



IEEE Guide for Technology of Unified Power Flow Controller Using Modular Multilevel Converter—Part 4: Control and Protection Application

IEEE Power and Energy Society

Developed by the
Transmission and Distribution Committee

IEEE Std 2745.4™-2022

STANDARDS

IEEE Guide for Technology of Unified Power Flow Controller Using Modular Multilevel Converter—Part 4: Control and Protection Application

Developed by the

Transmission and Distribution Committee
of the
IEEE Power and Energy Society

Approved 8 November 2022

IEEE SA Standards Board

Abstract: Abstract: The application of control and protection on a unified power flow controller (UPFC) using a modular multilevel converter (MMC) is specified in this guide, including application considerations, protection functions and performance, control strategies, and monitoring functions, as well as test and commissioning approaches. This guide can be used as the basis for the design, manufacture, testing, and commissioning of UPFC control and protection systems, benefiting both utilities and manufacturers.

Keywords: Keywords: control and protection, IEEE 2745.4™, modular multilevel converter, unified power flow controller

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

Copyright © 2023 by The Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 3 March 2023. Printed in the United States of America.

IEEE is a registered trademark in the U.S. Patent & Trademark Office, owned by The Institute of Electrical and Electronics Engineers, Incorporated.

PDF: ISBN 978-1-5044-9264-5 STD25828
Print: ISBN 978-1-5044-9265-2 STDPD25828

IEEE prohibits discrimination, harassment, and bullying.

For more information, visit <https://www.ieee.org/about/corporate/governance/p9-26.html>.

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

Important Notices and Disclaimers Concerning IEEE Standards Documents

IEEE Standards documents are made available for use subject to important notices and legal disclaimers. These notices and disclaimers, or a reference to this page (<https://standards.ieee.org/ipr/disclaimers.html>), appear in all standards and may be found under the heading “Important Notices and Disclaimers Concerning IEEE Standards Documents.”

Notice and Disclaimer of Liability Concerning the Use of IEEE Standards Documents

IEEE Standards documents are developed within the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (IEEE SA) Standards Board. IEEE develops its standards through an accredited consensus development process, which brings together volunteers representing varied viewpoints and interests to achieve the final product. IEEE Standards are documents developed by volunteers with scientific, academic, and industry-based expertise in technical working groups. Volunteers are not necessarily members of IEEE or IEEE SA, and participate without compensation from IEEE. While IEEE administers the process and establishes rules to promote fairness in the consensus development process, IEEE does not independently evaluate, test, or verify the accuracy of any of the information or the soundness of any judgments contained in its standards.

IEEE makes no warranties or representations concerning its standards, and expressly disclaims all warranties, express or implied, concerning this standard, including but not limited to the warranties of merchantability, fitness for a particular purpose and non-infringement. In addition, IEEE does not warrant or represent that the use of the material contained in its standards is free from patent infringement. IEEE standards documents are supplied “AS IS” and “WITH ALL FAULTS.”

Use of an IEEE standard is wholly voluntary. The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard.

In publishing and making its standards available, IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity, nor is IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing any IEEE Standards document, should rely upon his or her own independent judgment in the exercise of reasonable care in any given circumstances or, as appropriate, seek the advice of a competent professional in determining the appropriateness of a given IEEE standard.

IN NO EVENT SHALL IEEE BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO: THE NEED TO PROCURE SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE PUBLICATION, USE OF, OR RELIANCE UPON ANY STANDARD, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE AND REGARDLESS OF WHETHER SUCH DAMAGE WAS FORESEEABLE.

Translations

The IEEE consensus development process involves the review of documents in English only. In the event that an IEEE standard is translated, only the English version published by IEEE is the approved IEEE standard.

Official statements

A statement, written or oral, that is not processed in accordance with the IEEE SA Standards Board Operations Manual shall not be considered or inferred to be the official position of IEEE or any of its committees and shall not be considered to be, nor be relied upon as, a formal position of IEEE. At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that the presenter's views should be considered the personal views of that individual rather than the formal position of IEEE, IEEE SA, the Standards Committee, or the Working Group.

