



IEEE Guide for the Application of Shunt Power Capacitors

STANDARDS

IEEE Power and Energy Society

Developed by the
Transmission and Distribution Committee

IEEE Std 1036™-2020
(Revision of IEEE Std 1036-2010)



IEEE Guide for the Application of Shunt Power Capacitors

Developed by the

Transmission and Distribution Committee
of the
IEEE Power and Energy Society

Approved 5 March 2020

IEEE-SA Standards Board

THIS IS A REDLINE DOCUMENT PRODUCED BY TECHSTREET, AN ASME COMPANY.

This document is intended to provide users with an indication of changes from one edition to the next. It includes a full-text version of the new document, plus an indication of changes from the previous version.

Redlines are designed to save time and improve efficiencies by using the latest software technology to find and highlight document changes. More professionals are using valuable new technologies like redlines, to help improve outcomes in a fast paced global business world.

Because it may not be technically possible to capture all changes accurately, it is recommended that users consult previous editions as appropriate. In all cases, only the current base version of this publication is to be considered the official document.

This Redline is produced solely by Techstreet. IEEE has not prepared this Redline and is not responsible for its accuracy.

Redline Processing Notes:

1. ~~Red Text~~ - Red strikethrough text denotes deletions.
2. Blue Text - Blue underlined text denotes modifications and additions.

Abstract: This guide applies to the use of 50 Hz and 60 Hz shunt power capacitors rated 2400 Vac and above, and assemblies of such capacitors. Included are guidelines for the application, protection, and ratings of equipment for the improved safety and reliability in the utilization of shunt power capacitors. The guide is general and intended to be basic and supplemental to specific recommendations of the manufacturer. The guide covers applications that range from simple capacitor unit utilization to complex capacitor bank situations.

Keywords: capacitor, capacitor banks, externally fused, fuseless, IEEE 1036™, internally fused, power factor correction, shunt power capacitors

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

Copyright © 2021 by The Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 5 March 2021. Printed in the United States of America.

IEEE, National Electrical Safety Code, and NESC are registered trademarks in the U.S. Patent & Trademark Office, owned by The Institute of Electrical and Electronics Engineers, Incorporated.

National Electrical Code, NEC, and NFPA 70 are registered trademarks in the U.S. Patent & Trademark Office, owned by the National Fire Protection Association.

PDF: ISBN 978-1-5044-6566-3 STD24121
Print: ISBN 978-1-5044-6567-0 STDPD24121

IEEE prohibits discrimination, harassment, and bullying.

For more information, visit <https://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 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](#). An IEEE Account is needed to access the application.

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

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.

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](#). 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](#). 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](#).

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 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 Shunt Capacitor Application Guide Working Group had the following membership:

D.Joe Meisner, *Chair*

Mike Hulse, *Vice Chair*

Othmane Alaoui	Chuck Gougler	Pratap Mysore
Roy Alexander	Tom Grebe	Jeffrey Nelson
Steve Ashmore	Stephen Ladd	Sarah Newton
Thomas Callsen	Hua Liu	Jan Paramalingam
Bill Chai	Dan Luke	Reynaldo Ramos
Paul Datka	Halim Malaj	Vittal Rebbapragada
Vincent Deslauriers	Derrick Mar	Eduardo Sanchez
Bruce English	Paul Marken	Richard Sévigny
Clay Fellers	Mark McVey	Devki Sharma
Roberto Gonzales-Ramos	Stephen Miller	Biswajit Singh
	William Munn	Frederic St-Hilaire

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

William Ackerman	Thomas Grebe	Bansi Patel
Ali Al Awazi	Randall Groves	Iulian Profir
Roy Alexander	Jeffrey Helzer	Reynaldo Ramos
Saleman Alibhay	Werner Hoelzl	Charles Rogers
Peter Balma	Robert Hoerauf	Joseph Rostron
Thomas Barnes	Geza Joos	Daniel Sabin
Wallace Binder	Laszlo Kadar	Bartien Sayogo
Anne Bosma	Tanuj Khandelwal	Kenneth Sedziol
Gustavo Brunello	Yuri Khersonsky	Richard Sevigny
Demetrio Bucaneg Jr.	James Kinney	Devki Sharma
Thomas Callsen	Gary Kobet	Jerry Smith
Wen-Kung Chang	Jim Kulchisky	Gary Smullin
Arvind Chaudhary	Stephen Ladd	Kris Sommerstad
Michael Chirico	Chung-Yiu Lam	Wayne Stec
Robert Christman	Hua Liu	Gary Stoedter
Stephen Conrad	Albert Livshitz	K. Stump
Randall Crellin	Daniel Luke	James Van De Ligt
John Crouse	Bruce Mackie	John Vergis
Vincent Deslauriers	Reginaldo Maniego	Ilia Voloh
Gary Donner	Sean McGuinness	Reigh Walling
Cliff Erven	William Munn	Daniel Ward
Clay Fellers	Jerry Murphy	Kenneth White
Fredric Friend	Arthur Neubauer	Aaron Wilson
Kamal Garg	Joe Nims	Wilsun Xu
Edwin Goodwin	Gearold O. H. Eidhin	Jian Yu
Charles Gougler	T. W. Olsen	David Zech
Todd Goyette	Jan Paramalingam	Xi Zhu

When the IEEE-SA Standards Board approved this guide on 5 March 2020, it had the following membership:

Gary Hoffman, *Chair*
Jon Walter Rosdahl, *Vice Chair*
John D. Kulick, *Past Chair*
Konstantinos Karachalios, *Secretary*

Ted Burse
Doug Edwards
J. Travis Griffith
Grace Gu
Guido R. Hiertz
Joseph L. Koepfinger*

David J. Law
Howard Li
Dong Liu
Kevin Lu
Paul Nikolich
Damir Novosel
Dorothy Stanley

Mehmet Ulema
Lei Wang
Sha Wei
Philip B. Winston
Daidi Zhong
Jingyi Zhou

*Member Emeritus

Introduction

This introduction is not part of IEEE Std 1036-2020, IEEE Guide for the Application of Shunt Power Capacitors.

This application guide is widely recognized as a useful guide, and it needs to be revised in order to continue its functional life as an active standard. The content has been reviewed and updated to make sure that it is in line with current industry developments and practices.

This revision also complements updates included in the recent revision of IEEE Std 18-2012. [Subclause 9.4](#) and [Annex B](#) have been added to provide additional information on shunt capacitor bank rating considerations and terminal-to-case voltage considerations.

Contents

1. Scope.....	15
2. Normative references	15
3. Definitions.....	16
4. Power system considerations.....	18
4.1 Capacitor benefits	18
4.2 Size and number of capacitor banks.....	24
4.3 Control considerations.....	25
5. Capacitor rating capabilities and service conditions.....	26
5.1 Standard ratings.....	27
5.2 Related capabilities.....	30
5.3 Service conditions	33
6. Capacitor bank switching considerations	33
6.1 Switching of capacitors	33
6.2 Switching transients	34
6.3 Outrush current.....	50
6.4 Capacitor switching equipment	50
7. Harmonics	52
7.1 Capacitor limitations	52
7.2 Distortion limits.....	53
7.3 Operating and application considerations.....	53
7.4 Harmonic “problems”.....	54
8. Surge arresters	54
8.1 Substation applications.....	55
8.2 Distribution applications	55
9. Substation shunt power capacitor bank applications	56
9.1 Capacitor bank connections and grounding	56
9.2 Capacitor bank types	59
9.3 Protection	63
9.4 Shunt capacitor bank rating considerations	70
10. Shunt power capacitor applications on distribution lines	70
10.1 Protection	71
10.2 Sizing and locating capacitors	73
11. Inspection and maintenance	74
11.1 General	74
11.2 Safety and personnel protection.....	74
11.3 Initial inspection, measurements, and energization	75
11.4 Periodic inspection, measurements, and maintenance	76
11.5 Field testing	82
12. Special capacitor applications	83
12.1 Harmonic filters.....	83
12.2 Motor applications.....	84
12.3 Surge capacitors	85

Annex A (informative) Bibliography.....	87
Annex B (informative) Terminal to case voltage considerations	89

