12 MODULE GROUPS	
(1) Introductory/Overview Coverage;	*(7) Point-to-Point HVDC Configurations;*
(2) Station components;	*(8) Multi-Terminal HVDC Networks;*
(3) Converters;	*(9) Planning and Design;*
(4) Control;	*(10) HVDC System Simulation and Analysis;*
(5) HVDC Protection;	*(11) Regulatory Permitting Processes/Procedures;*
(6) HVDC Line and Cable Technologies;	*(12) Energy Equity and Environmental Justice.*

Module Table

(yellow to be completed year 1; blue in year 2; white in year 3)

Mod #	Lead-auth /Lead-rvwr	Module title	# of 1-h lectures	Comp date
1. INTRODUCTORY/OVERVIEW COVERAGE, Li				
1a	T2/UT1	Intro to HVDC technology	3	Q4
1b	UT1/T2	Application Guide for HVDC Transmission	3	Q2
1c	M1/T1	Intro to HVDC for offshore wind	3	Q2
1d	T1/C1	HVDC for executives	2	Q9
2. STATION COMPONENTS, Cui				
2a	V1/O1	HVDC reactive power, EMI, and filter design	4	Q3
2b	O1/C1	VSC-HVDC converter station technologies	3	Q4
3. CONVERTERS, Enslin				
3a	C2/C1	Interoperability between different HVDC converter technologies/vendors	3	Q12
3b	V1/M1	Power electronics 101: Fundamentals of switching pwr conv+EMT	3	Q5
3c	M1/UT2	Operation of thyristors & IGBTs in converters	4	Q7
3d	UT2/M1	Modular multilevel converter as HVDC cnvrtr interface and its control	3	Q3
4. CONTROL, Mehrizi-Sani				
4a	UT2/O1	Cnvtr cntrl fundamentals	4	Q6
4b	V1/C2	Dynamic modeling/cntrl of HVDC converters and grid-forming functions	4	Q8
4c	O1/V1	Control of multiterminal HVDC networks	4	Q8
4d	C2/C1	Offshore HVDC cnvrtr grid forming controller design for black start capability	3	Q4
5. HVDC PROTECTION, Nazir				
5a	M2/UT2	HVDC fault management & protection systems	6	Q4
5b	V1/UT1	HVDC measurements, faults, and misoperation	3	Q9
5c	C1/C2	Protection for multi-terminal HVDC networks	3	Q7

Mod #	Lead-auth /Lead-rvwr	Module title	# of 1-h lectures	Comp date
5d	UT2/M2	Protection: ability to ride through faults in HVDC	3	Q9
5e	V1/UT1	Cybersecurity in HVDC systems	3	Q11
6. HVDC LINE & CABLE TECHNOLOGIES, Wallace				
6a	M2/C1	Insulation - HVDC cables	5	Q10
7. POINT-TO-POINT HVDC CONFIGURATIONS, McCalley				
7a	I1/UT1	Onshore & offshore apps	2	Q3
8. MULTI-TERMINAL HVDC NETWORKS, Tolbert				
8a	UT2/O1	Design/operation of multiterminal HVDC grids	3	Q12
9. PLANNING AND DESIGN, McCalley				
9a	T2/O1	HVDC in pwr sys.; meshed HVDC systems	3	Q8
9b	I1/T1	Processes for planning & building offshore HVDC	3	Q2
9c	I1/T1	Expansion planning for offshore HVDC, topology/ capacity design for HVDC interregional transmission	5	Q6
9d	I1/M1	Macrogrid & HVDC offshore networks	4	Q8
9f	UT1/T2	A long-term planning study of offshore HVDC	4	Q8
10. HVDC SYSTEM SIMULATION & ANALYSIS, Fang				
10a	O1/C2	Hardware-in-the-loop electromag transient sim	3	Q12
10b	I1/T3	Large-sys analysis of multiterminal HVDC grids	4	Q10
10c	V1/M1	Frequency-dependent representation of AC syst	4	Q12
10d	M1/O1	Modeling of HVDC grids	6	Q11
10e	T3/I1	Reactive power & harmonics	6	Q8
11. REGULATORY/PERMITTING PROCESSES & PROC, McCalley				
11a	T1/T2	Offshore transmission development processes	3	Q5
11b	I1/UT1	HVDC right-of-way	3	Q12
12. ENERGY EQUITY & ENVIRONMENTAL JUSTICE, Hines				
12a	T1/V1	Effects of HVDC on enrgy equity & env. justice.	3	Q11

Module 1a: Introduction to HVDC Technology

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Last Update:	July 7, 2024
Prerequisite Competencies:	1. Basic electric power engineering knowledge (in electric circuits and electromagnetic concepts) 2. Interest in the development of HVDC technology
Module Objectives:	1. Present historic expose of the development of HVDC 2. Introduce objectives and components of HVDC systems 3. Characterize principal types of HVDC configurations and introduce basic control modes for HVDC systems

Abstract

After the 'war of the currents' between direct current (dc) and alternating current (ac) in the late 19th century, development of complete ac power systems with generators, transmission lines, and motors led towards development of today's power systems. Post World War 1, high voltage direct current (HVDC) technology started to gain interest, first based on mercury valves and later with thyristors. The first commercial HVDC interconnection was realized in 1954.

The objective of this module is to introduce HVDC technology from line commutated converter (LCC) point-to-point HVDC transmission with thyristors, via LCC multi-terminal systems and voltage source converter (VSC) systems, to present day development of meshed HVDC systems. The introduction of commercial HVDC technology allows for interconnection of non-synchronous power systems and is economically advantageous in case of long-distance power transmission, in particular where cables have to be used of e.g., for longer water crossings. This module will provide basic understanding by comparing technical and economic aspects of HVDC vs. HVAC transmission as well as provide examples of installed and planned HVDC schemes.

This module introduces main components and configurations for LCC and VSC HVDC systems. After introducing the principles of ac to dc conversion based on 6-pules and 12-pulse converters, different principal types of monopolar and bipolar HVDC configurations are presented. Basic introduction of control modes for HVDC systems and introducing their effects on voltage and reactive power control. This module will be concluded by a summary of introduced concepts.

Module 1b: Application Guide for HVDC Transmission

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Last Update:	July 22, 2024
Prerequisite Competencies:	1. Basics knowledge of power system operation and planning. 2. Familiarity with converters.
Module Objectives:	1. Understand the fundamentals of HVDC long-distance transmission 2. Understand the fundamentals of the back-to-back HVDC systems 3. Understand the fundamentals of the hybrid AC/DC transmissions 4. Understand the fundamentals of multi-terminal HVDC (MTDC) systems.