Comments on standards

Comments for revision of IEEE Standards documents are welcome from any interested party, regardless of membership affiliation with IEEE or IEEE SA. However, **IEEE does not provide interpretations, consulting information, or advice pertaining to IEEE Standards documents.**

Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Since IEEE standards represent a consensus of concerned interests, it is important that any responses to comments and questions also receive the concurrence of a balance of interests. For this reason, IEEE and the members of its Societies and Standards Coordinating Committees are not able to provide an instant response to comments, or questions except in those cases where the matter has previously been addressed. For the same reason, IEEE does not respond to interpretation requests. Any person who would like to participate in evaluating comments or in revisions to an IEEE standard is welcome to join the relevant IEEE working group. You can indicate interest in a working group using the Interests tab in the Manage Profile & Interests area of the [IEEE SA myProject system](#).¹ An IEEE Account is needed to access the application.

Comments on standards should be submitted using the [Contact Us](#) form.²

Laws and regulations

Users of IEEE Standards documents should consult all applicable laws and regulations. Compliance with the provisions of any IEEE Standards document does not constitute compliance to any applicable regulatory requirements. Implementers of the standard are responsible for observing or referring to the applicable regulatory requirements. IEEE does not, by the publication of its standards, intend to urge action that is not in compliance with applicable laws, and these documents may not be construed as doing so.

Data privacy

Users of IEEE Standards documents should evaluate the standards for considerations of data privacy and data ownership in the context of assessing and using the standards in compliance with applicable laws and regulations.

Copyrights

IEEE draft and approved standards are copyrighted by IEEE under US and international copyright laws. They are made available by IEEE and are adopted for a wide variety of both public and private uses. These include both use, by reference, in laws and regulations, and use in private self-regulation, standardization, and the promotion of engineering practices and methods. By making these documents available for use and adoption by public authorities and private users, IEEE does not waive any rights in copyright to the documents.

¹Available at: <https://development.standards.ieee.org/myproject-web/public/view.html#landing>.

²Available at: <https://standards.ieee.org/content/ieee-standards/en/about/contact/index.html>.

Photocopies

Subject to payment of the appropriate licensing fees, IEEE will grant users a limited, non-exclusive license to photocopy portions of any individual standard for company or organizational internal use or individual, non-commercial use only. To arrange for payment of licensing fees, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; +1 978 750 8400; <https://www.copyright.com/>. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Updating of IEEE Standards documents

Users of IEEE Standards documents should be aware that these documents may be superseded at any time by the issuance of new editions or may be amended from time to time through the issuance of amendments, corrigenda, or errata. An official IEEE document at any point in time consists of the current edition of the document together with any amendments, corrigenda, or errata then in effect.

Every IEEE standard is subjected to review at least every 10 years. When a document is more than 10 years old and has not undergone a revision process, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE standard.

In order to determine whether a given document is the current edition and whether it has been amended through the issuance of amendments, corrigenda, or errata, visit [IEEE Xplore](#) or [contact IEEE](#).³ For more information about the IEEE SA or IEEE's standards development process, visit the IEEE SA Website.

Errata

Errata, if any, for all IEEE standards can be accessed on the [IEEE SA Website](#).⁴ Search for standard number and year of approval to access the web page of the published standard. Errata links are located under the Additional Resources Details section. Errata are also available in [IEEE Xplore](#). Users are encouraged to periodically check for errata.

Patents

IEEE Standards are developed in compliance with the [IEEE SA Patent Policy](#).⁵

Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken by the IEEE with respect to the existence or validity of any patent rights in connection therewith. If a patent holder or patent applicant has filed a statement of assurance via an Accepted Letter of Assurance, then the statement is listed on the IEEE SA Website at <https://standards.ieee.org/about/sasb/patcom/patents.html>. Letters of Assurance may indicate whether the Submitter is willing or unwilling to grant licenses under patent rights without compensation or under reasonable rates, with reasonable terms and conditions that are demonstrably free of any unfair discrimination to applicants desiring to obtain such licenses.