List of Figures

Figure 1—Effect of adding shunt capacitors	19
Figure 2—Economical system power factor	21
Figure 3—Typical kilovar demand profile for switched and fixed capacitor banks	26
Figure 4—Maximum contingency power frequency overvoltage capability of capacitor units	31
Figure 5—Transient peak overvoltage capability of capacitor units.....	33
Figure 6—System diagram for energizing an isolated capacitor bank.....	35
Figure 7—Typical bus voltage and capacitor current during capacitor energizing	35
Figure 8—Example phase-to-phase transformer transient due to capacitor switching.....	37
Figure 9—Back-to-back switching circuit	40
Figure 10—Concept of synchronous closing control for ungrounded wye banks	42
Figure 11—System diagram for magnification condition.....	42
Figure 12—Equivalent circuit for magnification condition.....	43
Figure 13—Magnification of transient at remote capacitor bank.....	44
Figure 14—Adjustable speed motor drive: Voltage source inverter type with uncontrolled source converter	45
Figure 15—Transient voltages during capacitor switching	46
Figure 16—System diagrams for dynamic overvoltage conditions.....	47
Figure 17—Dynamic overvoltage on capacitors	47
Figure 18—Capacitor and bus voltage during de-energizing: (a) System frequency component of voltage and (b) system frequency and high-frequency component of voltage.....	48
Figure 19—De-energizing capacitor bank with restriking switching device.....	49
Figure 20—Single point grounding.....	57
Figure 21—Peninsula grounding	58
Figure 22—Schematic of an externally fused capacitor bank, single wye, 11 capacitors per series group, 4 series groups per phase	60
Figure 23—Schematic of an internally fused capacitor bank, wye-wye configuration with 24 capacitor units per phase.....	61
Figure 24—Schematic of a fuseless capacitor bank with 2 strings per phase, 12 capacitor units per string....	62
Figure 25—Grounded wye-connected, Δ , or grounded double wye-connected capacitor bank: Voltage on remaining capacitor units in series group versus percentage of capacitor units removed from series group	65
Figure 26—Ungrounded double wye-connected (neutrals tied together) capacitor bank: Voltage on remaining capacitor units in series group versus percentage of capacitor units removed from series group...	66

Figure 27—Ungrounded wye-connected or ungrounded double wye-connected (neutrals isolated) capacitor bank: Voltage on remaining capacitor units in series group versus percentage of capacitor units removed from series group	67
Figure 28—Typical case rupture curves for approximately 30 L case volume	73
Figure 29—Capacitor bank grounded in preparation for testing	78
Figure 30—Measurement of midpoint-to-ground capacitance for one string with capacitor bank phase and neutral grounded	78
Figure 31—Midpoint-to-ground measurement with one failed capacitor unit	79
Figure 32—Capacitance measurements across racks without and with a failed capacitor unit.....	79
Figure 33—Comparing capacitances with different numbers of capacitor units in various racks	80
Figure 34—Measuring individual capacitor units in a rack with an indicated failure.....	80
Figure 35—Capacitance measurement using a modified Schering bridge.....	81
Figure 36—Typical motor starting curve.....	85
Figure 37—Motor starting capacitor application	85
Figure 38—Surge capacitor application	86
Figure B.1—Example capacitor layout with $N_{SPR} = 4$ and $N_1 = N_2 = 2$	89
Figure B.2—Diagram of series rack capacitance grading across a capacitor bank	91

List of Tables

Table 1—Summary of benefits of applying shunt power capacitors.....	19
Table 2—Power factor correction kilowatt multipliers.....	22
Table 3—Typical power capacitor voltage and reactive power ratings.....	27
Table 4—Maximum ambient.....	30
Table 5—Capacitor peak transient current capability.....	32
Table 6—Restrike performance classifications	51
Table 7—Voltage distortion limits for medium- and high-voltage power systems	53
Table 8—Typical capacitance values for line-to-ground surge capacitors.....	86
Table B.1—Typical capacitor bank rack configurations.....	90
Table B.2—Relation of LOW bus voltage terminal-to-case (TC) to maximum terminal-to-terminal (TT) based on capacitor bank rack configuration	93
Table B.3—Example comparison of terminal-to-case insulation to standard levels.....	94

IEEE Guide for the Application of Shunt Power Capacitors

~~IMPORTANT NOTICE: This standard is not intended to ensure safety, security, health, or environmental protection. Implementers of the standard are responsible for determining appropriate safety, security, environmental, and health practices or regulatory requirements.~~

~~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. Scope

This guide applies to the use of 50 Hz and 60 Hz shunt power capacitors rated 2400 Vac and above, and assemblies of such capacitors. Included are guidelines for the application, protection, and ratings of equipment for the improved safety and reliable ~~reliability in the~~ utilization of shunt power capacitors. The guide is general and intended to be basic and supplemental to specific recommendations of the manufacturer. The guide covers applications that range from simple capacitor unit utilization to complex capacitor bank situations.

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.

Accredited Standards Committee ANSI C2-2012 2007, National Electrical Safety Code[®](NESC[®]).
American National Standards Institute.^{1,2}

IEEE Std 18TM-2002, IEEE Standard for Shunt Power Capacitors.^{3,4}

~~IEEE Std C37.012TM-2005, IEEE Application Guide for Capacitance Current Switching for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.~~

~~IEEE Std C37.48TM-2005, IEEE Guide for Application, Operation, and Maintenance of High Voltage Fuses, Distribution Enclosed Single Pole Air Switches, Fuse Disconnecting Switches, and Accessories.~~

IEEE Std 141TM-1993 (Reaff 1999), IEEE Recommended Practice for Electric Power Distribution for Industrial Plants (*IEEE Red Book*TM).

IEEE Std 519TM-2004, IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems.

IEEE Std 1247TM-2005, IEEE Standard for Interrupter Switches for Alternating Current, Rated Above 1000 Volts.

IEEE Std 1531TM-2003, IEEE Guide for Application and Specification of Harmonic Filters. ~~NFPA 70-2008, National Electrical Code~~[®] (NEC[®]).⁶

¹National Electrical Safety Code and NESC are both registered trademarks and service marks of The Institute of Electrical and Electronics Engineers, Inc.

¹~~The National Electrical Safety Code is available from the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, Piscataway, NJ 08854, USA; and from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.~~

²⁶ The NESC is available from The Institute of Electrical and Electronics Engineers, ~~Inc., 445 Hoes Lane, Piscataway, NJ 08854, USA~~ (~~http~~ <https://standards.ieee.org/>).

³IEEE publications are available from The Institute of Electrical and Electronics Engineers Inc. (<https://standards.ieee.org/>), ~~Service Center, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>).~~

⁴The IEEE standards or products referred to in this clause are trademarks of Institute of Electrical and Electronics Engineers, Inc.

[IEEE Std C37.012™, IEEE Guide for the Application of Capacitance Current Switching for AC High-Voltage Circuit Breakers Above 1000 V.](#)

[IEEE Std C37.016™, IEEE Standard for AC High-Voltage Circuit Switchers rated 15.5 kV through 245 kV.](#)

IEEE Std C37.04™~~-1999~~, IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers.

[IEEE Std](#) [ANSI C37.06™](#), [IEEE](#) ~~-2009, American National~~ Standard for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis—Preferred Ratings and Related Required Capabilities.²

[IEEE Std C37.48™, IEEE Guide and Tutorial for the Application of High-Voltage \(>1000 V\) Fuses and Accessories.](#)

[IEEE Std](#) [ANSI C37.66™](#), [IEEE](#) ~~-2005, American National~~ Standard Requirements for ~~Oil-Filled~~ Capacitor Switches for [AC Alternating-Current](#) Systems [\(1 kV to 38 kV\)](#).

IEEE Std C37.99™~~-2000~~, IEEE Guide for Protection of Shunt Capacitor Banks.

[IEEE Std C37.100.2™-2018, IEEE Standard for Common Requirements for Testing of AC Capacitive Current Switching Devices over 1000 V.](#)

[IEEE Std C57.12.00™, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.](#)

[IEEE Std C57.12.90™, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers.](#)

IEEE Std C62.2™~~-1987~~, IEEE Guide for the Application of Gapped Silicon-Carbide Surge Arresters for Alternating-Current Systems.

IEEE Std C62.22™~~-2009~~, IEEE Guide for the Application of Metal Oxide Surge Arresters for Alternating-Current Systems.

²~~ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.~~

[NFPA 70[®], 2017 Edition, National Electrical Code[®]\(NEC[®]\).⁵](#)

[PES-TR16, Transient Limiting Inductor Applications in Shunt Capacitor Banks.⁶](#)

3. Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary* ~~[Online: Glossary of Terms & Definitions](#)~~ should be [consulted](#) ~~referenced~~ for terms not defined in this clause.⁷

ambient temperature: The temperature of the medium, such as air, water, or earth, into which the heat of the equipment is dissipated.

