

IEEE Guide for Application of Shunt Power Capacitors

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

Approved September 17, 1992

IEEE Standards Board

Abstract: Guidelines for the application, protection, and ratings of equipment for the safe and reliable utilization of shunt power capacitors are provided. This guide applies to the use of 50 and 60 Hz shunt power capacitors rated 2400 Vac and above, and assemblies of capacitors. Applications that range from simple unit utilization to complex bank situations are covered.

Keywords: capacitor, power factor correction, shunt power capacitor, voltage control

The Institute of Electrical and Electronics Engineers, Inc.
345 East 47th Street, New York, NY 10017-2394, USA

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ISBN 1-55937-257-5

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Introduction

(This introduction is not a part of IEEE Std 1036-1992, IEEE Guide for Application of Shunt Power Capacitors.)

This application guide was prepared in response to a need created by the increasing use of shunt power capacitor banks at virtually all distribution and transmission voltage levels. Its objective is to provide a basis for reliability and quality in design, application, and protection of shunt capacitor banks. This standard was developed by an IEEE Working Group sponsored by the Capacitor Subcommittee of the Transmission and Distribution Committee of the IEEE Power Engineering Society. At the time it approved this guide, the Capacitor Subcommittee had the following membership:

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The members of the Working Group were as follows:

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F. D. Barrow, Jr.	G. R. Hanks	S. B. Ladd
S. H. Cheng	J. E. Harder	J. A. LaPoint
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IEEE Guide for Application of Shunt Power Capacitors

1. Overview

1.1 Scope

This guide applies to the use of 50 and 60 Hz shunt power capacitors rated 2400 Vac and above, and assemblies of capacitors. Included are guidelines for the application, protection, and ratings of equipment for the safe and reliable 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 unit utilization to complex bank situations.

1.2 References

This application guide shall be used in conjunction with the following publications. When the following standards are superseded by an approved revision, the revision shall apply:

ANSI C2-1990, National Electrical Safety Code.¹

ANSI C37.06-1987, American National Standard for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis—Preferred Ratings and Related Required Capabilities.²

ANSI/NFPA 70-1993, National Electrical Code.³

IEEE Std C37.04-1979 (Reaff 1988), IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis (ANSI).⁴

IEEE Std C37.012-1979 (Reaff 1988), IEEE Application Guide for Capacitance Current Switching for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis (ANSI).

IEEE Std C37.99-1990, IEEE Guide for Protection of Shunt Capacitor Banks (ANSI).

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

IEEE Std 18-1992, IEEE Standard for Shunt Power Capacitors.

IEEE Std 100-1992, The New IEEE Standard Dictionary of Electrical and Electronics Terms.

IEEE Std 141-1986, IEEE Recommended Practice for Electric Power Distribution for Industrial Plants (IEEE Red Book) (ANSI).

¹The National Electrical Safety Code is available from the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA; and from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

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

³NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA.

⁴IEEE publications are available from the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

IEEE Std 519-1992, IEEE Guide for Harmonic Control and Reactive Compensation of Static Power Converters.

1.3 Definitions

1.3.1 back-to-back switching. The switching of a capacitor bank that is connected in parallel with one or more other capacitor banks.

1.3.2 capacitor control. The device required to automatically switch shunt power capacitor banks.

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

1.3.4 capacitor line fuse (capacitor group fuse). A fuse applied to disconnect a faulted phase of its capacitor bank from a power system.

1.3.5 capacitor outrush current. The high-frequency, high-magnitude current discharge of one or more capacitors into a short circuit—such as into a failed capacitor unit connected in parallel with the discharging units, or into a breaker closing into a fault.

1.3.6 filter capacitors. Capacitors utilized with inductors and/or resistors for controlling harmonic problems in the power system, such as reducing voltage distortion due to large rectifier loads or arc furnaces.

1.3.7 fixed bank. A capacitor bank that does not have a capacitor control and must be manually switched.

1.3.8 individual capacitor fuse. A fuse applied to disconnect an individual faulted capacitor from its bank.

1.3.9 isolated capacitor bank. A capacitor bank that is not in parallel with other capacitor banks.

1.3.10 switched bank. A capacitor bank designed for controlled operation.