Essential Patent Claims may exist for which a Letter of Assurance has not been received. The IEEE is not responsible for identifying Essential Patent Claims for which a license may be required, for conducting inquiries into the legal validity or scope of Patents Claims, or determining whether any licensing terms or conditions provided in connection with submission of a Letter of Assurance, if any, or in any licensing agreements are

³Available at: <https://ieeexplore.ieee.org/browse/standards/collection/ieee>.

⁴Available at: <https://standards.ieee.org/standard/index.html>.

⁵Available at: <https://standards.ieee.org/about/sasb/patcom/materials.html>.

reasonable or non-discriminatory. Users of this standard are expressly advised that determination of the validity of any patent rights, and the risk of infringement of such rights, is entirely their own responsibility. Further information may be obtained from the IEEE Standards Association.

IMPORTANT NOTICE

IEEE Standards do not guarantee or ensure safety, security, health, or environmental protection, or ensure against interference with or from other devices or networks. IEEE Standards development activities consider research and information presented to the standards development group in developing any safety recommendations. Other information about safety practices, changes in technology or technology implementation, or impact by peripheral systems also may be pertinent to safety considerations during implementation of the standard. Implementers and users of IEEE Standards documents are responsible for determining and complying with all appropriate safety, security, environmental, health, and interference protection practices and all applicable laws and regulations.

Participants

At the time this guide was completed, the Unified Power Flow Controller Working Group P2745 Series had the following entity membership:

Yi Yang, Chair
Georg Pilz, Vice Chair
Xia Chen, Secretary
Chi Zhang, P2745.4 Subgroup Leader
Qun Li, P2745.4 Subgroup Co-Leader

Organization Represented

Name of Representative

Beijing Sifang Automation Co., Ltd.	Hongming Mei
China Energy Engineering Group Co., Ltd.	Dongsheng Zhu
Electric Power Research Institute, Inc.	Rambabu Adapa
Hohai University	Zhinong Wei
Huazhong University of Science and Technology	Xia Chen
Siemens Corporation.....	Georg Pilz
State Grid Corporation of China	Yi Yang
Tsinghua University.....	Qiang Song
Xi'an Jiaotong University	Tao Zheng

The Working Group gratefully acknowledges the contributions of the following participants. Without their assistance and dedication, this guide would not have been completed.

Wei Bao	Peng Li	Xiaomei Yang
Fengfeng Ding	Lei Lin	Wei Yao
Yunlong Dong	Lei Pan	Hualong Yu
Lei Gao	Daniel Sabin	Yubo Yuan
Kai Gao	Rajiv Varma	Xiong Zhan
Ruhai Huang	Xiaogang Wang	Haixiang Zhao
Brian Johnson	Xuan Wang	Qiwen Zhou
Xiangping Kong	Shilei Xiao	Zhicheng Zhou
Laifu Li	Haiqing Xu	Liu Zong

The following members of the entity Standards Association balloting group voted on this guide. Balloters may have voted for approval, disapproval, or abstention.

1 st Cycle Corporation	Hohai University	Siemens Corporation
ABB, Ltd.	Huazhong University of Science	Siemens Energy
Beijing Sifang Automation Co.,	and Technology	State Grid Corporation of China
Ltd.	Hydro-Quebec	(SGCC)
China Power Engineering	Institute of Biomedical	Tsinghua Shenzhen International
Consulting Group Co., Ltd.	Engineering, Chinese	Graduate School
ChongQing University	Academy of Medical	Xi'an Jiaotong University
Dalian University of Technology	Sciences & Peking Union	
Electric Power Research	Medical College	
Institute (EPRI)	Schneider Electric	

When the IEEE SA Standards Board approved this guide on 8 November 2022, it had the following membership.