Abstract

This module, titled "Application Guide for HVDC Transmission," offers comprehensive insights into the applications and innovations in HVDC transmission systems. It serves as a resource for understanding both current applications and future potentials of HVDC transmission technologies, providing readers with a thorough understanding of the field and preparing them for evolving challenges and opportunities.

The module begins by exploring the advantages of HVDC long-distance transmission over traditional HVAC systems, such as reduced transmission losses and enhanced stability, illustrated with real-world implementation examples. The module then introduces the back-to-back HVDC system by detailing the definitions, benefits, and real-world applications, which are significant for enhancing the flexibility and reliability of power transmission networks. Further, the guide discusses hybrid AC/DC transmission, addressing the motivations for combining these technologies and their operational advantages, such as increased grid flexibility and efficiency. The guide also addresses multi-terminal HVDC (MTDC) systems, focusing on their configuration and fault protection strategies. Additionally, it explores future trends and innovations in HVDC technology, including advancements in converter technology, new materials, and methods that promise improved system performance. Emerging applications, such as the integration of HVDC with energy storage systems and the increasing demand for DC power, are also discussed.

Module 1c: Introduction to HVDC for Offshore Wind

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Last Update:	July 5, 2024
Prerequisite Competencies:	1. Introduction to HVDC technology 2. HVDC converter types and operations as found in Modules 1a, 1b.
Module Objectives:	1. Identify components of offshore wind power plants 2. Distinguish from AC and DC offshore wind power plants. 3. Identify technologies in HVDC-connected offshore wind power plants

Abstract

In contrast to AC-connected offshore wind power plant integration, HVDC has been increasingly used to connect large-scale offshore wind power plants to the in-land transmission network. The fact that offshore wind power plants are increasingly larger in size and located further away from shore, forced by environmental and social factors, makes it more interesting to connect via HVDC technology.

This module aims to provide a general overview of HVDC-connected offshore wind power plant designs, considering using both AC and DC designs connected to the main grid through HVDC. It focuses on offshore wind power plants topology in Section 2, offshore equipment sizing in Section 3, offshore AC/DC transmission economic comparison in Section 4, and Section 5 summarizes the main learning points and concludes. The module focuses on offshore wind power plants topology, offshore equipment limits, offshore transmission options, and economics.

Module 1d: HVDC for Executives

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Last Update:	July 25, 2024
Prerequisite Competencies:	1. Motivating needs for high-capacity electric transmission.
Module Objectives:	1. High-level introduction to the energy transition, the need for large-scale electrification, and the role of multi-terminal HVDC technology in delivering this transition.

Abstract

The objective of this module is to provide decision makers with a high-level understanding of the technologies and policies relevant to the build-out of large-scale multi-terminal HVDC (MT-HVDC) transmission projects that can ultimately come together to form a North American macrogrid. The module provides an introduction to the U.S. energy transition, the role of electrification in this transition, and the need for expansion of our transmission system by a factor of 2-3. The module describes differences between the current U.S. HVAC grid and a possible MT-HVDC grid of the future. U.S. Supply chain needs and development opportunities provide decision makers with an integrated understanding of infrastructure requirements and economic development opportunities. This stand-alone module can also serve as a general introduction for decision makers and executives to the HVDC Learn curriculum.

Module 2a: HVDC reactive power, EMI, and filter design

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Last Update:	June 24, 2024
Prerequisite Competencies:	1. Elements of power electronics (Module 3b) 2. HVDC converter types and basics (Modules 1a, 1b, 1c) 3. Basics of reactive power
Module Objectives:	Four one-hour lectures 1. Calculate reactive power needs and rating of an HVDC converter. 2. Design filter for HVDC converters 3. Identify potential EMI issues with HVDC stations.

Abstract

HVDC converter stations interface an AC system to a DC system---both systems have real power but only the AC system has reactive power. Hence, the converter station needs to generate or sink the reactive power needed by the AC system. This reactive power may come from the converter itself or from the filters installed in the converter station. These filters may serve a second function as well: trap harmonics to reduce electromagnetic interference with communication devices and other equipment. Therefore, filter design is an important and multifaceted challenge in HVDC converter stations design.

This module provides an introduction to reactive power and EMI needs in a converter station and employs this knowledge for filter design. This module contains the following sections:

- Section 2a.1 provides an introduction and relevant references.
- Section 2a.2 discusses reactive power needs and calculations related to HVDC converter stations.
- Section 2a.3 describes harmonic and EMI issues related to HVDC.
- Section 2a.4 provides a methodology for design of HVDC filters to mitigate the issues identified in Sections 2a.2 and 2a.3.
- Section 2a.5 summarizes the learning points of the module and concludes.

Module 2b: VSC HVDC Converter Stations

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Last Update:	July 10, 2024
Prerequisite Competencies:	1. Introduction to HVDC technology (Module 1a)
Module Objectives:	e three one-hour lectures have two objectives: 1. The learner will understand the key components in VSC HVDC converter stations, as well as the operation principles and design. 2. The learner will be familiar with real-world applications of VSC HVDC for wind energy integration.

Abstract

This module will provide an overview of converter stations for VSC HVDC systems. Converter stations are crucial in the asynchronous connection of a DC system, such as an offshore wind farm, to the AC grid. This module will discuss the key components of VSC HVDC systems and show application examples for offshore wind integration. This module contains the following sections:

- Section 2b.1 Introduction to VSC HVDC Technology. This section will cover the historical development and advancements of VSC HVDC technologies and comparison with Line Commutated Converter (LCC) HVDC. Some real-world projects will be showcased.
- Section 2b.2 Key Components of VSC HVDC Converter Stations. This section will cover power electronic devices (IGBTs, capacitors, reactors), converter transformers, AC and DC switchgear, and control and protection systems.
- Section 2b.3 Operational Principles of VSC HVDC Systems. This section will include basic operation and control strategies, and modulation techniques (PWM, SVM).
- Section 2b.4 Design and Configuration of VSC HVDC Converter Stations. This section will cover station layout and design, cooling systems, and thermal management, and redundancy and reliability practices.
- Section 2b.5 Integration with AC Grids. This section will briefly discuss AC-DC asynchronous interconnection, followed by the impact on grid stability and power quality.
- Section 2b.6 Applications of VSC HVDC in Offshore Wind Integration. This section will discuss the application studies of offshore wind farm connections, the benefits and challenges, and trends and future directions.