2. Purpose of shunt power capacitors

Most power system loads and delivery apparatus (e.g., lines and transformers) are inductive in nature and therefore operate at a lagging power factor. When operating at a lagging power factor, a power system requires additional var flow, 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 var flow. The system load is reduced from kVA_1 to kVA_2 by the addition of the capacitive kilovar, shown in figure 1 as $Ckvar$. 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. The following subclauses describe each of these benefits in more detail.

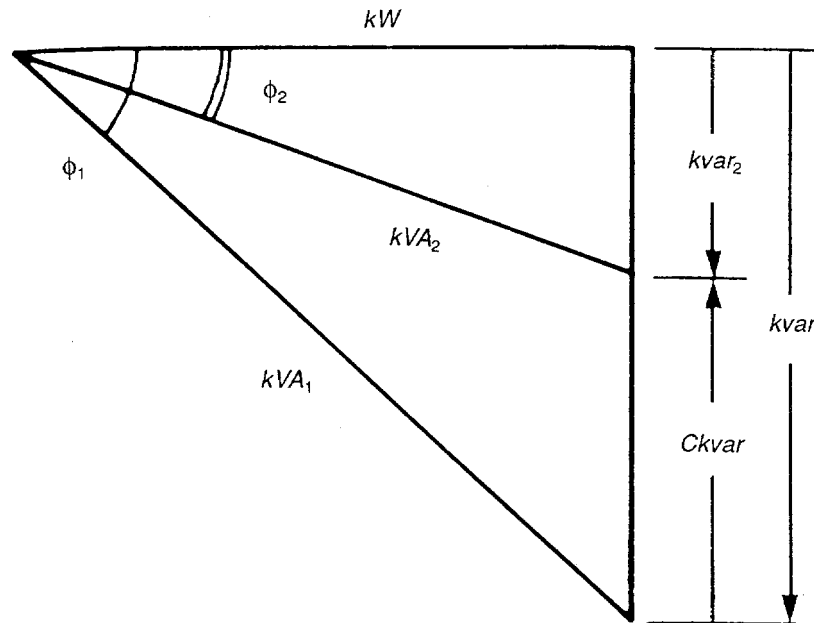


Figure 1—Effect of adding shunt capacitors

Table 1—Summary of benefits of applying shunt power capacitors

Benefits	Transmission system	Distribution system
Var support	*	†
Voltage control	*	*
Increase system capacity	†	*
Reduce system power loss	†	*
Reduce billing charges	—	*

*This is generally a primary benefit.

†This is generally a secondary benefit.

2.1 Var support

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. Capacitive vars are sized and located at transmission and distribution substations to supply vars close to the loads or to provide midway support across heavily loaded transmission circuits.

2.2 Voltage control

Applying capacitors to a system will result in a voltage rise in the system from the point of installation back to the generation. In a system with lagging power factor, this occurs because capacitors may reduce the amount of reactive current being carried in the system, thus decreasing the amount of resistive and reactive voltage drop in the system.

There are a number of formulas that can be used to estimate the voltage rise that capacitors will produce. A commonly used one is as follows:

$$\Delta V = \frac{(kvar)(X_L)}{10(kV)^2}$$

where

- ΔV is the percent voltage rise at the point of the capacitor installation
- kV is the system line-to-line voltage without capacitor in service
- $kvar$ is the three-phase kilovar rating of the capacitor bank
- X_L is the inductive reactance of the system at the point of the capacitor installation, in ohms

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 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.

2.3 Increased system capacity

Increased system capacity is often the most important benefit justifying 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 kilovoltampere 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 the following formula:

$$PF = \sqrt{1 - \left(\frac{C_i}{S_i}\right)^2}$$

where

- C is the cost per kilovar of capacitor bank
- S is the cost per kilovoltamperes of system equipment
- PF is optimum power factor

The formula compares the cost of capacitor banks to the cost of transformers, regulators, etc., as alternative means of providing increased system capacity. The graph of 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.