NOTE 1—For [natural convection cooled](#) ~~self-ventilated~~ equipment, the ambient temperature is the average temperature of the air in the immediate vicinity of the equipment.

NOTE 2—For air- or gas-cooled equipment with forced ventilation or secondary water cooling, the ambient temperature is taken as that of the ingoing air or cooling gas.

NOTE 3—For [natural convection cooled](#) ~~self-ventilated~~ enclosed (including oil-immersed) equipment considered as a complete unit, the ambient temperature is the average temperature of the air outside of the enclosure in the immediate vicinity of the equipment. See 5.7 ~~and Table 1~~ of IEEE Std 18-[2012](#) ~~2002~~.

back-to-back capacitor bank switching (back-to-back switching, back-to-back capacitor switching): Switching a capacitor bank in close enough electrical proximity to one or more other energized capacitor banks and/or cables to significantly influence the inrush current.

⁵[NFPA publications are available from the National Fire Protection Association \(<https://nfpa.org/>\).](#)

⁶[PES Technical Reports are available in the Resource Center at <https://www.ieee-pes.org/>.](#)

⁷[IEEE 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.](#)

~~⁷[The IEEE Standards Dictionary: Glossary of Terms & Definitions is available at <http://chop.ieee.org/>.](#)~~

~~3.3 capacitor bank: An assembly at one location of capacitor(s) and all necessary accessories, such as switching equipment, protective equipment, controls, et cetera, required for a complete operating installation. It may be a collection of components assembled at the operating site or may include one or more pieces of factory assembled equipment.~~

capacitor control: The device required to automatically operate the switching device(s) to energize and de-energize shunt power capacitor banks.

capacitor element: The basic component of a capacitor unit consisting of two electrodes separated by a dielectric.

capacitor equipment: A complete assembly of capacitors, including accessories such as buses, connectors, dischargers, and fuses suitable for connection to a power system.

capacitor line fuse (capacitor group fuse): A fuse applied [in order](#) to disconnect a faulted phase of a capacitor bank from the power system.

capacitor unit: *See:* [power capacitor](#).

externally fused capacitor bank: A capacitor equipment with fuses external to the (power) capacitor units.

filter capacitor: Capacitor(s) utilized with inductors and/or resistors for controlling harmonic voltages and currents in the power system.

fixed capacitor bank: A capacitor bank not designed for automatic operation or frequent switching.

fused capacitor: A capacitor [that has](#) ~~having~~ fuses mounted on its terminals, ~~or~~ inside a terminal enclosure, or inside the capacitor case, for the purpose of interrupting a failed capacitor element, unit, or group.

fuseless capacitor bank: A capacitor bank without any ~~fuses~~, internal or external [fuses, which](#), ~~that~~ is constructed of (parallel) strings of capacitor units. Each string consists of capacitor units connected in series.

geomagnetic disturbance: [A disturbance of the magnetic field of the earth caused by the ejection of plasma from the sun, due to coronal mass ejections \(CME\) and high speed solar wind streams, and its interaction with the earth's magnetic field. The changing magnetic field induces voltages in the loops formed by transmission lines, grounded-wye transformers, and the paths through earth between the transformer neutrals. The changing magnetic field induces the changes in the geoelectric field and the earth and surface potentials, resulting in the flow of geomagnetically induced current \(GIC\).](#)

indoor (prefix): Not suitable for exposure to the weather.

NOTE—For example, an indoor capacitor unit is designed for indoor service or for use in a weatherproof housing.

inrush current: The transient charging current that flows in a capacitor when a capacitor bank is initially connected to a voltage source.

internal fuse: A fuse connected inside a capacitor unit, in series with an element or a group of elements.

internally fused capacitor (unit): A capacitor unit [which](#) ~~that~~ includes internal fuses.

internally fused capacitor bank: A capacitor bank equipment with internally fused capacitor units.

isolated capacitor bank (single capacitor bank): A capacitor bank whose inrush current is limited by the inductance of the source and its own capacitance. Other capacitor banks and cables are not sufficiently coupled to the bank to significantly influence the inrush current.

metal-enclosed (prefix): A capacitor equipment assembly enclosed in a metal enclosure or metal house, usually grounded, to [help minimize](#) ~~prevent~~ accidental contact with live parts. *Syn:* **metal-housed**.

metal-housed (prefix): *See:* **metal-enclosed**.

outrush current: The transient discharge current that flows when an energized capacitor bank is initially connected to a short circuit.

power capacitor (shunt capacitor, capacitor unit): An assembly of dielectric and electrodes in a container (case), with terminals brought out, that is intended to introduce capacitance into an electric power circuit.

NOTE—The abbreviated term “capacitor” or “capacitor unit” is used interchangeably with “power capacitor” throughout this standard.

shunt capacitor bank: An assembly at one location of capacitor(s) and all necessary accessories, such as switching equipment, protective equipment, controls, etc., required for a complete operating installation. It may be a collection of components assembled at the operating site or may include one or more pieces of factory-assembled equipment. A shunt capacitor bank is connected parallel to the system and is not connected in the series power flow. Additionally, shunt capacitors can reduce the reactive current flow and affect the system voltage.

string (string of capacitors) (string of capacitor elements): Capacitors connected in series between two terminals without parallel connection(s).

switched capacitor (switched capacitor bank): A capacitor bank designed for controlled operation and/or frequent switching.

weatherproof: An apparatus is designated as weatherproof, when so constructed, protected, or treated that its successful operation is not interfered with when subjected to adverse weather.

4. Power system considerations

4.1 Capacitor benefits

As power systems become heavily loaded (above surge impedance loading), shunt power capacitors become essential to the reliable operation of the power system. Shunt ~~The~~ capacitors support the system voltage and reduce the reactive current flow through the power system. Shunt power capacitors are required when acceptable system voltages ~~generally~~ cannot be maintained by the generators and transmission system alone. ~~Shunt power capacitors are required.~~

During system contingencies, when parts of the transmission system are unavailable, increased loading on the remaining system causes additional voltage drop. Shunt capacitors are required to support the system voltage during these contingencies. The lack of available shunt capacitors can (and has) [led lead](#) to system voltage collapse.

Most power system loads and delivery apparatus (e.g., motors, lines, and transformers) are inductive in nature and therefore operate at a lagging power factor. When operating at a lagging power factor, power system loads require reactive current from the system, which results in reduced system capacity, increased system losses, and reduced system voltage.

Figure 1 illustrates how the application of shunt power capacitors increases system capacity and reduces system losses by reducing reactive power needs from Q_{r1} to Q_{r2} through the addition of Q_c . As a result, the system load is reduced from S_1 to S_2 as shown in Figure 1.

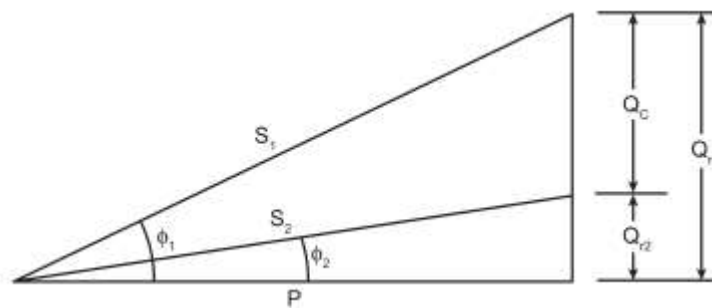


Figure 1—Effect of adding shunt capacitors

Table 1 gives a summary of benefits derived from shunt power capacitors as they apply to transmission and distribution systems. Var support and voltage control are the primary benefits for a transmission system while the distribution system benefits may be more varied depending upon whether the system belongs to a generating utility, a nongenerating utility, or an industrial power user. [Subclauses 4.1.1 through 4.1.5](#) ~~The following subclauses~~ describe each of these benefits in more detail.