Module 3a: Interoperability between different HVDC converter technologies/vendors

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Last Update:	July 08, 2024
Prerequisite Competencies:	1. Introduction to HVDC technology (Module 1a) 2. Different HVDC converter technologies and operations (Module 2b)
Module Objectives:	1. Interoperability challenges between different HVDC converter technologies/vendors 2. Approaches to enhance interoperability

Abstract

HVDC systems are critical for long-distance power transmission, integrating renewable energy sources, and enhancing the stability and reliability of power grids. Multi-vendor equipment utilization is essential to building extensive HVDC grids, as it allows access to the global market and alternatives availability and drives competition, leading to cost reduction and innovation. However, the lack of standardization has introduced several challenges in reliable grid operation. This module contains the following sections:

- Section 3a.1 This section will highlight why multi-vendor equipment utilization is essential to building extensive HVDC grids.
- Section 3a.2 This section will introduce challenges that arise from equipment utilization from different HVDC converter vendors.
- Section 3a.3 This section will provide a way forward to handle these challenges for an all-inclusive HVDC grid.
- Section 3a.4 This section will conclude this module by providing a summary of the introduced concepts.

Module 3b: Power electronics 101: Fundamentals of switching power converters and EMT

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Last Update:	June 24, 2024
Prerequisite Competencies:	1. HVDC converter types and basics (Modules 1a, 1b, 1c) 2. VSC-HVDC converter station technologies (Module 2b)
Module Objectives:	Three one-hour lectures 1. Understand basics of power electronics converters 2. Analyze AC/DC converters 3. Simulate AC/DC converters in EMT simulation software tools

Abstract

HVDC is primarily a power electronics technology that processes power from one form of AC or DC to another. Therefore, understanding how this is done via power electronic converters is paramount to understanding HVDC technology. Power electronics operation is based on operation of switches and therefore inherently nonlinear---which is a major departure from the common mode of operation of the power system. However, their understanding can be greatly facilitated using the concept of voltage averaging to discuss technologies for achieving this conversion. Considering the fast timeline involved in converters, electromagnetic transient simulation of converters, which is different from phasor-based transient simulation, important to understand.

This module provides an introduction to power electronics, emphasizing applications in HVDC technology and discusses how they can be analyzed and simulated. This module contains the following sections:

- Section 3b.1 provides an introduction and relevant references.
- Section 3b.2 introduces switching circuits and the concept of time averaging of voltages using a simple DC-DC example.
- Section 3b.3 takes the DC-DC example in the previous section and extends to create our very first DC-AC converter.
- Section 3b.4 discusses pulse width modulation (PWM) techniques for three-phase converters.
- Section 3b.5 provides example simulation results for a VSC system in PSCAD.
- Section 3b.6 summarizes the learning points of the module and concludes.

Module 3c: Operation of thyristors & IGBTs in converters

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Last Update:	July 25, 2024
Prerequisite Competencies:	1. Power electronics 101, Module 3b
Module Objectives:	1. Introduction to thyristors operating characteristics 2. Introduction to IGBT. 3. Losses in HVDC thyristors and IGBT

Abstract

The thyristor is an essential component in high-voltage direct current (HVDC) valves and is still one of the most common devices used in power-switching applications in all industries. This is attributed to its high power ratings and high efficiency. Single devices have up to 8500V and 4500A capability; they are built on single wafers of up to 150mm diameter and have existed for over 60 years. IGBTs (insulated gate bipolar transistors) are voltage-controlled devices with fast switching times and simple gate drive requirements. The individual semiconductor chip size for IGBTs is constrained because high-power switches consist of numerous internal parallel connected units. IGBTs are asymmetrical devices (have no reverse blocking capability) and, therefore, cannot be used with current source converters.

This module introduces the operating characteristics of thyristors and IGBTs in converters. It will explain their operating and switching characteristics and introduce the losses in thyristor and IGBT converters. Section 2 introduces the operating characteristics of thyristors, switching characteristics and losses. Section 3 introduces thyristor rating selection and overload capability. Section 4 introduces IGBT technology including IGBT operating characteristics, switch requirements and losses. Section 5 summarizes and concludes.

Module 3d: Modular multilevel converter as HVDC converter interface

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Last Update:	July 6, 2024
Prerequisite Competencies:	1. VSC HVDC converter station technologies – Module 2b 2. Power electronics 101: operation and switching of IGBTs – Module 3b
Module Objectives:	1. Understand advantages and disadvantages of multilevel converters. 2. Understand operation and control of MMC as HVDC interface. 3. Understand the need to balance the voltages of individual levels and to reduce circulating current in MMCs.

Abstract

Multilevel converters have enabled relatively low voltage power electronic devices such as IGBTs to be connected in a modular way to form converters that can span the high voltages needed to interface between AC HV transmission systems and HVDC transmission systems. Voltage source converter (VSC) connected in a multilevel modular fashion have now become a primary option to LCC converters especially at voltages up to 400 kV.

The objective of this module is to know how modular multilevel converters work especially as it relates to HVDC interface. In Section 2, the structure of the MMC will be introduced and the operation of submodules explained in detail. In Section 3, the equivalent circuit for an MMC will be derived and its operation principle shown. Different modulation methods will be covered in Section 4 including nearest level control, carrier level shift PWM, carrier phase shift PWM (N+1 and 2N+1), selective harmonic elimination, and space vector PWM. In Section 5, circulating current control, capacitor balancing, and arm inductance design will be discussed.

Module 4a: Converter control fundamentals

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Last Update:	July 6, 2024
Prerequisite Competencies:	1. Fundamentals of switching power converters – Module 3b 2. Operation of thyristors and IGBTs – Module 3c
Module Objectives:	1. Learn how to develop open loop and closed loop voltage and current control in power electronic inverters / rectifiers. 2. Learn abc to dq and inverse transformation. 3. Understand common real and reactive power control strategies and voltage regulation.

Abstract

In HVDC systems, power electronic converters are used to convert ac voltages and currents to dc voltages and currents and vice versa at converter station terminals. Basic voltage, current, and power control strategies are necessary to control the power flow in these systems.

The objective of this module is to discuss the common control means in inverters and rectifiers which make up HVDC terminal stations. In section 2, the abc to dq and its inverse transformation will be covered. In section 3, the open loop current control and voltage control for VSC and LCC converters will be discussed. In section 4, closed control in order to regulate voltage and/or current will be covered. In section 5, common real and reactive power control strategies for converters connected to the grid will be covered.