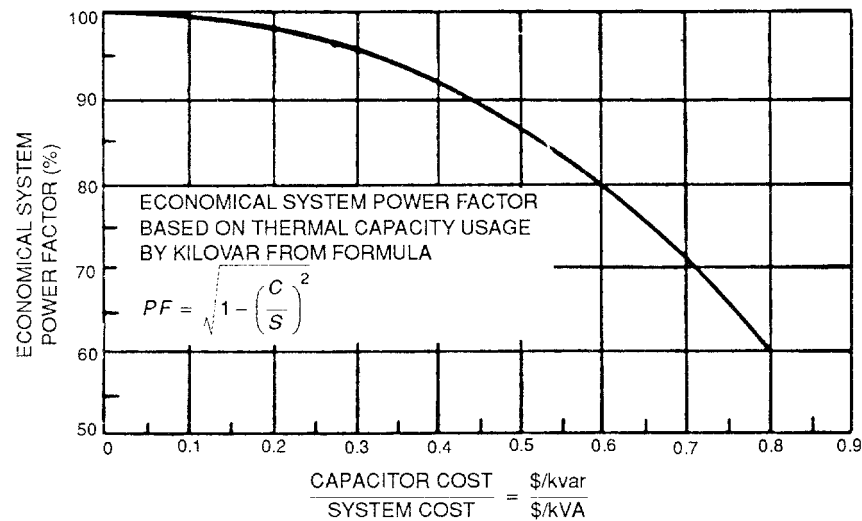


Figure 2—Economical system power factor

The power factor required to release a desired amount of system kilovoltamperes can be determined by the following formula:

$$PF_{\text{new}} = \frac{PF_{\text{old}}}{1 - kVA_{\text{release}}}$$

where

PF_{new} is the corrected power factor

PF_{old} is the existing power factor

kVA_{release} is the amount of kilovoltamperes to be released (in per unit of existing kilovoltamperes)

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. The following formula is a convenient way of doing this:

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

where

kW is the system kilowatt load

$kvar$ is the amount of capacitive kilovar to be added

Table 2 is a chart that may be used in place of 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 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	1.0
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	1.589	1.732
0.51	0.937	0.962	0.989	1.015	1.041	1.067	1.094	1.120	1.147	1.175	1.203	1.231	1.261	1.292	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	1.050	1.076	1.103	1.131	1.159	1.187	1.217	1.248	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	1.457	1.600
0.54	0.809	0.835	0.861	0.887	0.913	0.939	0.966	0.992	1.019	1.047	1.075	1.103	1.133	1.164	1.196	1.230	1.267	1.308	1.356	1.416	1.559
0.55	0.769	0.795	0.821	0.847	0.873	0.899	0.926	0.952	0.979	1.007	1.035	1.063	1.093	1.124	1.156	1.190	1.227	1.268	1.316	1.376	1.519
0.56	0.730	0.756	0.782	0.808	0.834	0.860	0.887	0.913	0.940	0.968	0.996	1.024	1.054	1.085	1.117	1.151	1.188	1.229	1.277	1.337	1.480
0.57	0.692	0.718	0.744	0.770	0.796	0.822	0.849	0.875	0.902	0.930	0.958	0.986	1.016	1.047	1.079	1.113	1.150	1.191	1.239	1.299	1.442
0.58	0.655	0.681	0.707	0.733	0.759	0.785	0.812	0.838	0.865	0.893	0.921	0.949	0.979	1.010	1.042	1.076	1.113	1.154	1.202	1.262	1.405
0.59	0.619	0.645	0.671	0.697	0.723	0.749	0.776	0.802	0.829	0.857	0.885	0.913	0.943	0.974	1.006	1.040	1.077	1.118	1.166	1.226	1.369
0.60	0.583	0.609	0.635	0.661	0.687	0.713	0.740	0.766	0.793	0.821	0.849	0.877	0.907	0.938	0.970	1.004	1.041	1.082	1.130	1.190	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	1.156	1.299
0.62	0.516	0.542	0.568	0.594	0.620	0.646	0.673	0.699	0.726	0.754	0.782	0.810	0.840	0.871	0.903	0.937	0.974	1.015	1.063	1.123	1.266
0.63	0.483	0.509	0.535	0.561	0.587	0.613	0.640	0.666	0.693	0.721	0.749	0.777	0.807	0.838	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	0.608	0.634	0.661	0.689	0.717	0.745	0.775	0.806	0.838	0.872	0.909	0.950	0.998	1.068	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	0.713	0.743	0.774	0.806	0.840	0.877	0.918	0.966	1.026	1.169
0.66	0.388	0.414	0.440	0.466	0.492	0.518	0.545	0.571	0.598	0.626	0.654	0.682	0.712	0.743	0.775	0.809	0.846	0.887	0.935	0.995	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	0.965	1.108
0.68	0.328	0.354	0.380	0.406	0.432	0.458	0.485	0.511	0.538	0.566	0.594	0.622	0.652	0.683	0.715	0.749	0.786	0.827	0.875	0.935	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	0.906	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	0.564	0.594	0.625	0.657	0.691	0.728	0.769	0.817	0.877	1.020
0.71	0.242	0.268	0.294	0.320	0.346	0.372	0.399	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	0.371	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	0.369	0.396	0.424	0.452	0.480	0.510	0.541	0.573	0.607	0.644	0.685	0.733	0.793	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	0.399	0.429	0.460	0.492	0.526	0.563	0.604	0.652	0.712	0.855
0.77	0.079	0.105	0.131	0.157	0.183	0.209	0.236	0.262	0.289	0.317	0.345	0.373	0.403	0.434	0.466	0.500	0.537	0.578	0.626	0.685	0.829
0.78	0.052	0.078	0.104	0.130	0.156	0.182	0.209	0.235	0.262	0.290	0.318	0.346	0.376	0.407	0.439	0.473	0.510	0.551	0.599	0.659	0.802
0.79	0.026	0.052	0.078	0.104	0.130	0.156	0.183	0.209	0.236	0.264	0.292	0.320	0.350	0.381	0.413	0.447	0.484	0.525	0.573	0.633	0.776
0.80	0.000	0.026	0.052	0.078	0.104	0.130	0.157	0.183	0.210	0.238	0.266	0.294	0.324	0.355	0.387	0.421	0.458	0.499	0.547	0.609	0.750
0.81		0.000	0.026	0.052	0.078	0.104	0.131	0.157	0.184	0.212	0.240	0.268	0.298	0.329	0.361	0.395	0.432	0.473	0.521	0.581	0.724
0.82			0.000	0.026	0.052	0.078	0.105	0.131	0.158	0.186	0.214	0.242	0.272	0.303	0.335	0.369	0.406	0.447	0.495	0.555	0.698
0.83				0.000	0.026	0.052	0.079	0.105	0.132	0.160	0.188	0.216	0.246	0.277	0.309	0.343	0.380	0.421	0.469	0.529	0.672
0.84					0.000	0.026	0.053	0.079	0.106	0.134	0.162	0.190	0.220	0.251	0.283	0.317	0.354	0.395	0.443	0.503	0.646
0.85						0.000	0.027	0.053	0.080	0.108	0.136	0.164	0.194	0.225	0.257	0.291	0.328	0.369	0.417	0.477	0.620
0.86							0.000	0.026	0.053	0.081	0.109	0.137	0.167	0.198	0.230	0.264	0.301	0.342	0.390	0.450	0.593
0.87								0.000	0.027	0.055	0.083	0.111	0.141	0.172	0.204	0.238	0.275	0.316	0.364	0.424	0.567
0.88									0.000	0.028	0.056	0.084	0.114	0.145	0.177	0.211	0.248	0.289	0.337	0.397	0.540
0.89										0.000	0.028	0.056	0.086	0.117	0.149	0.183	0.220	0.261	0.309	0.369	0.512
0.90											0.000	0.028	0.058	0.089	0.121	0.155	0.192	0.233	0.281	0.341	0.484
0.91												0.000	0.30	0.061	0.093	0.127	0.164	0.205	0.253	0.313	0.456
0.92													0.000	0.031	0.063	0.097	0.134	0.175	0.223	0.283	0.426
0.93														0.000	0.032	0.066	0.103	0.144	0.192	0.252	0.395
0.94															0.000	0.034	0.071	0.112	0.160	0.220	0.363
0.95																0.000	0.037	0.079	0.126	0.186	0.329
0.96																	0.000	0.041	0.089	0.149	0.292
0.97																		0.000	0.048	0.108	0.251
0.98																			0.000	0.060	0.203
0.99																				0.000	0.143

2.4 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 can reduce 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 the following formula. The formula assumes constant kilowatt and constant voltage at the load.