David J. Law, *Chair*
Ted Burse, *Vice Chair*
Gary Hoffman, *Past Chair*
Konstantinos Karachalios, *Secretary*

Edward A. Addy
Ramy Ahmed Fathy
J. Travis Griffith
Guido R. Hiertz
Yousef Kimiagar
Joseph L. Koepfinger*
Thomas Koshy
John D. Kulick

Johnny Daozhuang Lin
Kevin Lu
Daleep C. Mohla
Andrew Myles
Damir Novosel
Annette D. Reilly
Robby Robson
Jon Walter Rosdahl

Mark Siira
Dorothy V. Stanley
Lei Wang
F. Keith Waters
Karl Weber
Sha Wei
Philip B. Winston
Daidi Zhong

*Member Emeritus

Introduction

This introduction is not part of IEEE Std 2745.4-2022, IEEE Guide for Technology of Unified Power Flow Controller Using Modular Multilevel Converter—Part 4: Control and Protection Application.

As the most flexible, powerful, and comprehensive flexible ac transmission system (FACTS) device, a unified power flow controller (UPFC) can realize the bidirectional control of power flow, flexibly control voltage and reactive power, as well as improve the steady and dynamic stability of power grids. Since the 1990s to 2004, three UPFC projects were put into operation—Inez substation of American Electric Power (AEP), Kangjin substation of Korea Electric Power Corporation (KEPCO), and Marcy substation of the New York Power Authority (NYPA)—all of which utilized gate turn-off thyristor (GTO) devices and three-level converter technology. With the increasing development of power electronics equipment and technology, modular multilevel converter (MMC) technology with an insulate-gate bipolar transistor (IGBT) has been successfully applied into UPFC, such as Tiebei substation of the State Grid Corporation of China (SGCC), Yunzaobang substation of SGCC, and Mudu substation of SGCC. Compared with the GTO device and three-level multiple technology, MMC technology is superior in expandable structure, low output waveform deviation, easy control of capacitor voltage, and desirable fault tolerance of sub-modules. Therefore, the MMC technology is the development trend of UPFC in the future. With the decreasing cost of converters, more MMC-UPFC projects will be put into commercial operation and satisfy the requirements of power flow control and system stability.

A series of documents, the IEEE 2745 series, are proposed to provide guides for a technology of unified power flow controllers using modular multilevel converters. This guide, IEEE P2745.4, is the fourth part of P2745 series, focusing on control and protection application.

The purpose of this guide is to provide technical guidelines for the design, research, development, implementation, operation, maintenance, as well as testing of UPFC systems using MMC. Utilities, manufacturers, and other interested entities can use this guide to specify application requirements, protective and performance functions, control strategies, monitoring functions, testing, and commissioning of UPFC control and protection systems.

Contents

1. Overview	11
1.1 Scope	11
1.2 Purpose	11
1.3 Word usage	11
2. Normative references	12
3. Definitions, acronyms, and abbreviations	12
3.1 Definitions	12
3.2 Acronyms and abbreviations	14
4. Application considerations	14
5. General configuration requirements	15
6. UPFC control	16
6.1 Control equipment and function configuration	16
6.2 Control function requirements	16
6.3 Performance requirements of control equipment	21
7. UPFC protection	24
7.1 Protection configuration requirements	24
7.2 Protection system configuration zoning and measuring point location	28
7.3 Protection function requirements	29
7.4 Performance requirements of protection equipment	31
8. UPFC monitor	31
8.1 Configuration requirements	31
8.2 Function requirements	32
9. Communication and interface	34
9.1 General requirements	34
9.2 Interface and communication in the UPFC station	34
9.3 Communication between the remote terminal unit (RTU) and the remote control center	35
9.4 Network security	35
10. Test of UPFC control and protection system	36
10.1 Test classification	36
10.2 Device unit test	37
10.3 Control system test	37
10.4 Protection system test	39
10.5 Monitor system test	40
10.6 Communication interface test	40
Annex A (informative) Bibliography	42
Annex B (informative) Real application cases	43