Table 1—Summary of benefits of applying shunt power capacitors

Benefits	Transmission system	Distribution system
Voltage support	Primary benefit	Primary benefit
Var support	Primary benefit	Secondary benefit
Increase system capacity	Secondary benefit	Primary benefit
Reduce system power loss	Secondary benefit	Primary benefit
Reduce billing charges	Secondary benefit	Primary benefit

(New)

Benefits	Transmission system	Distribution system
Voltage support	*	*
Var support	*	†

(Deleted)

Benefits	Transmission system	Distribution system
Increase system capacity	†	*
Reduce system power loss	†	*
Reduce billing charges	†	*

(Deleted)

*This is generally a primary benefit

†This is generally a secondary benefit

4.1.1 Voltage support

Applying shunt capacitors to a system results in a voltage rise. This voltage rise is caused by the flow of a capacitor current (or the reduction of inductive current) through the inductive reactance of the system from the point of installation back to the generation. The voltage rise at the capacitor location is approximately equal to the capacitor current I_C times the inductive reactance of the system to the capacitor location X_L . There is a voltage rise present at the capacitor location all the way back to the voltage source.⁷ The magnitude of the voltage rise at any point between is dependent ~~depending~~ on the inductive reactance ~~between the source and the location. In a radial system, there is also an increase in the voltage beyond the capacitor location resulting from the voltage source to that point~~ increase at the capacitor location.

There are a number of formulas that can be used to estimate the voltage rise that capacitors will produce. Based on the capacitor current and the inductive reactance of the system to the capacitor location:

$$\Delta V \approx I_C X_L \quad (1)$$

For systems with a reasonably high X/R ratio, where the short circuit impedance to the capacitor location is about the same as the inductive reactance, the X_L of Equation (1) is the impedance that determines the system short circuit current available at the capacitor location. This short circuit current is useful in estimating the voltage rise. A commonly used estimate is given ~~as follows~~ in Equation (2) as follows:-

$$\Delta V \approx \frac{I_C}{I_{sc}} = \frac{Q_C}{S_{sc}} \quad (2)$$

(New)

$$\Delta V \approx \frac{I_C}{I_{sc}} = \frac{Q_C \text{ kvar}}{S_{sc} \text{ kva}} \quad (2)$$

~~(Deleted)~~

where

ΔV is the percent ~~per-unit~~ voltage rise at the point of the capacitor installation

I_C is the capacitor current in amperes ~~amps~~

I_{SC} is the system short circuit current at the capacitor location in amperes

Q_C is the capacitor three phase reactive power ~~kvar~~ at system voltage in Mvar

S_{SC} is the system three phase short circuit strength ~~kva~~ at the capacitor location in megavolt-amperes (MVA)

NOTE—Equation (2) is a close approximation when $S_{SC} \gg Q_C$. A more accurate approximation for weak systems is $\Delta V \approx Q_C / (S_{SC} - Q_C)$.

Capacitor banks are typically installed on the transmission system at major buses to provide voltage support for a large area. They are also installed at distribution buses and directly on customer delivery buses to provide voltage support to both smaller areas and ~~to~~ individual customers. Capacitor banks installed on distribution lines support voltage along the entire length of line.

Capacitor banks that are installed for voltage support are generally switched on during the peak loading periods or low-voltage conditions, and switched off during light loading periods or high-voltage conditions.

Capacitors have also been used on distribution feeders to keep the feeder voltage constant (acceptable, but low) during substation voltage reduction contingencies. Voltage reduction can decrease feeder power and current during peak load conditions.

4.1.2 Reactive power (var) support

Reactive power (var) support encompasses many of the different benefits of shunt power capacitors, such as improved voltage control and power factor, reduced system losses and reactive power requirements at generators and increased steady-state stability limits. Capacitors are sized and located at transmission and distribution substations to supply reactive power close to the loads or to provide midway support across heavily loaded transmission circuits.

4.1.3 Increased system capacity

Increased system capacity may justify the addition of shunt power capacitors on a distribution system. This is particularly significant when loads supplied by the system are increasing rapidly. The addition of shunt power capacitors reduces the kilovolt-ampere loading on the system, thereby releasing capacity that can then be used to supply future load increases. The optimum economical power factor for a system, with regard to released capacity only, can be estimated by use of Equation (3):

$$PF = \sqrt{1 - \left(\frac{C}{S}\right)^2} \quad (3)$$

where

C is the cost per kvar ~~kilovar~~ of new capacitor bank

S is the cost per kva ~~kilovoltamperes~~ of new system equipment

PF is optimum power factor

Equation (3) compares the cost of capacitor banks to the cost of transformers, regulators, and/or other system equipment, as ~~an~~ alternative means of providing increased system capacity. The graph of Equation (3) ~~the formula~~, the optimum power factor as a function of the cost ratio of the capacitor bank versus other system equipment, is illustrated in Figure 2.

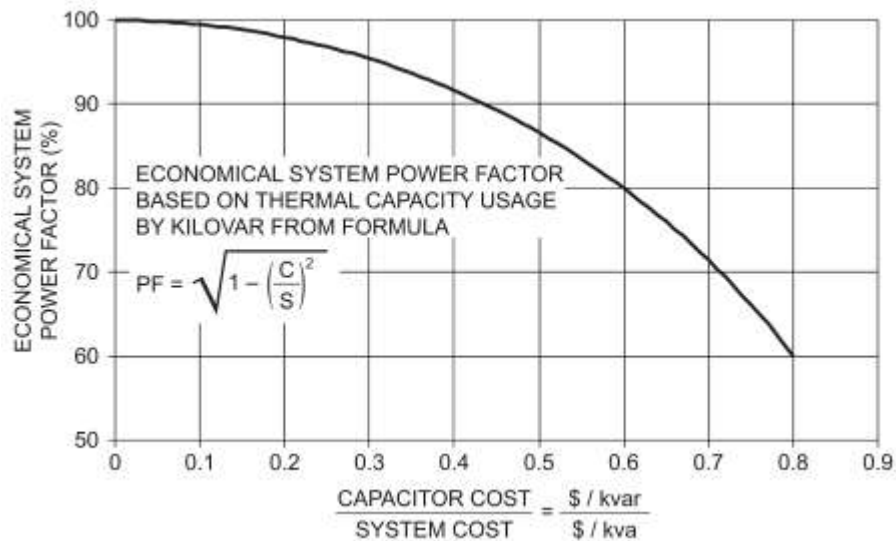


Figure 2—Economical system power factor

The power factor required to release a desired amount of system kilovolt-amperes can be determined by Equation (4):

$$PF_{new} = \frac{PF_{old}}{1 - S_{release} \text{ kva}} \quad (4)$$

(New)

$$PF_{target} = \frac{PF_{existing}}{1 - S_{release}} \quad (4)$$

(Deleted)

where

$PF_{target \text{ new}}$ is the target ~~corrected~~ power factor

$PF_{existing \text{ old}}$ is the existing power factor

$S_{release}$ is the amount of kilovolt-amperes (kVA) to be released (in per unit of existing kilovolt-ampere)

To calculate the capacitive kilovar necessary to correct to a new, higher power factor, ~~one must~~ subtract the inductive kvar of the new (corrected) power factor from the old (existing) power factor. The difference is the amount of capacitive kilovar to be added to the system. Equation (5) is a convenient way of doing this:-

$$Q_C = P_S \left[\tan(\cos^{-1} PF_{\text{existing}}) - \tan(\cos^{-1} PF_{\text{target}}) \right] \quad (5)$$

(New)

~~$$Q_C \text{ kvar} = P_S \text{ kW} [\tan(\cos^{-1} PF_{\text{old}}) - \tan(\cos^{-1} PF_{\text{new}})] \quad (5)$$~~

(Deleted)

where

P_S is the system ~~kilowatt~~ load in kilowatts (kW)

Q_C is the amount of capacitive kilovar to be added

Table 2 is a chart that may be used in place of Equation (5) ~~this formula~~. Simply find the row corresponding to the existing system power factor and the column corresponding to the corrected new power factor. The number located where these intersect should be multiplied by the system kilowatt load to arrive at the additional ~~total~~ capacitive kilovar necessary to correct to the new power factor.

