

# IEEE Guide for the Functional Specification of Fixed-Series Capacitor Banks for Transmission System Applications

IEEE Power and Energy Society

Sponsored by the  
Transmission and Distribution Committee

Currently in preview, click buy full version

# IEEE Guide for the Functional Specification of Fixed-Series Capacitor Banks for Transmission System Applications

Sponsor

**Transmission and Distribution Committee  
of the  
IEEE Power and Energy Society**

Approved 11 December 2013

**IEEE-SA Standards Board**

Currently in preview, click buy full version

**Abstract:** General guidelines toward the preparations of a functional specification of transmission fixed-series capacitor (FSC) banks using overvoltage protection based on three technologies are provided. The three technologies are:

- metal oxide varistors
- metal oxide varistors with a forced-triggered bypass gaps, and thyristor protected series capacitors
- thyristor protected series capacitor

This guide does not apply comprehensively to thyristor-controlled series capacitors.

**Keywords:** bypass gap, capacitor bank, capacitor segment, discharge reactor, IEEE 1725™, metal-oxide varistor, protective level, reactive compensation, series capacitor, series compensation, subsynchronous resonance risk (SSR), trigger circuit, triggered gap, varistor

---

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

Copyright © 2014 by The Institute of Electrical and Electronics Engineers, Inc.  
All rights reserved. Published 7 March 2014. 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 978-0-7381-8769-3 STD98464  
Print: ISBN 978-0-7381-8770-9 STDPD98464

*IEEE prohibits discrimination, harassment, and bullying.*

For more information, visit <http://www.ieee.org/web/aboutus/whatis/policies/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 documents are made available for use subject to important notices and legal disclaimers. These notices and disclaimers, or a reference to this page, appear in all standards and may be found under the heading “Important Notice” or “Important Notices and Disclaimers Concerning IEEE Standards Documents.”

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

IEEE Standards documents (standards, recommended practices, and guides), both full-use and trial-use, are developed within IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (“IEEE-SA”) Standards Board. IEEE (“the Institute”) develops its standards through a consensus development process, approved by the American National Standards Institute (“ANSI”), which brings together volunteers representing varied viewpoints and interests to achieve the final product. Volunteers are not necessarily members of the Institute 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 does not warrant or represent the accuracy or content of the material contained in its standards, and expressly disclaims all warranties (express, implied and statutory, not included in this or any other document relating to the standard, including, but not limited to, the warranties of: merchantability; fitness for a particular purpose; non-infringement; and quality, accuracy, effectiveness, currency, or completeness of material. In addition, IEEE disclaims any and all conditions relating to: results; and workmanlike effort. 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: PROCUREMENT OF 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 should be considered 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, or 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 his or her views should be considered the personal views of that individual rather than the formal position of IEEE.

## Comments on standards

Comments for revision of IEEE Standards documents are welcome from any interested party, regardless of membership affiliation with IEEE. However, IEEE does not provide 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 revisions to an IEEE standard is welcome to join the relevant IEEE working group.

Comments on standards should be submitted to the following address:

Secretary, IEEE-SA Standards Board  
445 Hoes Lane  
Piscataway, NJ 08854 USA

## 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 imply compliance to any applicable regulatory requirements. Implementers of the standards 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.

## Copyrights

IEEE draft and approved standards are copyrighted by IEEE under U.S. 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.

## Photocopies

Subject to payment of the appropriate fee, 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. 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 ten years. When a document is more than ten 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 the IEEE-SA Website at <http://ieeexplore.ieee.org/xpl/standards.jsp> or contact IEEE at the address listed previously. For more information about the IEEE-SA or IEEE's standards development process, visit the IEEE-SA Website at <http://standards.ieee.org>.

### Errata

Errata, if any, for all IEEE standards can be accessed on the IEEE-SA Website at the following URL: <http://standards.ieee.org/findstds/errata/index.html>. Users are encouraged to check this URL for errata periodically.

### Patents

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 <http://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 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.

## Dedication

This document is dedicated to memory of Stan Miske, our friend and colleague.