IEEE Guide for Technology of Unified Power Flow Controller Using Modular Multilevel Converter—Part 4: Control and Protection Application

1. Overview

1.1 Scope

This guide specifies the application of control and protection on a unified power flow controller (UPFC) using a modular multilevel converter (MMC) in transmission lines, including application considerations, protection functions and performance, control strategies, and monitoring functions, as well as test and commissioning approaches. The guide also provides informative case studies of control and protection systems based on the application experience of UPFC projects.

1.2 Purpose

The purpose of this guide is to provide technical guidelines for the design, research, development, implementation, operation, maintenance, as well as testing of UPFC systems using MMC. Utilities, manufacturers, and other interested entities can use this guide to specify application requirements, define protective and performance functions, control strategies and monitoring functions, testing and commissioning of UPFC control and protection systems.

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{6,7}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

⁶The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

⁷The use of *will* is deprecated and cannot be used when stating mandatory requirements; *will* is only used in statements of fact.

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEC 60044-8:2002, Instrument transformers—Part 8: Electronic current transformers.⁸

IEC 60364-4-41:2017, Low voltage electrical installations—Part 4-41: Protection for safety—Protection against electric shock.

IEC 60870-5-1:1990, Telecontrol equipment and systems. Part 5: Transmission protocols—Section One: Transmission frame formats.

IEC 62351, Power systems management and associated information exchange—Data and communications security—ALL PARTS.

IEEE Std 2745.1™-2019, IEEE Guide for Technology of Unified Power Flow Controller Using Modular Multilevel Converter—Part 1: Functions.^{9,10}

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The IEEE Standards Dictionary Online should be consulted for terms not defined in this clause.¹¹

blocking: An operation that prevents a controlled valve or converter from opening by stopping the control pulse.

control and protection system: A system to realize the control, protection, operation data acquisition, and monitoring functions of all unified power flow controller (UPFC) equipment.

control mode: A method for unified power flow controller (UPFC) to control one or more electrical variables at setting values. The setting values are measured variables or predefined functions varying with time.

converter: A machine or device for changing ac power into dc power (rectifier operation) or dc power into ac power (inverter operation). It connects between three ac phase terminals and two dc pole terminals.

converter control layer: All functions that enable the application control layer to perform its mission by implementing the functions common to all converters.

deblocking: An operation that allows the opening of a controlled valve or converter by unlocking it.

⁸IEC publications are available from the International Electrotechnical Commission (<https://www.iec.ch>) and the American National Standards Institute (<https://www.ansi.org/>).

⁹The IEEE standards or products referred to in [Clause 2](#) are trademarks owned by The Institute of Electrical and Electronics Engineers, Incorporated.

¹⁰IEEE publications are available from The Institute of Electrical and Electronics Engineers (<https://standards.ieee.org/>).

¹¹IEEE Standards Dictionary Online is available at: <http://dictionary.ieee.org>. An IEEE account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

fault ride-through: In case of power grid failure, the unified power flow controller (UPFC) can continue operation, or it can be put into operation automatically after being temporarily blocked, and play the role of power regulation to support grid recovery.

human machine interface (HMI): A device/function that displays data/information to, and allows control and monitor of a unified power flow controller (UPFC) station by, an operator. A HMI may also be local to a specific device for operator interaction specific to that device.

modular multilevel converter (MMC): A multilevel converter in which each voltage source converter (VSC) valve consists of a number of sub-modules connected in series.

response time: The duration from a step change in control signal input until the device output reaches 90% of required output, before any overshoot.

settling time: The duration from a step change in control signal input until the device output settles to within $\pm 5\%$ of the required control output.