Table 2—Power factor correction kilowatt multipliers

	Corrected power factor																					
	0.80	0.81	0.82	0.83	0.84	0.85	0.86	0.87	0.88	0.89	0.90	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.00	
Existing power factor	0.50	0.982	1.008	1.034	1.060	1.086	1.112	1.139	1.165	1.192	1.220	1.248	1.276	1.306	1.337	1.369	1.403	1.440	1.481	1.529	1.590	1.732
	0.51	0.937	0.963	0.989	1.015	1.041	1.067	1.093	1.120	1.147	1.174	1.202	1.231	1.261	1.291	1.324	1.358	1.395	1.436	1.484	1.544	1.687
	0.52	0.893	0.919	0.945	0.971	0.997	1.023	1.049	1.076	1.103	1.130	1.158	1.187	1.217	1.247	1.280	1.314	1.351	1.392	1.440	1.500	1.643
	0.53	0.850	0.876	0.902	0.928	0.954	0.980	1.007	1.033	1.060	1.088	1.116	1.144	1.174	1.205	1.237	1.271	1.308	1.349	1.397	1.458	1.600
	0.54	0.809	0.835	0.861	0.887	0.913	0.939	0.965	0.992	1.019	1.046	1.074	1.103	1.133	1.163	1.196	1.230	1.267	1.308	1.356	1.416	1.559
	0.55	0.768	0.794	0.820	0.846	0.873	0.899	0.925	0.952	0.979	1.006	1.034	1.063	1.092	1.123	1.156	1.190	1.227	1.268	1.315	1.376	1.518
	0.56	0.729	0.755	0.781	0.807	0.834	0.860	0.886	0.913	0.940	0.967	0.995	1.024	1.053	1.084	1.116	1.151	1.188	1.229	1.276	1.337	1.479
	0.57	0.691	0.717	0.743	0.769	0.796	0.822	0.848	0.875	0.902	0.929	0.957	0.986	1.015	1.046	1.079	1.113	1.150	1.191	1.238	1.299	1.441
	0.58	0.655	0.681	0.707	0.733	0.759	0.785	0.811	0.838	0.865	0.892	0.920	0.949	0.979	1.009	1.042	1.076	1.113	1.154	1.201	1.262	1.405
	0.59	0.618	0.644	0.670	0.696	0.723	0.749	0.775	0.802	0.829	0.856	0.884	0.913	0.942	0.973	1.006	1.040	1.077	1.118	1.165	1.226	1.368
	0.60	0.583	0.609	0.635	0.661	0.687	0.714	0.740	0.767	0.794	0.821	0.849	0.878	0.907	0.938	0.970	1.005	1.042	1.083	1.130	1.191	1.333
	0.61	0.549	0.575	0.601	0.627	0.653	0.679	0.706	0.732	0.759	0.787	0.815	0.843	0.873	0.904	0.936	0.970	1.007	1.048	1.096	1.157	1.299
	0.62	0.515	0.541	0.567	0.593	0.620	0.646	0.672	0.699	0.726	0.753	0.781	0.810	0.839	0.870	0.903	0.937	0.974	1.015	1.062	1.123	1.265
	0.63	0.483	0.509	0.535	0.561	0.587	0.613	0.639	0.666	0.693	0.720	0.748	0.777	0.807	0.837	0.870	0.904	0.941	0.982	1.030	1.090	1.233
	0.64	0.451	0.477	0.503	0.529	0.555	0.581	0.607	0.634	0.661	0.688	0.716	0.745	0.775	0.805	0.838	0.872	0.909	0.950	0.998	1.058	1.201
	0.65	0.419	0.445	0.471	0.497	0.523	0.549	0.576	0.602	0.629	0.657	0.685	0.714	0.743	0.774	0.806	0.840	0.877	0.919	0.966	1.027	1.169
	0.66	0.388	0.414	0.440	0.466	0.492	0.519	0.545	0.572	0.599	0.626	0.654	0.683	0.712	0.743	0.775	0.810	0.847	0.888	0.935	0.996	1.138
	0.67	0.358	0.384	0.410	0.436	0.462	0.488	0.515	0.541	0.568	0.596	0.624	0.652	0.682	0.713	0.745	0.779	0.816	0.857	0.905	0.966	1.108
	0.68	0.328	0.354	0.380	0.406	0.432	0.459	0.485	0.512	0.539	0.566	0.594	0.623	0.652	0.683	0.715	0.750	0.787	0.828	0.875	0.936	1.078
	0.69	0.299	0.325	0.351	0.377	0.403	0.429	0.456	0.482	0.509	0.537	0.565	0.593	0.623	0.654	0.686	0.720	0.757	0.798	0.846	0.907	1.049
	0.70	0.270	0.296	0.322	0.348	0.374	0.400	0.427	0.453	0.480	0.508	0.536	0.565	0.594	0.625	0.657	0.692	0.729	0.770	0.817	0.878	1.020
	0.71	0.242	0.268	0.294	0.320	0.346	0.372	0.398	0.425	0.452	0.480	0.508	0.536	0.566	0.597	0.629	0.663	0.700	0.741	0.789	0.849	0.992
	0.72	0.214	0.240	0.266	0.292	0.318	0.344	0.370	0.397	0.424	0.452	0.480	0.508	0.538	0.569	0.601	0.635	0.672	0.713	0.761	0.821	0.964
	0.73	0.186	0.212	0.238	0.264	0.290	0.316	0.343	0.370	0.396	0.424	0.452	0.481	0.510	0.541	0.573	0.608	0.645	0.686	0.733	0.794	0.936
	0.74	0.159	0.185	0.211	0.237	0.263	0.289	0.316	0.342	0.369	0.397	0.425	0.453	0.483	0.514	0.546	0.580	0.617	0.658	0.706	0.766	0.909
	0.75	0.132	0.158	0.184	0.210	0.236	0.262	0.289	0.315	0.342	0.370	0.398	0.426	0.456	0.487	0.519	0.553	0.590	0.631	0.679	0.739	0.882
	0.76	0.105	0.131	0.157	0.183	0.209	0.235	0.262	0.288	0.315	0.343	0.371	0.400	0.429	0.460	0.492	0.526	0.563	0.605	0.652	0.713	0.855

AVA Doc
Docum

Full document details: IEEE 1036-2020

4.1.4 Reduced system power losses

On some distribution and transmission systems, a significant reduction in losses may be achieved by the installation of shunt power capacitors.

The installation of shunt power capacitors reduces current flow through the system from the point of the capacitor installation back to the generation. Since power losses are directly proportional to the square of the current, a reduction of current flow results in a much greater reduction of power losses. Capacitors are often installed as close to the load as possible for this reason.

The ratio of the system losses associated with the local load, with and without capacitors installed, can be estimated with Equation (6), which assumes constant kilowatt and constant voltage at the load with no harmonics present (the effect of harmonics is addressed in Clause 7).

$$\text{loss ratio} = \frac{\text{loss with capacitors}}{\text{loss without capacitors}} = \left(\frac{PF_{\text{existing}}}{PF_{\text{target}}} \right)^2 \quad (6)$$

(New)

$$\begin{aligned} \text{loss ratio} &= \frac{\text{loss with capacitors}}{\text{loss without capacitors}} \\ &= \left(\frac{PF_{\text{old}}}{PF_{\text{new}}} \right)^2 \end{aligned} \quad (6)$$

(Deleted)

where

$PF_{\text{existing old}}$ is the existing power factor

$PF_{\text{target new}}$ is the target corrected power factor

This reduction in losses reduces ~~will reduce~~ the generation fuel requirement to supply these losses as well as the system equipment costs to supply the losses at peak load.

4.1.5 Reduced billing charges

A number of utilities use some form of kilovolt-ampere billing for their large customers (e.g., municipal utilities and large industrial customers). Since the application of shunt power capacitors beyond the meter can result in a reduced kilovolt-ampere loading, this can result in reduced billing charges.

The kilovolt-ampere billing charge may be calculated in many different ways, including the following:

- a) A fixed charge for each kilowatt plus a fixed charge for each kilovar.
- b) A certain amount for each kilowatt at or above a certain power factor, with additional charges made for each kilovar in excess of that required by a minimum power factor.
- c) A charge per kilowatt demand multiplied by a factor that increases with decreasing power factor.
- d) A fixed charge per peak kilovolt-ampere.

4.2 Size and number of capacitor banks

The shunt capacitance requirements are determined for a power system by modeling the system for various contingencies and determining the capacitors required to maintain acceptable system voltage. For specific applications, capacitors are applied to optimize the benefits described in 4.1 for a given set of system requirements. Distribution capacitors are often sized to supply the reactive power requirements of the load plus the reactive requirements of the transformer bank(s) at peak load. This provides for power factor correction to unity at the high side of the transformers and effective operation of the transmission or subtransmission system. Transmission substation capacitors are often sized and located based on load flow and stability studies of the transmission network. ~~The~~ Capacitors [help](#) minimize system losses, increase the system voltage, and increase stability margins. After the capacitor requirements are known, the individual capacitor bank [Mvar](#) ~~megavar~~ sizes and number of steps are determined. To take advantage of the economies associated with standardized equipment, other limitations may influence the maximum and minimum capacitor bank sizes used.