Module 4b: Dynamics modeling and control of HVDC converters and grid-forming functions

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Last Update:	June 24, 2024
Prerequisite Competencies:	1. Basics of power electronics (Module 3b) 2. MMC and control (Module 3d) 3. Basics of converter control (Module 4a)
Module Objectives:	Four one-hour lectures 1. Derive the dynamic model of a DC/AC converter (VSC) 2. Design set point tracking controls for the converter based on PIs 3. Design and analyze higher level controls and limiters for grid-forming functionalities

Abstract

As an engineering system, converters used in HVDC stations need to be controlled to the set points determined for their voltage, current, and real and reactive power injection/absorption levels. To control a converter, a dynamic model based on first principles needs to be developed. This model is obtained using fundamental circuit laws (KVL and KCL) and applies engineering sound assumptions so a simple, yet effective controller can be design for it. Most controllers used in industry are based on PI controllers that are designed and tuned for system applications. Considering their full controllability, at a higher level, these converters can also provide grid-forming functionalities such as fault ride-through and start up.

This module introduces converter modeling and control and discusses their potential to provide grid-forming functions. This module contains the following sections:

- Section 4b.1 provides an introduction and relevant references.
- Section 4b.2 derives the dynamic model of a three-phase VSC as a set of two SISO (single input, single output) systems.
- Section 4b.3 utilizes the model developed in the previous section to design a PI-based controller. Other control approaches are also briefly mentioned.
- Section 4b.4 discusses grid-forming (GFM) capabilities that could be provided by HVDC converters.
- Section 4b.5 summarizes the learning points of the module and concludes.

Module 4c: Control of Multi-Terminal HVDC Networks

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Last Update:	July 10, 2024
Prerequisite Competencies:	1. Power electronics 101 (Module 3b) 2. Modular multilevel converter (Module 3d)
Module Objectives:	The four one-hour lectures have two learning objectives: 1. The learner will become familiar with the control techniques for active power and DC voltage, as well as reactive power and voltage for multi-terminal HVDC networks. 2. The learner will be able to use simulation software to implement control methods for multi-terminal HVDC networks.

Abstract

Multi-terminal HVDC requires proper control and coordination on both the AC and DC sides to ensure stable operations. This module will cover the control architectures, coordination strategies, and practical applications to MT-HVDC networks.

- Section 4b.1 Overview of the Control Architecture. This section will talk about the high-level components of the control systems for multi-terminal HVDC networks. We will introduce local, decentralized, and centralized controls.
- Section 4b.2 Active Power and DC Voltage Control. This section will discuss techniques for coordinating active power flow between multiple terminals, such as droop control. This section will also discuss how these controls impact the DC voltage.
- Section 4b.3 Reactive Power and Voltage Control. This section will discuss voltage control and reactive power control and how it impacts the AC network, especially during AC network transients.
- Section 4b.4 Advanced Control Strategies. This section will cover advanced techniques such as model predictive control, robust control, and control design techniques to ensure system stability.
- Section 4b.5 Simulation Tools and Case Studies. This section will briefly introduce the available tools for simulating multi-terminal VSC HVDC. We will present real-world examples of multi-terminal HVDC control.

Module 4d: Offshore HVDC Converter grid forming controller design for black start capability

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Last Update:	July 08, 2024
Prerequisite Competencies:	1. Introduction to HVDC technology (Module 1a) 2. HVDC control fundamentals and applications (Modules 4a, 4b, 4c)
Module Objectives:	1. Black start capability requirements for offshore HVDC systems 2. OWFs grid forming controller design and requirements for HVDC systems

Abstract

Power systems are transitioning towards decarbonization with the widespread integration of renewable energy sources replacing conventional thermal power plants, the primary providers of black start services. Consequently, conventional black-start resources may not be available during a total or partial blackout. The OWFs are typically connected to onshore grids with VSC-based HVDC converters and transmission lines. These converters have a fast and outstanding voltage and frequency response, thus bearing the capability to reduce restoration time after a grid blackout. They can also precisely control the power flow, which is valuable for gradual and controlled energization of a reviving network during black start. The grid-forming capability is crucial for black start operations where the offshore grid must be restored without relying on external power sources/onshore grid. This module comprises of the following sections:

- Section 4d.1 of this module will present the challenges and potential solutions for integrating black start services into OWFs.
- Section 4d.2 will focus on differentiating grid forming controllers (GFR) from traditional grid following controllers (GFL) and the importance of GFL in providing black start services for offshore HVDC systems.
- Section 4d.3 will introduce a grid-forming controller design followed by a black start restoration strategy for offshore HVDC systems.
- Section 4d.4 will conclude by providing a summary of the introduced concepts.

Module 5a: HVDC fault management and protection systems

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Last Update:	July 30,2024
Prerequisite Competencies:	1. Power electronics 101: Fundamentals of switching pwr conv + EMT – Module 3b 2. Operation of thyristors & IGBTs in converters – Module 3c
Module Objectives:	1. Identify different fault types in HVDC systems 2. Categorize the faults based on severity 3. Develop protection schemes based on fault types

Abstract
As HVDC systems become more common place in the electrical grid topology, detection of faults will play a critical role in the reliability and safety of the grid. Unlike the well-established AC fault management and protection systems employed by today's electrical grid, detection of DC faults will require a new approach. In addition to DC fault detection, methods of protecting the grid from the various types of DC fault will need to be developed to ensure the least amount of damage and downtime to the electrical grid.

The objective of this module is to discuss the various type of faults available in a two-point and multi-terminal HVDC network, assign severity levels to the faults and manage the proper response to each fault to minimize the disruption and damage to the electrical grid. Fault management will entail the development of protection schemes relevant to each fault type.

Module 5b: HVDC measurements, faults, and misoperation

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Last Update:	June 24, 2024
Prerequisite Competencies:	1. Basics of HVDC faults (Module 5a) 2. Converter topologies and control (Modules 1a, 2b, 3b, 3d)
Module Objectives:	Three one-hour lectures 1. Analyze faults in HVDC converters 2. Understand the methods to mitigate the impact of faults in HVDC converters 3. Understand converter misoperation and switching impacts on the waveform quality

Abstract

HVDC converters can be prone to faults and misoperations. Such malfunctions can be the result of a faulty switch (IGBT), improper firing command, or system faults. There are methods to reduce the likelihood of these faults and, when they do happen, to mitigate their impact. Strategies include adding redundant switches, utilizing careful timing of firing commands, and ensuring proper operation and coordination of the system-level protection mechanisms. Paramount to all of these is availability of accurate measurements.

