Grid Architecture Component Class Specification

Component Class Designation: Power Flow Controller

Summary Overview

The power flow controller is presented here as a class of grid components which are able to asynchronously transmit real and reactive power flow between two systems or subsystems. This class includes two primary categories: those which are electro-mechanical devices, and those which are static, solid state devices. These devices can be dispatched by grid operators, however, unlike a generator, their input energy comes from the grid, thus they cannot be used as an energy source to supply electrical demand. Categorically, these resources have the ability to augment the natural flow of energy between different parts of the same grid system, or between separate grid systems.

Individually, their functions become more unique. Each type of power flow controller is different in its specific capability, although collectively they offer benefits which include the ability to; 1) efficiently utilize available capacity of transmission lines that are lightly loaded, 2) transmit power from one synchronous system to another without the necessity of synchronous alignment, 3) decrease the cost of transmission over long distances, and 4) manage the stability and reliability of the grid.

Definitions

Power Flow Controller – A class of grid components which are able to asynchronously transmit real and reactive power flow between two systems or subsystems.

High Voltage Direct Current (HVDC) Transmission – A type of power flow controller that is used to transmit power over long distances. Cost justification typically requires minimizing the number of midpoint AC-DC converter stations. Line losses are low due to very high voltages utilized and uniform current density afforded by DC.

Variable Frequency Transformer – an electro-mechanical device that acts as a rotating phase-shifting transformer, and which can asynchronously transmit power between systems. The VFT does not make a step change in voltage magnitude although it can offer reactive power support. Although the device is electro-mechanical, it also relies on the use of solid state components to create a rotating magnetic field on its rotor that is decoupled with its physical rotation.

Solid State Transformer – a solid state device that dually transmits power and adjusts a step change in AC voltage between its input and output terminals.

Phase Shifting Transformer – a physical transformer that is designed to control voltage phase angle change rather than a step change in voltage magnitude.

Static – a device that has no moving parts, or does not move as part of its functional operation.

Solid State – an electronic device made using semiconductor materials.

Inverter – a collection of solid state components arranged in a manner to convert DC energy into an AC waveform of specific frequency, voltage, power and reactive power. Smart inverters include capabilities to aid the management, performance, and efficiency of the grid to which they are connected.

Component Class Description

Purpose and Function

Unlike a DC system, power flow is dictated by the change in voltage angle between nodes on the grid [7]. Generators naturally augment the voltage angle at their point of injection so that real power is injected into the grid. After that, however, the path the power takes through the network to the loads is largely uncontrolled. This fact creates complexity in ensuring that system constraints are met while simultaneously trying to dispatch the least costly generation. Some of these constraints include ensuring that no transmission lines are overloaded, the preservation of system reliability, and the ability to minimize system power losses. By physically inserting power flow control devices into the grid, voltage angles are controlled, thus the power flow is controlled and the above constraints are remediated. As is the case most often, justification requires the cost of inefficient operation to surpass the cost of the power flow control device used to remedy the issues.

Electro-mechanical versions of power flow converters include phase-shifting transformers and variable frequency transformers [1,5]. The former is a unique transformer design that results in an imaginary turns ratio. Although it is a transformer, it is not used to change voltage magnitude as a typical transformer does, but rather the voltage angle. Variable Frequency Transformers [4] are relatively new, and are designed as a rotating phase-shifting transformer. Functionally, they are similar to HVDC systems [9,10].

Static devices include UPFCs [5], solid-state transformers [2], and HVDC systems [9,10]. These devices hold special promise as the cost of wide-bandgap semiconductors decreases and their performance increases. UPFCs, a type of FACTS device, are typically connected both in series and parallel with transmission lines and primarily are used to enhance system stability. These systems can be used on lower voltage systems too, but require cost justification that typically only occurs for specialty applications such as advanced micogrids. HVDC systems have been in use for a few decades in north America and are financially justified above HVAC transmission when the transmission distance is long and there are few, if any, midpoint converter stations required. These systems operate with lower line losses due to a) the higher voltage levels used and b) the uniform current density across the conductor cross section. These systems are used to transfer power within the same synchronous interconnection (such as the 3.5GW Pacific DC

Intertie in the Western Interconnection) and to transfer power across interconnection boundaries (such as those used to connect Quebec and the US New England area). A HVDC system variant is used to asynchronously connect the Western and Eastern Interconnections at various locations. These 'back-to-back' converters are not used to transmit power over distance, but rather transmit power across synchronous system boundaries.