4.2.1 Maximum size

The maximum capacitor bank size is influenced by the following factors:

- a) Change in system voltage upon capacitor bank switching.
- b) Switchgear continuous current limitations.

When a capacitor bank is energized or de-energized, the fundamental system voltage increases or decreases, respectively. In order to have a minimal effect upon customer loads, this voltage change is often limited to a value in the range of 2% to 3% [for distribution systems, and less than or equal to 5% for transmission systems](#). This voltage change (ΔV) can be estimated by Equation (7):

$$\Delta V = \left(\frac{Q_C \text{ Mvar}}{S_{sc} \text{ Mva}} \right) \times 100\% \quad (7)$$

(New)

$$\Delta V = \left(\frac{Q_C}{S_{sc}} \right) \times 100\% \quad (7)$$

(Deleted)

where

ΔV is the voltage change as a percentage of the fundamental frequency rms system voltage

Q_C ~~Mvar~~ is the ~~Mvar~~-size of the capacitor bank [in Mvar](#)

SSC ~~Mva~~ is the [symmetrical, available](#) three-phase short-circuit ~~MVA~~-at the capacitor bank location [in megavolt-amperes \(MVA\)](#)

The continuous-current rating of switchgear used for capacitor bank switching may be a factor in choosing the capacitor bank size. The rating is usually determined by multiplying the nominal capacitor current by 1.25 for ungrounded capacitor banks and by 1.35 for grounded-wye capacitor banks [\(due to additional harmonic consideration for grounded applications\)](#). Where currents with substantial harmonic components are likely to be encountered, provision should be made for additional current-carrying capacity in the circuit breakers, fuses, and other auxiliary devices. More detailed information is available in IEEE Std [18](#), IEEE Std C37.04, [IEEE Std 1999](#), [ANSI C37.06-2009](#), IEEE Std C37.012, [IEEE Std 2005](#), [ANSI C37.66-2005](#), and IEEE Std 1247-2005.

4.2.2 Minimum size

While there is no absolute minimum capacitor bank size, the practical minimum capacitor bank size may be influenced by the following factors:

- a) The type of capacitor bank used: externally fused, internally fused, fuseless, etc.
- b) The easily available ratings of capacitor units
- c) Capacitor bank unbalance considerations
- d) Fuse performance and/or coordination
- e) The cost of the required switchgear and protection

The principal concerns when installing a small capacitor bank are the proper performance of the proposed capacitor bank (including the protection) and the cost of the installation. Under some circumstances, the cost of the installation may be reduced by installing the capacitor on a lower voltage bus in the same substation.

4.3 Control considerations

Capacitor banks are either switched or fixed, i.e., not switched. Generally, in determining the type of capacitor bank required, consider the following guidelines:

- a) Fixed capacitor banks are sized for minimum load conditions.
- b) Switched capacitor banks are designed for load levels above the minimum condition up to peak load.

The curve shown in Figure 3, which can be determined by a recording kilovar meter or calculated using kilowatt and power factor measurements, illustrates a typical kilovar demand over a 24 ~~h~~ ~~hour~~ period. In this figure, the fixed capacitor banks satisfy the base load requirements, and the switched capacitor banks compensate for the inductive kilovar peak during the heavier load periods.

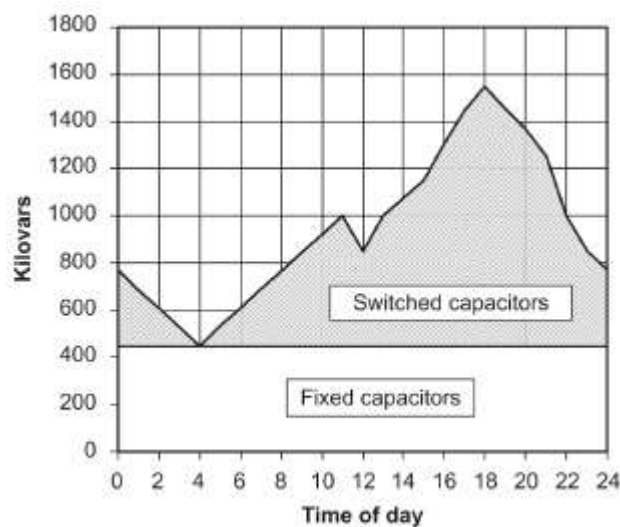


Figure 3—Typical kilovar demand profile for switched and fixed capacitor banks ~~Switching capacitors~~

In the operation of a power system, however, it is often desirable to use existing loads to hold down the system voltage during periods of light load (compensate for the excess capacitance of the transmission system). In this case, some of the “fixed capacitors” of this figure should actually be switched to allow the load to hold down the system voltage. In other cases, where excess capacitance can be tolerated during periods of light load, it may be less expensive to leave some of the “switched capacitors” unswitched. In more general terms, the “fixed capacitors” are those which ~~that~~ can be left on the system all of the time, and the “switched capacitors” are those which ~~that~~ are switched to meet system operating requirements or a billing tariff.

5. Capacitor ~~rating ratings~~, capabilities, and service conditions

Capacitor ratings and service conditions are specified in IEEE Std 18-~~2002~~. Application guidelines for transient, short time, and contingency capacitor overvoltages and overcurrents are given in this document. Key aspects of the ratings and service conditions are provided in this clause for easy reference. Short time “momentary” capabilities of capacitors are also explained in this clause.

The life of a capacitor is shortened by overstressing, overheating, chemical change, physical damage, or repeated temperature changes. Life to 90% survival ~~should~~ ~~might~~ exceed 20 years when capacitors are applied according to the guidelines of this application guide.

Shunt capacitors cause a voltage rise at the point where they are located and are therefore more likely to operate at ~~voltages higher overvoltages~~ than other types of equipment. Recognizing this factor, the nameplate voltage ratings of capacitors and permissible overvoltage operation are generally higher than those established for motors and most other equipment (see 9.4 for more information).

~~5.2.2.1 Limitations on continuous operation~~

Capacitors are ~~designed~~ ~~intended~~ to be operated continuously at or below their rated voltage ~~and frequency~~.

Capacitors ~~shall be~~ ~~are~~ capable of ~~continuous~~-operation under contingency system condition and ~~capacitor~~-bank conditions, such as failed elements, provided that none of the following limitations are exceeded. This operation is not intended to be a permanent condition.:

- a) 110% of rated rms voltage~~;~~
- b) 120% of rated ~~peak~~ ~~crest~~ voltage, i.e., ~~peak~~ ~~crest~~ voltage not exceeding $1.2 \times 2 \times$ rated rms voltage, including harmonics, but excluding transients ~~(see Clause 7 for more on harmonics)~~;
- c) 135% of nominal rms current based on rated kvar and rated voltage, ~~including fundamental and harmonic currents (see Clause 7 for more on harmonics)~~;
- d) 135% of rated kvar ~~(see 5.2.2)~~;

The continuous and short time overvoltage capabilities (without loss of life) of any series element of a capacitor unit (at designed frequency) shall be considered to be included in ~~its share of~~ the designed total capacitor unit voltage rating capability. (In internally fused capacitor units, capacitor elements in parallel with blown fuses sometimes are operated beyond their normal capability, accepting the possibility of shortened life. Similarly, in some externally fused capacitor banks and in some capacitor banks without capacitor unit fuses, capacitor units with failed elements are allowed to remain in service with the remaining healthy capacitor elements in those capacitor units operating above their normal capability, accepting the possibility of shortened life.) Capacitor units without failed elements are intended to be operated within guideline ~~the guidelines~~ a) through guideline d) above ~~shown previously~~.

5.1 Standard ratings

The standard ratings established in IEEE Std 18-~~2002~~ are as follows:

- a) Voltage, rms (terminal-to-terminal)
- b) Terminal(s)-to-case (or ground) insulation class
- c) Reactive power
- d) Number of phases
- e) Frequency

Typical power capacitor ratings are provided in Table 3.