This module discusses faults and misoperations in HVDC converters and presents methods to mitigate or reduce their impact. This module contains the following sections:

- Section 5b.1 provides an introduction and relevant references.
- Section 5b.2 discusses measurements in HVDC systems.
- Section 5b.3 discusses faults that can result from malfunctions of the power electronics switches (open-circuit or short-circuit switch faults) as well as firing command timing issues.
- Section 5b.4 discusses the impact of system level faults on the converters within the HVDC station.
- Section 4b.5 provides an overview of fault impact reduction techniques
- Section 4b.6 summarizes the learning points of the module and concludes.

Module 5c: Protection for multi-terminal HVDC Networks

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Last Update:	July 05, 2024
Prerequisite Competencies:	1. HVDC converter types and operations (Modules 1a, 1b, 1c) 2. HVDC measurements, faults and protection systems (Module 5a, 5b)
Module Objectives:	1. Differences between HVAC and HVDC protection requirements 2. Protection possibilities for multi-terminal HVDC networks

Abstract

Protection for High Voltage Direct Current (HVDC) networks is critical for ensuring the reliability and safety of power transmission systems. The HVDC systems bring unique challenges when compared with HVAC systems. One prime challenge with DC protection is breaking fault currents that exhibit zero crossing, unlike AC currents. The HVAC breaker technology is quite mature and must be utilized for HVDC protection where possible, till the HVDC protection techniques become mature enough to replace them in the field. The protection of multi-terminal HVDC (MT-HVDC) systems presents a greater challenge compared to two-terminal HVDC systems due to several technical, operational, and coordination complexities. Effective protection schemes are critical to ensuring the reliability and resilience of these advanced power systems.

This module consists of the following sections:

- Section 5c.1 of this module will introduce differences between HVAC and HVDC protection requirements.
- Section 5c.2 will introduce various protection possibilities for multi-terminal HVDC networks considering current and future protection equipment.
- Section 5c.3 will introduce protection scheme design steps for multi-terminal HVDC (MT-HVDC) systems.
- Section 5c.4 of this module will conclude by providing a summary of the introduced concepts.

Module 5d: Protection: ability to ride through faults in HVDC

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Last Update:	July 6, 2024
Prerequisite Competencies:	1. VSC HVDC converter station technologies – Module 2b 2. HVDC fault management and protection systems, HVDC faults, measurement, and misoperation – Modules 5a, 5b
Module Objectives:	1. Learn how to quickly identify fault in an HVDC system and to isolate fault. 2. Learn strategies for reconfiguring and riding through faults on HVDC systems. 3. Use test cases to understand different faults to be considered on AC and DC lines for HVDC converters.

Abstract

Faults are a common occurrence in electric systems, and HVDC converters and transmission systems must be designed to quickly identify fault conditions and provide a means to ride-through or re-route power if possible. Power electronics in power converters cannot sustain fault currents, and so must be protected during fault events so that damage does not occur to these multimillion-dollar installations.

The objective of this module is to identify the different fault possibilities for HVDC systems including the HVDC lines, AC lines, and within the HVDC converter stations themselves. For ac systems, a comparison between single phase tripping and three phase tripping will be shown in Section 2. In Section 3, different SLG faults will be investigated including their effect on converters. The modeling, control, and restoration of converters for fault events will be covered in Section 4. Faults on the dc system and their effects on HVDC converters will be discussed in Section 5. A fault handling scheme and flow diagram will be provided in the conclusion of the module.

Module 5e: Cybersecurity in HVDC systems

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Last Update:	June 24, 2024
Prerequisite Competencies:	1. Intro to HVDC (Module 1a) 2. Power system fundamentals
Module Objectives:	Three one-hour lectures 1. Understand communication needs for HVDC 2. Evaluate cybersecurity risks in a power system 3. Evaluate cybersecurity risks related to HVDC and the attack surface

Abstract

As a critical infrastructure, power system is a common target for cyberattacks; this is reflected in actual recent successful attacks on the power system as shown in DOE documents. Cyberattacks use vulnerabilities in the cyber later of the system, e.g., communication and control, to find an entry point in the system and then launch an attack; attack types could include false data injection (FDI), man in the middle (MitM), and denial of service (DoS). As HVDC systems typically process large amounts of power, it is important to protect them against cyberattacks and if cyberattacks do occur, to mitigate their impacts.

This module introduces cybersecurity concerns and vulnerabilities and discusses attack, detection, and mitigation algorithms. This module contains the following sections:

- Section 5e.1 provides an introduction and relevant references.
- Section 5e.2 derives the cyber-physical model of an HVDC system.
- Section 5e.3 discusses potential cyber vulnerabilities of an HVDC system.
- Section 5e.4 introduces detection and mitigation methods for an HVDC system.
- Section 4b.5 summarizes the learning points of the module and concludes.

Module 6a: Insulation – HVDC cables

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Last Update:	July 30,2024
Prerequisite Competencies:	1. Intro to HVDC technology – Module 1a 2. Application guide for HVDC transmission – Module 1b
Module Objectives:	1. Design of HVDC cables 2. Description of insulation materials available for cable construction.

Abstract

As HVDC systems become more common, HV cables will be needed to carry the required DC voltage/currents of the system. Traditionally, HVDC cables fall into three insulation types: mass-impregnated (MI), self-contained fluid-filled (SCFF) and cross-linked polyethylene (XLPE). There is a new material being developed, N-EPR, which uses nanoclay particles to reinforce ethylene propylene rubber (EPR) insulation. HVDC cables are very expensive and, depending on the system voltage and line distance, can compromise up to 70% of the project's total cost. Therefore, it is important to performance vs cost ratio when choosing the insulating material.

The objective of this module is to investigate the various insulating materials available for the design of HVDC cables. This will involve comparing the properties of the materials and determining which will give the best performance vs cost ratio for specific applications.

Module 7a: Point-to-Point HVDC Configurations

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Last Update:	July 17, 2024
Prerequisite Competencies:	1. Motivating needs for high-capacity electric transmission 2. Introductory HVDC as found in Modules 1a, 1b, 1c.
Module Objectives:	1. Identify features of point-to-point HVDC transmission 2. Distinguish from multi-terminal HVDC systems. 3. Identify point-to-point applications and describe implementations of each

Abstract

In contrast to multi-terminal HVDC systems, point-to-point (P2P) HVDC transmission connects only two converter terminals via a direct current transmission path. They may connect two asynchronous AC systems, or they may provide a DC transmission path within a single AC system. P2P is the oldest HVDC design, having seen application since the early 1950s, and with over 200 implementations worldwide, it is by far the most common design. Many new P2P HVDC projects are being planned or built today.