SSSC operation mode: An operation mode in which the series part of unified power flow controller (UPFC) is connected to the ac system separately, and the dc side of the series converter is isolated from that of the shunt converter.

STATCOM operation mode: The static synchronous compensator (STATCOM) operation mode is one in which the shunt part of unified power flow controller (UPFC) is separately connected to the ac system, and the series part of UPFC is bypassed, as well as the dc side of the shunt converter is isolated from that of the series converter.

static synchronous compensator (STATCOM): A static synchronous generator employing a voltage source converter (VSC) in parallel with the transmission line(s), whose capacitive or inductive output current can be controlled independently of the ac system voltage.

static synchronous series compensator (SSSC): A static synchronous compensator employing a voltage source converter (VSC) in series with the transmission line(s), which can continuously and fast control the equivalent impedance of transmission line(s).

step response: The normalized output as a function of time, t , when the input is a step.

system control layer: All functions involved in the determination of the system mission and the duties of the power electronics system.

unified power flow controller (UPFC): A combined power electric device employing two (or more) voltage source converters (VSCs) coupled via a common dc bus, which is connected in series and in parallel to an ac power grid. The UPFC is able to control the active and reactive power flow independently and provide controllable shunt reactive compensation.

UPFC operation mode: An operation mode in which the series and shunt parts of the unified power flow controller (UPFC) are connected to the ac system and the dc sides of the shunt converter and series converter are connected.

voltage source converter (VSC): A voltage source converter is characterized by a stiff dc voltage in the intermediate dc link. The line-side network voltage is converted to a constant dc voltage provided by, for example, a common dc link capacitor or distributed dc capacitors within the converter arms.

3.2 Acronyms and abbreviations

AVC	automatic voltage control
HMI	human machine interface
MMC	modular multilevel converter
PCC	point of common coupling
RTU	remote terminal unit
SSSC	static synchronous series compensator
STATCOM	static synchronous compensator
TBS	thyristor bypass switch
TFR	transient fault recorder
UPFC	unified power flow controller
VBC	valve based controller
VBE	valve based electronics
VSC	voltage source converter

4. Application considerations

The installation of a unified power flow controller (UPFC) will provide a huge benefit for the transmission network. The main benefit is the control of all three parameters in the ac network that define the power flow, namely the voltage, impedance, and phase angle. Additionally, the control of these parameters is not only possible during steady-state condition but also during contingencies where these variables can be influenced, for example, for damping of power or voltage oscillations.

For application scenarios where the cross-section transmission capacity is limited because of uneven power flow distribution, the UPFC focuses on solving problems including transmission section power control, multi-circuit coordinated control, power flow optimization control, and grid power emergency control. For application scenarios where it is utilized to improve the reactive power and voltage support capability of the power grid, the UPFC focuses on solving problems including grid reactive power and voltage control, grid voltage emergency control, etc.

The control algorithm for different tasks and network scenarios has to be developed, implemented, and tested for correct operation of the UPFC. Note that not all theoretical functionalities of a UPFC must be integrated in each individual installation. In advance of a UPFC project, several studies should be carried out that identify and define the individual requirements per project to the control. A short summary of investigations follows.

Load flow studies are the decisive investigation for defining the necessity of a UPFC in a network. Thereby the requirements for active and reactive power exchange with the network will be calculated. Further, the input variables of the UPFC control algorithm will be identified depending on the network parameter (e.g., voltage level, phase angle of voltage, current, frequency) that will be influenced. Most of the time, these input parameters will be available directly on the point of common coupling (PCC) of the UPFC. Nevertheless, it is conceivable that the input parameter will not be available in the same substation, for example, the line current of a transmission line that can be influenced by the UPFC. This will define additional demands on the control due to probable time delays of the input parameter.

Short-circuit current calculations of the network are essential for dimensioning of the components of a UPFC, especially for the series part. Additionally, the calculation of the minimum short-circuit level can be decisive