## Participants

This standard was revised by a working group sponsored by the Capacitor Subcommittee of the Transmission and Distribution Committee of the IEEE Power Engineering Society. At the time this standard was approved, the Capacitor Subcommittee consisted of the following membership:

**Tom Grebe, Chairman**  
**Richard Sevigny, Vice-Chair**  
**Mike Hulse, Secretary**

Roy Alexander  
S. Ashmore  
J. Bonner  
T. Callsen  
Bill Chai  
V. Deslauriers  
Stuart Edmondson  
B. English  
C. Erven  
Clay Fellers  
Karl Fender

Tom Grebe  
J. Harder  
Ivan Horvat  
Mike Hulse  
Gerald Lee  
Per Lindberg  
Dan Luke  
P. Marken  
Mark McVey  
D. Meisner

J. Nelson  
J. Peggs  
P. Rancou  
R. Vittal Rebbapragada  
S. Kuo-Marcuello  
I. Rork  
D. Ruthman  
Richard Sevigny  
Rao Thallam  
L. Vovan  
Ahmed Zobaa

At the time this IEEE guide was completed, the Series Capacitor Working Group had the following membership:

**Mark McVey, Chair**  
**Bruce English, Vice Chair**

Bharat Bhargava  
Pierre Bilodeau  
Marcello Capistrano  
Bill Chai  
Stuart Edmonson  
Clay Fellers  
Karl Fender  
Luther Holloman

Ivan Horvat  
Mike Hulse  
John Joyce  
Carlet Langford  
Lauri Latipaa  
Gerald Lee  
Per Lindberg  
Dan Luke

Paul Marken  
Joe Meisner  
Richard Piwko  
R. Vittal Rebbapragada  
Jan Samuelsson  
Richard Sevigny  
Biswajit Singh  
Rao Thallam

The following members of the individual balloting committee voted on this guide. Balloters may have voted for approval, disapproval, or abstention.

William Ackerman  
Roy Alexander  
Saleman Alibhay  
Hubert Bilodeau  
Wallace Binder  
Michael Bio  
Gustavo Brunello  
William Bush  
William Byrd  
James Chapman II  
Robert Christman  
Michael Comber  
Gary Donner  
Randall Dotson  
Gearold O. H. Eidhin  
C. Erven  
David Gilmer  
Edwin Goodwin  
Thomas Grebe

Randall Groves  
Ajit Gwal  
Yi Hu  
Jeffrey Kester  
Yuri Khersonsky  
Joseph Koepfinger  
Jim Kulchisky  
Chung-Yiu Lam  
Greg Luri  
Mark McVey  
David Mueller  
Michael Newman  
Charles Ngethe  
Lorraine Padden  
Bansi Patel  
David Peelo  
Reynaldo Ramos  
Michael Roberts  
Bartien Sayogo

Richard Sevigny  
Nikunj Shah  
Hamid Sharifnia  
Devki Sharma  
Gil Shultz  
Jerry Smith  
Joshua Smith  
Gary Stoedter  
K. Stump  
John Vergis  
Ilia Voloh  
Daniel Ward  
Yingli Wen  
Kenneth White  
James Wilson  
Jonathan Woodworth  
Jian Yu  
Luis Zambreno  
Ahmed Zouaa

When the IEEE-SA Standards Board approved this guide on 11 December 2013, it had the following membership:

**John Kulick, Chair**  
**David J. Law, Vice Chair**  
**Richard H. Hulet, Past Chair**  
**Konstantinos Karachalios, Secretary**

Masayuki Ariyoshi  
Peter Balma  
Farooq Bari  
Ted Burse  
Stephen Dukes  
Jean-Philippe Faure  
Alexander Gelman

Mark Halpin  
Gary Hoffman  
Paul Houze  
Jim Hughes  
Michael Janezic  
Joseph L. Koepfinger\*  
Oleg Logvinov  
Ron Petersen

Gary Robinson  
Jon Walter Rosdahl  
Adrian Stephens  
Peter Sutherland  
Yatin Trivedi  
Phil Winston  
Yu Yuan

\*Member Emeritus

Also included are the following non-voting IEEE-SA Standards Board liaisons:

Richard DeBlasio, *DOE Representative*  
Michael Janezic, *NIST Representative*

Patrick Gibbons  
*IEEE Standards Program Manager, Document Development*

Erin Spiewak  
*IEEE Standards Program Manager, Technical Program Development*

## Introduction

This introduction is not part of IEEE Std 1726™-2013, IEEE Guide for the Functional Specification of Fixed-Series Capacitor Banks for Transmission System Applications.

The purpose of this guide is to provide general guidelines toward the preparation of a functional specification of transmission fixed-series capacitor banks (FSC) using overvoltage protection based on three technologies: metal oxide varistors, metal oxide varistors with a forced bypass gap, and thyristor valve bypass.