Key externally visible properties

These systems offer an increase in overall system efficiency and grid reliability. They do so under a variety of control mechanisms. For example, phase shifting transformers are typically adjusted as transmission flow patterns change seasonally. Whereas HVDC systems have autonomous control to manage real and reactive power in real time, and with the ability to be adjusted as often as needed by grid dispatch.

Interface descriptions

All of these devices are capable of autonomous and remote operation and control. The extent to which these devices employ automated action is predicated largely on technical complexity as well as coordination between participating organizations. For example, the control of a HVDC line is subject to the agreements and approvals of reliability entities (balancing authorities) at each end of the system.

Table of relevant standards

Standard Name	Description	Version/Date
IEC, 2012	IEC, 2012. Grid Integration of Large-Capacity Renewable Energy Sources and Use of Large-Capacity Electrical Energy Storage. White Paper	
IEC, 2008	IEC, 2008. High Voltage Direct Current (HVDC) transmission for DC voltages above 100 kV. Strategic Business Plan (SBP) SMB/4758/R.	
ENTSO-E, 2013b	ENTSO-E, 2013b. NC HVDC – Preliminary Scope Network Codes on HVDC Connections and DC Connected Power Park Modules.	
	EPRI HVDC Reference Book , Product id 3002003519, dec . 2014	

List of Attached Documents

Document Name/File Name	Description	Version/Date

References

No.	Reference
1	J. Verboomen, D. Van Hertem, P. H. Schavemaker, W. L. Kling, and R. Belmans, "Phase shifting transformers: principles and applications," in *Future Power Systems, 2005 International Conference on*, 2005, pp. 6 pp.-6: IEEE.
2	X. She, A. Q. Huang, and R. Burgos, "Review of solid-state transformer technologies and their application in power distribution systems," *IEEE Journal of Emerging and Selected Topics in Power Electronics,* vol. 1, no. 3, pp. 186-198, 2013.
3	T. P. G. T. A. Priyankara, M. J. L. R. Fernando, I. A. K. Sandeepa, N. M. K. D. Bandara, H. W. D. Hettiarachchi, and K. T. M. U. Hemapala, "Design, simulation and implementation of a UPFC (unified power flow controller) for transmission line model," in *2017 Innovations in Power and Advanced Computing Technologies (i-PACT)*, 2017, pp. 1-6.
4	R. J. Piwko, E. V. Larsen, and C. A. Wegner, "Variable frequency transformer - a new alternative for asynchronous power transfer," in *2005 IEEE Power Engineering Society Inaugural Conference and Exposition in Africa*, 2005, pp. 393-398.
5	K. Elamari and L. A. C. Lopes, "Comparison of Static Phase Shifter and Unified Power Flow Controller-Based Interphase," *Canadian Journal of Electrical and Computer Engineering,* vol. 40, no. 2, pp. 139-148, 2017.
6	J. L. Brooks, "Solid State Transformer Concept Development," CIVIL ENGINEERING LAB (NAVY) PORT HUENEME CA1980.
7	J. D. Glover, M. S. Sarma, and T. Overbye, *Power System Analysis & Design, SI Version*. Cengage Learning, 2012.
8	N. Ahmed *et al.*, "HVDC SuperGrids with modular multilevel converters — The power transmission backbone of the future," in *International Multi-Conference on Systems, Sygnals & Devices*, 2012, pp. 1-7.
9	U. Astrom, B. Westman, V. Lescale, and G. Asplund, "Power transmission with HVDC at voltages above 600 kV," in *2005 IEEE Power Engineering Society Inaugural Conference and Exposition in Africa*, 2005, pp. 44-50.
10	W. Litzenberger, K. Mitsch, and M. Bhuiyan, "When It's Time to Upgrade: HVdc and FACTS Renovation in the Western Power System," *IEEE Power and Energy Magazine,* vol. 14, no. 2, pp. 32-41, 2016.

Version History

Action	Date	Description	Author(s)

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