Table 3—Typical power capacitor voltage and reactive power ratings

Volts, rms (terminal-to-terminal)	kvar	Number of phases	BIL kV*
2 400	50, 100, 150, 200, 300, and 400	1 and 3	75, 95, 125, 150
2 770	50, 100, 150, 200, 300, 400, and 500	1 and 3	75, 95, 125, 150
4 160, 4 800	50, 100, 150, 200, 300, 400, 500, and 600	1 and 3	75, 95, 125, 150, and 200
6 640, 7 200, 7 620, 7 960, 8 320, 9 540, 9 960, 11 400, 12 470, 13 280, 13 800, 14 400	50, 100, 150, 200, 300, 400, 500, 600, 700, and 800	1	95, 125, 150, and 200

(New)

Table 3—Typical power capacitor voltage and reactive power ratings

(continued)

Volts, rms (terminal-to-terminal)	kvar	Number of phases	BIL kV ^a
15 125	50, 100, 150, 200, 300, 400, 500, 600, 700, and 800	1	125, 150, and 200
19 920	100, 150, 200, 300, 400, 500, 600, 700, and 800	1	125, 150, and 200
20 800, 21 600, 22 800	100, 150, 200, 300, 400, 500, 600, 700, and 800	1	150 and 200

(New)

^aSee IEEE Std 18-~~2002~~ for impulse test specifications

NOTE—The user should consider access to the installation, maintenance tools, and personnel restrictions related to the size and weight of the capacitor unit when specifying a specific capacitor size.

5.1.1 **Tolerance** ~~Tolerances~~ in **capacitance** ~~ratings~~

Older capacitors may have tolerances as high as ~~−0%~~ to +15% for capacitance of individual capacitor units at 25 °C uniform case and internal temperature. Beginning with the 2002 edition, capacitors built to IEEE Std 18 have a tolerance of ~~−0%~~ to +10% at 25 °C.

Temperature affects ~~will-affect~~ capacitance measurements. Therefore, the capacitance of capacitor units that are much colder or much warmer than 25 °C may measure outside the rated tolerance without having failed elements.

NOTE—Certain applications may require a tighter tolerance of the measured capacitance. The user may specify alternate tolerance requirements based on the specific application.

5.1.2 Voltage rating

Typical capacitor unit voltage ratings are summarized in Table 3. The voltage rating is the maximum voltage the capacitor can continuously withstand safely without the loss of expected service life. The capacitor unit can withstand voltages higher than rated voltage for contingencies at the expense of shortening its life expectancy.

NOTE—The reduction of capacitor life is an exponential function of the overvoltage the capacitor is exposed to and even a small overvoltage (less than 10%) still results in significant loss of life.

5.1.3 ~~Voltage and~~ Reactive power ratings

Typical ~~voltage and~~ reactive power ratings are summarized in Table 3.

5.2.2 ~~Continuous operation~~

Capacitors are suitable for continuous operation at 135% of rated reactive power. This maximum reactive power includes the following factors, the combined effects not exceeding 135%:

- a) Reactive power due to voltage in excess of nameplate rating at fundamental frequency but within the permissible voltage limitations described in [Clause 5.2.2.1](#).
- b) Reactive power due to harmonic voltages superimposed on the fundamental frequency.
- c) Reactive power in excess of nameplate rating due to manufacturing tolerance within the limits specified in 5.1.1.

The reactive power output can be calculated as: ~~shown in Equation (8).~~

$$Q_{OP} = (2\pi fC) V_A^2 \quad (8)$$

[\(New\)](#)

$$Q_{OP} = \frac{(2\pi fC) V_A^2}{1000} \quad (8)$$

~~(Deleted)~~

where

Q_{OP} is the operating reactive power of the capacitor in [kvar](#) ~~kilovoltamperes reactive~~

V_A is the applied voltage in [kilovolts](#) ~~volts~~

f is the supply frequency in hertz

C is the capacitance of the capacitor in [microfarads](#) ~~farads~~

The reactive power output will vary according to the actual applied voltage, which may be different than the rated voltage. The operating kvar can also be calculated as: ~~shown in Equation (9).~~

$$Q_{OP} = Q_R \left(\frac{V_A}{V_R} \right)^2 \quad (9)$$

[\(New\)](#)

$$Q_{OP} \text{ kvar} = Q_R \text{ kvar} \left(\frac{V_A}{V_R} \right)^2 \quad (9)$$

~~(Deleted)~~

where

Q_{OP} is the operating reactive power of the capacitor in [kvar](#) ~~kilovoltamperes reactive~~

Q_R is the rated reactive power of the capacitor [in kvar](#)

V_A is the applied voltage

V_R is the rated voltage

5.1.4 Insulation classes

The standard basic impulse insulation levels (BIL) of capacitor units are given in Table 3.

Capacitors may be used on circuits of higher voltage than the terminal-to-case insulation class, provided the cases are supported on external insulation suitable for the circuit voltage and provided the terminal-to-terminal voltage limits are not exceeded.

5.1.5 Frequency

Power capacitors are designed for operation at the device's rated nominal frequency of either 50 Hz or 60 Hz. When capacitors are operated at frequencies lower than rated, both the reactive power and the capacitive current are reduced in direct proportion to the operating frequency as shown in [the following equations: Equation \(10\) and Equation \(11\)](#).

$$Q_{OP} = \left(\frac{f_{OP}}{f_R} \right) Q_R \quad (10)$$

(New)

$$Q_{OP} \text{ kvar} = \left(\frac{f_{OP}}{f_R} \right) Q_R \text{ kvar} \quad (10)$$

(Deleted)

$$I_{OP} = I_{NOM} \left(\frac{f_{OP}}{f_R} \right) \quad (11)$$

where

Q_{OP} is the operating reactive power of the capacitor [in](#) kvar

Q_R is the rated reactive power of the capacitor [in](#) kvar

I_{OP} is the capacitive current at the applied frequency and rated voltage [in amperes](#)

I_{NOM} is the capacitive current at the rated frequency and rated voltage [in amperes](#)

f_{OP} is the frequency at which the capacitor unit is to be applied [in hertz](#)

f_R is the rated frequency of the capacitor unit [in hertz](#)

5.2 Related capabilities

5.2.1 Operating and ambient temperatures

Capacitors are designed for switched or continuous operation in outdoor locations with unrestricted ventilation and direct sunlight under the maximum ambient temperatures for each mounting arrangement shown in Table 4.

Table 4—Maximum ambient

Mounting arrangement	Maximum ambient air temperature, °C ^a
Isolated capacitor	46
Single row of capacitors	46
Multiple rows and tiers of capacitors	40
Metal-enclosed or housed equipment	40

^aThe arithmetic average of the four highest hourly readings during the hottest day expected at the capacitor location

For applications at temperatures higher than indicated in Table 4, consult the capacitor manufacturer.

5.2.1.1 Minimum ambient

Capacitors are designed for continuous operation and switching operations at temperatures not lower than -40°C . The capacitor manufacturer should be consulted for operation below -40°C .

5.2.1.2 Effect of temperature

It is essential that consideration be given to the arrangement of capacitors and complete equipment as an installation to provide adequate ventilation and dissipation of heat. Capacitors are designed to operate at a lower temperature rise than most other types of apparatus for the following specific reasons:

- Unlike most other power apparatus, shunt capacitors (whether unswitched or switched) normally operate for relatively long periods of time at full load and, therefore, do not benefit from the lower average temperature rise characteristic of typical daily load cycles.
- Capacitors are designed to operate at comparatively high dielectric stresses. The combination of these stresses with operation at high temperature for extensive periods of time will result in gradual deterioration and shortened life.

5.2.2 Design mounting considerations

Capacitor ratings are based on maximum ambient temperatures with an allowance for heat dissipation by radiation and convection. The arrangement and mounting of capacitors and the conditions of installations will affect the heat dissipation and thereby limit the ambient temperature in which capacitors may be operated. Capacitors and capacitor equipment operating outdoors in direct sunlight and with unrestricted ventilation will normally operate with lower temperature rise than those operating indoors in still air. The following points are important in relating the operating temperature of a capacitor to the conditions of installation.⚠

- An individual non-enclosed capacitor, such as one that is mounted on an outdoor pole, will dissipate heat with the least temperature rise (the heat dissipation being approximately 45% by radiation and 55% by convection).
- The mounting of capacitors in rows side by side or in tiers, or both, increases the temperature rise because of heating of the air stream and because of reduced radiation.
- The enclosing of capacitors in a housing or room without forced air ventilation increases the temperature rise because of reduced radiation and restriction of the natural circulation of air.
- Capacitors subjected to radiation from the sun or from any surface, the temperature of which is above the ambient, show a higher temperature rise.