# Contents

1. Overview .....	1
1.1 Scope .....	1
1.2 Purpose .....	2
1.3 Application .....	2
2. Normative references.....	2
3. Definitions, acronyms, and abbreviations .....	2
3.1 Definitions .....	2
3.2 Acronyms and abbreviations .....	5
4. Fixed-series capacitor (FSC) project description.....	7
5. Scope of supply and schedule.....	10
5.1 Scope of supply .....	10
5.2 Schedule .....	14
6. Site and environmental data .....	15
7. Power system characteristics.....	16
8. Main FSC characteristics.....	17
8.1 Overall FSC bank ratings.....	17
8.2 Protection and control philosophy .....	17
8.3 Reliability, availability, and maintainability.....	19
9. FSC main component requirements.....	21
9.1 Capacitors .....	21
9.2 Varistors .....	22
9.3 Triggered bypass gaps .....	23
9.4 Thyristors and thyristor reactors.....	23
9.5 Insulation and air clearances.....	23
9.6 Discharge current-limiting and damping equipment .....	28
9.7 Bypass switches.....	28
9.8 Protection, control, and monitoring .....	29
10. Spare parts and special tools.....	31
11. Engineering studies .....	31
11.1 Power system studies .....	31
11.2 Equipment design studies .....	35
12. Tests and quality assurance .....	37
12.1 Test and quality assurance reference .....	37
12.2 Type/design (pre-production) testing.....	37
12.3 Routine (production) testing .....	38
13. Safety.....	38
14. Documentation .....	38

15. Training .....	39
16. Balance of plant determination.....	40
17. Maintenance agreement.....	42
Annex A (informative) Bibliography .....	43
Annex B (informative) Notes for a functional specification .....	45
B.1 Introduction.....	45
B.2 FSC project description, see Clause 4.....	45
B.3 Scope of supply and schedule, see Clause Error! Reference source not found. ....	48
B.4 Site and environmental data, see Clause 6 .....	48
B.5 Power system characteristics, see Clause 7.....	49
B.6 Main FSC characteristics, see Clause 8 .....	50
B.7 FSC main component requirements, see Clause 9 .....	61
B.8 Spare parts and special tools, see Clause 10 .....	79
B.9 Engineering studies, see Clause 11 .....	79
B.10 Tests and quality assurance, see Clause 12.....	84
B.11 Documentation, see Clause 14.....	85
B.12 Training, see Clause 15.....	85
Annex C (informative) Subsynchronous resonance risk (SSR) on turbine generators .....	86
C.1 Introduction.....	86
C.2 Subsynchronous resonance (SSR).....	86
C.3 Interaction between electrical and mechanical resonant systems.....	88
C.4 SSR instability .....	89
C.5 Transient torque amplification .....	89
C.6 SSR mitigation and protection .....	90
C.7 SSR protection .....	91
C.8 Conclusions.....	92
Annex D (informative) Effects of series capacitors on line breaker TRV.....	93
Annex E (informative) Power system modeling for use in fixed-series capacitor (FSC) equipment rating studies.....	94
E.1 Defining a power system equivalent circuit and associated fault currents for use in defining the fault withstand requirements of series capacitor protective devices .....	94
E.2 Discussion of system studies for determining the ratings for varistors and thyristor valves.....	95
Annex F (informative) Fault current discussion .....	97
F.1 Overview .....	97
F.2 Waveforms and analytical expressions of fault currents in inductive and series-compensated networks .....	97
F.3 Modeling of series capacitors in traditional short-circuit calculations .....	102
F.4 Modeling of series capacitors in transient short-circuit calculations.....	102
F.5 Definition of total fault current and through fault current (partial fault current).....	103
Annex G (informative) Characterization of short circuits and their currents .....	106
G.1 Discussion of swing current.....	106
G.2 Stresses on a FSC caused by a swing current .....	107
G.3 Gap-protected banks .....	107
G.4 MOV-protected banks.....	107
Annex H (informative) Watts loss evaluation .....	108

# IEEE Guide for the Functional Specification of Fixed-Series Capacitor Banks for Transmission System Applications

*IMPORTANT NOTICE: IEEE Standards documents are not intended to ensure safety, security, health, or environmental protection, or ensure against interference with or from other devices or networks. Implementers 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.*

*This IEEE document is made available for use subject to important notices and legal disclaimers. These notices and disclaimers appear in all publications containing this document and may be found under the heading “Important Notice” or “Important Notices and Disclaimers Concerning IEEE Documents.” They can also be obtained on request from IEEE or viewed at <http://standards.ieee.org/IPR/disclaimers.html>.*

## 1. Overview

### 1.1 Scope

This guide provides general guidelines toward the preparations of a functional specification of transmission fixed-series capacitor (FSC) banks using overvoltage protection based on three technologies:

- metal oxide varistors
- metal oxide varistors with a forced-triggered bypass gaps
- thyristor valve bypass

The commercial aspects of the specification for a particular project are outside the scope of this guide.

This guide does not apply comprehensively to thyristor-controlled series capacitors. A more complete reference is IEEE Std 1534™-2002.<sup>1</sup> The standard for fixed-series capacitors is IEEE Std 824™-2004.

---

<sup>1</sup> Information on references can be found in Clause 2.