The objective of this module is to characterize P2P HVDC designs. To do so, we begin in Section 2 by summarizing P2P design basics in terms of types of components, e.g., converters, protection, filters, and conductors, and in terms of configuration (monopole, bipole, and tripole). Section 3 describes four different P2P applications, including overhead, back to back, underground, and submarine, and provides descriptive examples of each. Section 4 describes P2P applications for offshore wind. Section 5 summarizes the main learning points of this module and concludes.

Module 8a: Design/operation of multiterminal HVDC grids

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Last Update:	July 6, 2024
Prerequisite Competencies:	1. Control of multiterminal HVDC networks – Module 4c 2. Protection for multiterminal HVDC networks – Module 5c
Module Objectives:	1. Identify different topologies of networked multiterminal HVDC systems. 2. Design MT-HVDC systems including converter components. 3. Learn the control strategies for these MT-HVDC networked systems.

Abstract

As HVDC systems become more common, there are expected to be significantly more multiterminal HVDC systems put into operation. These will be able to better integrate large wind farms (on-shore and off-shore) and to act as an HVDC overlay to strengthen the existing HVAC transmission systems.

The objective of this module is to discuss the design and operation of multiterminal HVDC grids including the various considerations that need to be made for these systems. In Section 2, a three-terminal MT-HVDC example topology will be shown, and its operation detailed. In Section 3, a 4-terminal networked HVDC converter operation will be detailed. Voltage regulation and power transfer for these systems will be discussed. In Section 4, the different operation modes and transitions among operation modes will be shown.

Module 9a: HVDC in Power Systems (incl. Meshed HVDC Systems)

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Last Update:	July 7, 2024
Prerequisite Competencies:	1. HVDC converter types and operations as found in Modules 1a, 1b, and 1c. 2. Processes for planning & building offshore HVDC as found in Module 9b. 3. Basic knowledge of steady-state analysis of power systems (voltage and reactive power control).
Module Objectives:	1. Understand differences in technical impacts based on use of HVDC and HVAC interconnections. 2. Knowledge of technical and economic considerations when evaluating HVDC vs. HVAC interconnections.

Abstract

The purpose of electric transmission network planning is to design and build a power system with adequate technical and economical qualities to meet the demand and realistic contingencies under specified future generating and loading conditions. Quality of power supply include constancy of frequency, constancy of voltage, and level of reliability, which can be achieved by various types of controls. To achieve a reasonable level of reliability, i.e., a power system that can withstand instability, uncontrolled events, cascading failures, or unanticipated loss of system components, including generation, transmission systems are generally designed as meshed networks.

There are many factors, both technical and economic, affecting the choice between use of HVDC or HVAC transmission options. Interconnection over long distances, longer water crossings, or between non-synchronous networks is best achieved by introduction of high voltage direct current (HVDC) connections. This module will review system stability and capacity limits concepts for HVDC vs. HVAC systems, including multi-terminal (meshed) HVDC networks. HVDC systems can strengthen reliability by improving power system stability and increasing transfer capability.

This module will discuss line commutated converter (LCC) and voltage source converter (VSC) HVDC systems for onshore and offshore applications. Implementation of point-to-point and back-to-back HVDC systems as well as multi-terminal and meshed HVDC network configurations will be presented. This module will be concluded by a summary of introduced comparisons.

Module 9b: Processes for planning and developing offshore HVDC

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Prerequisite Competencies:	1. Motivation of HVDC for offshore wind as found in Module 1c.
Module Objectives:	1. Identify/describe the sequence of work necessary to plan and develop offshore HVDC transmission along US coasts; 2. Compare and contrast the US processes with those of various countries throughout the world.

Abstract

HVDC transmission is attractive for offshore wind applications because it can provide submarine power transfer at relatively high capacity. However, the processes necessary to plan and build offshore transmission are new with complexities stemming from the deployment in both marine and land-based regions involving multiple organizations including governmental agencies charged with oversight of coastal waters, transmission planning coordinators and utility companies, and various agencies representing the interest of state and local governments. In addition, use of HVDC, compared to AC transmission, is less familiar for most of the electric power industry.

The objective of this module is to identify the sequence of work necessary to plan and develop offshore HVDC transmission, and to describe the major steps. The module focuses on the US situation but also identifies salient differences in the situation of other regions in the world. Section 1 introduces the topic and provides a high-level outline of the overall process. Sections 2-6 describe, respectively, each of six major steps, including

- identification of opportunity areas and initial design with techno-economic assessment to ensure the project is economically viable;
- federal application through the Bureau of Ocean Energy Management (BOEM) - here we describe the application process as part of an offshore wind lease and as part of an offshore right-of-way grant;
- interaction with states for right-of-way access through state waters and through land;
- detailed design/development, with engagement in the planning processes of regional transmission organizations (RTOs) and affected local transmission owners;
- interaction with FERC to identify cost allocation;

In all the above, the permitting roles of specific federal and state agencies are identified. A final section compares/contrasts the above processes with those of other countries, including various European countries, particularly those having North Sea coastline.

Module 9c: Expansion planning for interregional HVDC

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Prerequisite Competencies:	1. Motivation of HVDC for offshore wind as found in Module 1c. 2. Power flow analysis. 3. Continuous variable optimization modeling for linear programming solution methods.
Module Objectives:	1. Formulate the cooptimzied (generation & transmission) expansion planning problem; 2. Illustrate use of CEP to design offshore HVDC interregional transmission networks.

Abstract

Although most early offshore wind designs connected resources to load through radial connections to shore, for high offshore wind growth, an offshore HVDC interregional backbone grid offers benefits over radial designs in terms of economics, reliability, and resilience and adaptability. Cooptimized expansion planning (CEP) is useful in designing such grids and in quantifying associated benefits.

The objective of this module is to describe and illustrate, for a targeted offshore wind capacity, use of CEP for designing HVDC offshore networks in terms of offshore topology and branch capacities, the interconnections to onshore grids, the onshore generation additions and retirements, and the onshore transmission expansions. Section 1 will introduce offshore HVDC backbone networks and lay out the basis for its expected benefits, including an illustration using a simple, stylized backbone network. Section 2 will provide a high level CEP problem statement together with modeling methods specific to HVDC. Additional information on modeling methods and solution techniques, including network reduction methods, will be provided in an Appendix. Section 3 will illustrate use of CEP for obtaining grid designs associated with the US East Coast. Section 4 will describe the application of these methods to identify a grid design sequence that evolves as offshore wind levels grow. Section 5 concludes.