5.2.3 Short duration ~~Momentary~~ capabilities

Capacitors are capable of withstanding with full-life expectancy switching transients having peak voltages up to $2\sqrt{2}$ times rated rms voltage and other transient disturbances inherent in the operation of power systems.

Capacitors may be subjected to both high voltage and high current under certain conditions associated with switching. The magnitude of the permissible current and voltage peaks depends on the frequency of occurrence. In the case of a frequently switched capacitor, current and voltage peaks should ~~must~~ be held to relatively low values. Comparatively high values may be tolerated on a capacitor bank switched infrequently. Guidance ~~Figure 4 through Figure 6 provide a guide~~ for the evaluation of service conditions relating to ~~from the standpoint of~~ peak currents and peak voltages ~~are shown in Figure 4, Table 5, and Figure 5~~ ~~voltage~~.

The capabilities indicated in these figures may be increased, upon recommendation by the manufacturer, when fewer overvoltages are expected or when less severe temperature conditions exist.

5.2.3.1 Momentary power frequency overvoltage and duration

A capacitor, tested in accordance with IEEE Std 18-~~2002~~ may reasonably be expected to withstand, during normal service life, a combined total of 300 applications of power frequency terminal-to-terminal overvoltages without superimposed transients or harmonic content, of the magnitudes and durations shown in Figure 4.

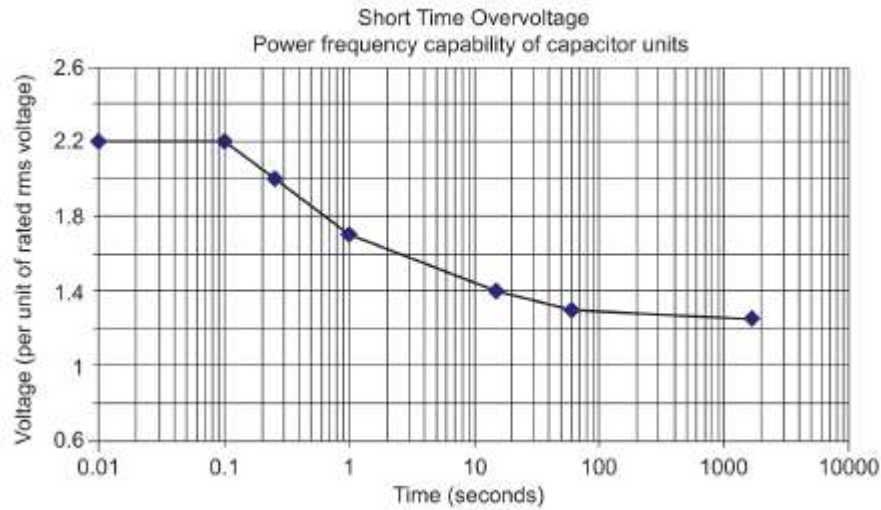


Figure 4—Maximum contingency power frequency overvoltage capability of capacitor units

NOTE—Figure 4 is based on straight line segments between the following points on semi-log coordinates: (0.01, 2.2), (0.1, 2.2), (0.25, 2.0), (1.0, 1.7), (15.0, 1.4), (60, 1.3), and (1800, 1.25).

In using Figure 4, the overvoltage capability is for the capacitor unit, not the capacitor bank. Evaluation of capacitor unit overvoltage exposure should include allowance for any [operating conditions and](#) voltage unbalance in the capacitor bank.

Overvoltages may cause localized damaging discharges (partial discharge) in a capacitor unit. Trapped charges and gas generated in the first half cycle make the discharge more severe in the second half cycle. The accumulation of damage makes the severity of the overvoltage event increase with the time of the event. When the overvoltage is eliminated, the trapped charges and accumulated gas tend to dissipate and be absorbed; [improving](#) ~~This improves~~ the dielectric capability of the capacitor from what it was at the end of the overvoltage event.

The time axis of Figure 4 indicates the maximum time for a single event. Capacitor unit damage tends to escalate during an event, so that damage is happening more rapidly at the end of the event than at the beginning. Two continuous seconds at 1.73 per unit is much more severe than two separate events of one second ~~1-s~~ each, with a time in between to allow for localized cooling, absorption of ~~corona-gasses~~-accumulated gasses ~~gas~~, etc. The curve should not be used to estimate the effect of contingency overvoltage events exceeding the maximum time indicated by the curve.

For event times shorter than those indicated by the curve, the times of the individual events can be accumulated to estimate the effect of the shorter events. For example, ten 1.73 per unit events of 0.1 s each (shorter than the allowable 1 s ~~one-second~~ limit of the curve) would create equal or less damage to the capacitor unit than one 1.73 per unit event of 1 s duration.

5.2.3.2 Transient overcurrent

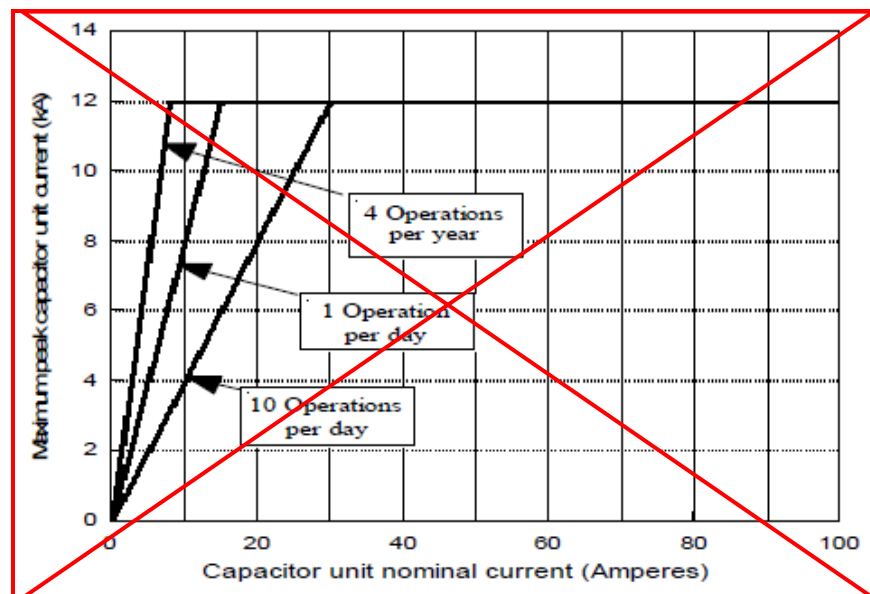
A capacitor unit may reasonably be expected to withstand transient currents inherent in the operation of power systems. These include infrequent high lightning currents and discharge currents to nearby faults. Table 5 provides recommended limits on the peak capacitor current based on kvar and voltage rating of the capacitor unit.

Table 5—Capacitor peak transient current capability

kvar rating	Voltage rating	Frequent switching and back-to-back	Seasonally switched	Close in faults
		>100 000 events	<10 000 events	100 events
50–100	Any	10 kA	11 kA	25 kA
101–200	>8 kV	10 kA	11 kA	25 kA
101–200	<8 kV	15 kA	16.5 kA	37 kA
201–300	>8 kV	15 kA	16.5 kA	37 kA
201–00	<8 kV	20 kA	22 kA	50 kA
>300	All	20 kA	22 kA	50 kA
NOTE—This table does not apply to internally fused capacitors. Typical recommendation is not to exceed 100 times nominal capacitor unit current for internally fused applications.				

(New)

For frequently switched banks (switched daily or greater) and for frequent back-to-back capacitor bank-switching, the peak capacitor unit current should be held to a lower than the 100 000 value. For seasonally switched bank that are not switched daily the 10 000 event limit should be observed. The 100 event limit should be followed for close as indicated in faults and other infrequent high current transients Figure-5. (The capacitor bank current is the capacitor unit current times the number of capacitor units or strings in parallel.) Other equipment such as fuses, circuit breakers, and protection and control circuits may require limitation to a lower peak current.



(Deleted)

Figure 5—Transient current capability of capacitor units for regularly occurring transients

NOTE—In Figure 5 these curves are based on straight lines from the origin to 12 kA. The slopes are 1500 times the nominal current for 4 operations per year, 800 times the nominal current for 1 operation per day, and 400 times nominal current for 10 operations per day.

5.2.3.3 Transient overvoltage

A capacitor may reasonably be expected to withstand the transient overvoltages indicated in Figure 5 6.