simulation tools for understanding grid behavior and training.

He is an experienced trainer having conducted training programs for EPG's customers and industry organizations on synchrophasor data analysis, grid events signatures and analytic tools. Prashant is a graduate of Illinois Institute of Technology, Chicago, IL with a Master's in power systems engineering.

2.5 ITP V: Power System Oscillations – Types, Causes, Monitoring

2.5.1 Session Description – Power System Oscillations

This is the fifth session in the "Introduction to Synchrophasors" course. This session describes power system oscillations and how to detect and monitor oscillations in the power grid. The topics covered in this session are given below:

- Introduction to Power System Oscillations

  This section introduces the concept of power system oscillations explaining what oscillations are and why they are important. It explains characteristics of oscillations such as frequency, damping, amplitude and phase. This section also explains the different types of oscillations (Natural oscillations and Forced Oscillations) that can occur in the power grid and describes the differences between them.

- Identifying and Analyzing Oscillations

  This section explains how to identify and analyze oscillations in the power system. It describes the tools and techniques that can be used to monitor and detect the known and unknown oscillations in the grid.

- Oscillation Monitoring

  This section describes the approach to be adopted for monitoring oscillations. It explains the concept of a mode meter. It explains the best practices for selecting signals and locations for oscillation monitoring. It describes how to identify situations of concern by looking at the damping and energy of an oscillation. This section also describes different types of visualization displays that can be used by operators to monitor oscillations in real time and take corrective action when needed.

- Oscillation Detection

  This section describes the approach and best practices for detecting oscillations. It provides recommendations for selecting signals and locations for detecting oscillations in the power system. It describes how to perform root cause diagnostics and identify the cause of oscillations. It discusses concepts like frequency and energy in different oscillatory frequency bands. Also provided in this section are examples of 4 forced oscillations and the detection and corrective action for each.

- Use Cases

  This section consists of two use case examples – inter-area oscillation & wind power plant forced oscillation. These are real events that occurred in the power grid and this section explains how these oscillations can be detected, analyzed and mitigated. This section also includes a video demonstration of the forced oscillation and shows how this event would appear in a synchrophasor monitoring system.

A preview of this session: Power System Oscillations – Types, Causes & Monitoring is available here: https://youtu.be/WOUp1HeHHUE

2.5.2 Instructor (s)

The instructor for this session is **Kevin Chen**.

Kevin Chen has extensive expertise and experience in the areas of real time grid dynamics. As the product manager for EPG's portfolio of real-time solutions - the Real Time Dynamics Monitoring System and associated products, Kevin works with customers, users and industry for implementing and enhancing the use of synchrophasor technologies in grid operations and analytics.

Kevin has conducted research and development related to voltage stability, phasor dynamics in transmission/distribution, oscillations, power flow and power systems transient programming. Kevin has applied his experience to research and application of advanced techniques to reliability issues related to reactive margins, contingencies, grid dynamics, nomograms, oscillation detection and damping.

He has developed and conducted training programs in the area of real time monitoring and use of EPGs portfolio of solutions for both EPG's customers including Dominion, Duke Energy, CAISO, ERCOT, NYISO, PJM, SCE as well represented at NASPI, JSIS, IEEE.

Kevin completed his M.S. in electrical engineering from the University of Wisconsin-Madison. He is a licensed Professional Engineer in Electrical Engineering in the State of California, USA.

3 SYNCHROPHASOR TRAINING PORTAL - TECHNOLOGY & DELIVERY

3.1 TECHNOLOGY ADVANTAGES

The course is provided on a MOOC (Massive Online Open Course) Portal which provides an efficient, cost effective system for delivering on-demand training.

The portal has been developed to meet industry expressed needs to deliver training in a cost and time efficient manner by:

1. Enabling online access 24 x 7 x 365 access from anywhere or anytime via internet connection and browser on a PC, laptop or tablet.
2. Reducing training costs – no equipment, facilities, food service, training rooms etc. are needed.
3. Eliminating logistics challenge of scheduling training to match work schedules and shifts.
4. Providing flexibility to trainees to complete courses at their own pace, plus the convenience of taking the courses again at no additional cost.
5. Incorporating expert lectures with state of the art video hosted on the industry leading "Kannu" platform to deliver course material, quizzes, and tests.

3.2 CONVENIENT & SIMPLE PROCESS

The platform is convenient delivery system that follows a simple process:

- ☐ Previews and Dashboard
- ☐ Enroll in course or /Assign course
- ☐ Sign In
- ☐ Complete on own schedule
  - ✓ Attend – in one sitting or multiple with breaks
  - ✓ Quizzes
  - ✓ Proficiency Evaluation
  - ✓ Review, repeat, refresh

4 ENROLLMENT & PAYMENT

4.1 FOR CORPORATE SUBSCRIPTION

For **corporate subscriptions involving multiple seats,** or an evaluation account, please contact:
Ashley Wang (wang@electricpowergroup.com) Phone: 626-685-2015 x 137

4.2 FOR INDIVIDUAL ENROLLMENT

Individuals may obtain a 1 year enrollment to the course upon payment of $1,500.00 per person.

Please complete the accompanying Enrollment & Payment Authorization form and fax/email a signed copy to EPG.

Upon verification and processing the payment, you will receive an email to login and start your course. This process takes approximately 2 working days.

ENROLLMENT & PAYMENT AUTHORIZATION FORM

Please print, sign and return to Electric Power Group.
Fax: 626.685.2039. Email: contact@electricpowergroup.com

To:

Electric Power Group, LLC
201 S. Lake Ave, Suite 400, Pasadena, CA 91101

I would like to enroll in the training course: Introduction to Synchrophasors. Please charge the course fee to the credit card below.

Name: _____

Email Address: _____

Telephone No: _____

NERC CEH Requested: ☐ Yes ☐ No

Credit Card Authorization for Introduction to Synchrophasors training course

Name on Credit Card: _____

Credit Card Billing Address: _____

City, State, Zip: _____ , _____ , _____

Type of Card: VISA ☐ MasterCard ☐ Amex ☐ Discover☐

Card Number: _____ Expiry: __ /__

CVV or Security code: _____
(3 digits on back of Visa/MasterCard or 4 digits in front of Amex)

I, _____ hereby authorize Electric Power Group, LLC to charge $ _____ to

my credit card for the above enrollment and course fee.

Signature of Card Holder: _____ Date: _____

Fax to: 626-685-2039 OR Email to: contact@electricpowergroup.com

 9.27.2016