Module 9d: Macrogrid and HVDC offshore networks

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Prerequisite Competencies:	1. Motivating needs for high-capacity electric transmission. 2. Introductory HVDC as found in Modules 1a,1b, 1c. 3. Use of expansion planning as a transmission design tool, as shown in Module 9c.
Module Objectives:	1. Summarize macrogrid design methods. 2. Illustrate macrogrid benefits..

Abstract

A Macrogrid is a high-capacity multi-regional HVDC transmission system that operates as an overlay to one or more existing AC grids. Studies have shown macrogrid benefit-to-cost ratios between 1 and 3. They can be designed as multiple point-to-point HVDC lines, as a single multi-terminal HVDC (MTDC) system, or as a hybrid of the two.

The objective of this module is to illustrate macrogrid design methods, identify and quantify macrogrid benefits, and characterize the interdependent relationship between a macrogrid and an offshore HVDC transmission grid. Section 1 introduces macrogrids, summarizes previous work, summarizes design methods, and identifies macrogrid benefits. Section 2 quantifies benefits associated with interconnecting load centers with least-cost renewables and with sharing energy and resources because of load diversity occurring across systems in different time zones. Section 3 quantifies the benefit due to avoiding generation investment needed to satisfy planning reserve requirements through capacity-sharing enabled by annual peak diversity. Section 4 shows how a macrogrid facilitates resilience via the ability to share resources during extreme events that cause capacity shortfalls in one or more regions. Section 5 identifies interdependencies between macrogrid operation and an East Coast offshore MTDC grid, focusing on the macrogrid's ability to relieve loading on the underlying AC transmission systems and to reduce AC transmission expansion. Section 6 concludes.

Module 9e: Long-term HVDC planning for offshore wind

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Last Update:	July 22, 2024
Prerequisite Competencies:	1. Working knowledge of power system planning. 2. Familiarity with HVDC technologies (modules 1a, 1b, 1c and 1d).
Module Objectives:	1. Learn the fundamentals of offshore wind power and the difference between offshore and onshore wind power 2. Understand the technical aspects of HVDC to ensure the feasibility of offshore wind integration. 3. Understand the economic and environmental considerations for offshore wind integration with HVDC 4. Explore real-world case studies of offshore wind HVDC projects

Abstract

With the rapid growth and immense installed capacity of offshore wind farms, the module "Long-term HVDC Planning for Offshore Wind" is highly necessary.

It begins with a fundamental overview of offshore wind power, covering geographical conditions, climate requirements, capacity scale, voltage levels, and growth data. Then, a comprehensive comparison between offshore and onshore wind power is conducted, highlighting various benefits such as higher wind speeds and larger scale, alongside limitations like higher costs and environmental impacts. The technical aspects of HVDC are discussed to ensure the feasibility of offshore wind integration, including converter design, cable installation, and substation construction. Furthermore, economic and environmental considerations are thoroughly examined, with detailed cost-benefit analyses and discussions on reducing carbon footprints which is crucial for the sustainability of offshore wind projects. The module incorporates real-world case studies of successful offshore wind HVDC projects from the US, Europe, China, India, and more, providing insights into best practices and lessons learned. These case studies serve as practical examples to illustrate the application of theoretical principles in real-world scenarios. In addition, the module explores future trends in offshore wind HVDC technology, such as advancements in converter technology and the development of multi-terminal HVDC networks, which promise to further enhance the efficiency and scalability of offshore wind integration.

Module 10a: Hardware-in-the-Loop Electromagnetic Transient Simulation of HVDC Systems

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Last Update:	July 10, 2024
Prerequisite Competencies:	1. Control of HVDC (Module 4)
Module Objectives:	The three one-hour lectures have two learning objectives: 1. The learner will become familiar with an HIL simulation environment. 2. The learner will be able to develop HIL simulation models for HVDC applications.

Abstract

Hardware-in-the-loop (HIL) simulation is a useful technique for testing and validating HVDC systems by integrating real hardware components with simulated grids. This approach enables HVDC control evaluation and protection systems testing under realistic operating conditions without needing an actual setup. HIL simulation provides a safe and cost-effective means to study the dynamic behavior of HVDC systems, identify potential issues, and optimize performance. This module will discuss

- Section 5b.1 Introduction to HIL Simulation. This section will cover the definition and history of HIL simulation tools and their applications to HVDC systems.
- Section 5b.2 Software Environment for HIL Simulation. This section will discuss one of the commonly used HIL simulation platforms for developing HVDC simulation models.
- Section 5b.3 Hardware Configuration. This section will cover hardware connections to the HIL platform, including data acquisition and signal processing fundamentals.
- Section 5b.4 Application of HIL for HVDC. This section will provide a hands-on tutorial for developing and running the HVDC test system in an HIL environment.

Module 10b: Control of frequency dynamics using multiterminal HVDC grids

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Last Update:	July 16, 2024
Prerequisite Competencies:	1. Basics of positive-sequence modeling and analysis for power system time-domain dynamic analysis using commercial grade tools (e.g., PSS®E). 2. Macrogrid design as found in module 9d.
Module Objectives:	1. Describe use of VSC-based control available at the terminals of a multi- terminal HVDC system for AC system frequency stability. 2. Illustrate for an HVDC multiterminal system inter- connecting two asynchronous AC grids.

Abstract

Traditional dynamic analysis of power systems deploy positive-sequence networks, an approach that is appropriate for analysis of frequency dynamics following large generation trips, even under high levels of inverter-based resources (IBRs). This is of interest for analysis of multiterminal HVDC (MTDC) grids because such grids (i) contribute potentially large single-source outage events as seen by the AC system, via HVDC terminal failures; and (ii) increase opportunities for stabilizing frequency dynamics by leveraging the control capabilities of the voltage sourced converters (VSC) at each terminal.

The objective of this module is to use positive sequence simulation to characterize and illustrate the influence on an AC system of VSC-based control available at the terminals of a multiterminal HVDC system interconnected with an existing AC grid. We utilize the commercial grade tool PSS®E to do this together with user-defined models of VSC-based controllers. Section 1 introduces the topic of frequency dynamics and identifies how they interact with MTDC grids. Section 2 describes VSC-based controllers used with MTDC to control frequency dynamics. Section 3 describes the user-defined models for implementing MTDC grids and VSC control in the PSS®E power flow tool and in the PSS®E dynamics tool. Section 4 illustrates the influence of deploying the various types of control for a US macrogrid design. Section 5 describes a similar deployment for an offshore wind MTDC grid. Section 6 concludes.

Module 10c: Frequency-dependent representation of AC system

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Last Update:	June 24, 2024
Prerequisite Competencies:	1. Intro to HVDC (Module 1a) 2. Power system fundamentals 3. Modeling of HVDC grids (Module 10d)
Module Objectives:	Four one-hour lectures 1. Derive the transfer function for a single-port power system 2. Calculate the reduced-order equivalent of a system transfer function 3. Evaluate the bandwidth of a frequency-dependent representation of the system

Abstract

The power grid is made up of dynamic elements whose performance varies based on the system frequency. A well-known example is the system impedance whose value is proportional to the frequency. However, the common phasor representation of the power system assumes constant frequency (60 Hz in the US) operation. Frequency-dependent representation of the AC system is paramount for dynamic studies to ensure consistency of models used for the power electronics (HVDC converter) and the power system (AC transmission) sides of the grid.

This module derives a frequency-dependent model of the system, discusses different approaches for such derivation, and evaluates reduced-order equivalencing methods. This module contains the following sections:

- Section 10c.1 provides an introduction and relevant references.
- Section 10c.2 derives the frequency dependent model of the AC system.
- Section 10c.3 discusses the concept of reduced order equivalencing and passivity enforcement.
- Section 10c.4 evaluates different modeling approaches and the assumptions involved.
- Section 10c.5 summarizes the learning points of the module and concludes.

Module 10d: Modeling of HVDC Grid

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Last Update:	June 25, 2024
Prerequisite Competencies:	1. Large system analysis of Multiterminal HVDC grids 2. HVDC grid modeling and analysis as found in Modules 10a, 10b, 10c.
Module Objectives:	1. Identify steady state and dynamic models of HVDC grids 2. Power flow and optimal power flow of HVDC grids.

Abstract

In contrast to AC networks, HVDC introduces complexity into the system by changing it to a hybrid AC/DC network. To ensure reliable hybrid AC/DC grid operation, traditional power system analysis programs such as power flow calculation and optimal power flow simulation should be adapted to consider the characteristics of the DC grid to analyze hybrid AC/DC networks with HVDC.

This module's objective is to model HVDC and converter components in power flow and optimal power flow problems. It will introduce the components modeling of converter and HVDC lines in Section 2. It will also introduce the power flow calculation methods in Section 3 and optimal power flow methods for hybrid AC/DC networks in Section 4. Section 5 will summarize the modeling challenges of AC/DC networks and conclude.

Module 10e: Reactive power and harmonics

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Last Update:	July 31, 2024
Prerequisite Competencies:	1. Understanding of sources of harmonics in power systems 2. HVDC converter types and operations.
Module Objectives:	1. Identify transients that affect HVDC systems and their environment 2. Introduce dynamic phasors 3. Discuss decompositions of apparent power that can describe transients in HVDC systems

Abstract

HVDC systems intertwine the dynamics of power electronic components with the dynamics of the remainder of the power interconnection, amalgamating electronics and electromechanics. Thus, it is essential for students to understand the behavior of harmonics and reactive power during sudden system changes.

This module aims to characterize the analytical tools used to address system operation, particularly during 'close-to 'periodic conditions. These tools include the 'sinusoidal quasi-steady-state' approximation in drives and power systems, and detailed time-domain simulations ('point on wave'). The concept of the 'middle ground' was not fully explored until the development of dynamic phasors. These phasors, which represent time-varying harmonics, can be measured or estimated in real-time. For lower frequencies (multiples of 60/50 Hz), this technology is already mature. As data becomes more important, statistical concepts become useful at various scales, such as providing estimates of the uncertainty of model predictions. We use dynamic phasors to extend the various time-invariant decompositions to the case where steady-state operation is disrupted by the occurrence of transients. The resulting time-dependent apparent power and its components can accurately indicate the onset and duration of a transient, in addition to their role as power quality metrics during steady-state operation.

Module 11a: Offshore Transmission Development Processes

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Last Update:	July 25, 2024
Prerequisite Competencies:	1. Motivating needs for high-capacity electric transmission. 2. Introductory HVDC as found in Modules 1a, 1b, 1c.
Module Objectives:	1. Identify jurisdictions and decision-making structures including federal, regional, state, and local. 2. Review relevant state and regional initiatives. 3. Outline a possible future for offshore transmission procurement.

Abstract

Offshore transmission development raises both technological and policy questions at multiple scales. Technological issues include the high-level design and planning of multi-terminal HVDC transmission and power systems analyses associated with bringing gigawatt scale transmission to shore and connecting it to the existing grid. Policy issues include the permitting of transmission corridors offshore and on land, the coordination of landing points, relationships between national, regional, state, and local scales, and questions of cost allocation.

The objective of this module is to explore these intertwined technology and policy issues through a series of examples that include the New Jersey State Agreement Approach (SAA), New England's multi-state approach as envisioned by the Massachusetts clean energy transmission working group (CETWG), and the instructors' proposed offshore transmission procurement and development processes.

Module 11b: HVDC right-of-way

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Prerequisite Competencies:	1. Introductory HVDC as found in Modules 1a, 1b,1c.
Module Objectives:	1. Describe different strategies and options for facilitating right-of-way procurement for HVDC transmission, for both onshore and offshore applications

Abstract

Traditionally, obtaining right-of-way for onshore electric transmission is a complex process involving interaction with landowners and various federal and state agencies. Deployment of HVDC for onshore transmission opens additional options because, unlike AC transmission, HVDC cables incur no charging currents and can thus be undergrounded for any distance. Both HVDC and AC transmission encounter similar right-of-way issues for offshore submarine cables.

The objective of this module is to describe different strategies and options for facilitating right-of-way procurement for HVDC transmission, for both onshore and offshore applications. Section 1 introduces general right-of-way issues and compares them for HVDC and AC transmission. Section 2 identifies onshore options including deployment along highways and railways. Section 3 addresses influences on offshore right-of-way including shipping, oil and gas extraction facilities, communication cables and pipelines, military uses, fisheries, conservation areas, and sand extraction facilities. Section 4 concludes.

Module 12a: Effects of HVDC on energy equity & environmental justice

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Last Update:	July 25, 2024
Prerequisite Competencies:	1. Motivating needs for high-capacity electric transmission.
Module Objectives:	1. Integrated assessment of community needs and HVDC landing points for offshore wind with a focus on specific communities in the Northeast.

Abstract

The objective of this module is to provide engineers, communities, private sector executives, public sector decision makers, and NGOs with a language for how well-planned multi-terminal HVDC grids can benefit communities through decommissioning of fossil fuel fired power plants, economic development, movement of overhead transmission lines underground. Bridgeport, Connecticut will serve as a case study for understanding the climate, infrastructure, and economic development benefits behind high-capacity HVDC connections into coastal points of interconnection.