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

where

PF_{old} is the existing power factor
 PF_{new} is the corrected power factor

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

2.5 Reduced billing charges

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

The kilovoltampere billing charge may be calculated in many different ways, including the following:

- a) A fixed dollar amount for each kilowatt plus a fixed dollar amount for each kilovar.
- b) A certain dollar amount for each kilowatt at or above a certain power factor, with additional charges made for each kvar 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 kilovoltampere.

3. Capacitor ratings and service conditions

Capacitor ratings and service conditions are specified in IEEE Std 18-1992. Key aspects of the ratings and service conditions are given here for easy reference.

3.1 Ratings

3.1.1 Standard Ratings

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

3.1.2 Tolerances in ratings

3.1.2.1

Capacitors give not less than the rated reactive power at rated sinusoidal voltage and frequency, and not more than 115% of this value, measured at 25 °C uniform case and internal temperature.

3.1.2.2

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 3.1.2.3.
- 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 3.1.2.1.

3.1.2.3

Capacitors are capable of continuous operation provided that none of the following limitations are exceeded:

- a) 135% of nameplate kvar (see 3.1.2.2).
- b) 110% of rated voltage rms, and crest voltage not exceeding $1.2 \cdot \sqrt{2}$ of rated rms voltage, including harmonics but excluding transients (see 5.5).
- c) 180% of rated current rms, including fundamental and harmonic currents (see 5.5).

3.1.3 Momentary ratings

Capacitors are capable of withstanding with full-life expectancy switching transients having peak voltages up to $2 \cdot \sqrt{2}$ times rated voltage rms and other transient disturbances inherent in the operation of power systems (see 5.1.2).

3.1.4 Voltage and reactive power ratings

Voltage and reactive power ratings are summarized in table 3.

3.1.5 Insulation classes

The basic impulse insulation levels (BIL) of standard rating capacitors are given in table 3.

3.1.6 Frequency

Power capacitors are designed for operation at a rated nominal frequency of either 50 or 60 Hz.

3.1.7 Ambient temperature

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

3.1.7.1 Minimum ambient

Capacitors are designed for continuous operation at -40 °C.

Table 3—Voltage and kvar ratings for 60 Hz capacitors

Volts, rms (terminal-to-terminal)	Kilovar	Number of phases	BIL (kilovolts)
216	5, 7-1/2, 13-1/3, 20, and 25	1 and 3	30*
240	2.5, 5, 7-1/2, 10, 15, 20, 25, and 50	1 and 3	30*
480	5, 10, 15, 20, 25, 35, 50, 60, and 100	1 and 3	30*
600	5, 10, 15, 20, 25, 35, 50, 60, and 100	1 and 3	30*
2 400	50, 100, 150, and 200	1	75
2 770	50, 100, 150, and 200	1	75
4 160	50, 100, 150, and 200	1	75
4 800	50, 100, 150, and 200	1	75
6 640	50, 100, 150, 200, 300, and 400	1	95
7 200	50, 100, 150, 200, 300, and 400	1	95
7 620	50, 100, 150, 200, 300, and 400	1	95
7 960	50, 100, 150, 200, 300, and 400	1	95
8 320	50, 100, 150, 200, 300, and 400	1	95
9 540	50, 100, 150, 200, 300, and 400	1	95
9 960	50, 100, 150, 200, 300, and 400	1	95
11 400	50, 100, 150, 200, 300, and 400	1	95
12 470	50, 100, 150, 200, 300, and 400	1	95
13 280	50, 100, 150, 200, 300, and 400	1	95 and 125
13 800	50, 100, 150, 200, 300, and 400	1	95 and 125
14 400	50, 100, 150, 200, 300, and 400	1	95 and 125
15 125	50, 100, 150, 200, 300, and 400	1	125
19 920	100, 150, 200, 300, and 400	1	125
19 920 [†]	100, 150, 200, 300, and 400	1	125 and 150
20 800 [†]	100, 150, 200, 300, and 400	1	150 and 200
21 600 [†]	100, 150, 200, 300, and 400	1	150 and 200
22 800 [†]	100, 150, 200, 300, and 400	1	150 and 200
23 800 [†]	100, 150, 200, 300, and 400	1	150 and 200
24 940 [†]	100, 150, 200, 300, and 400	1	150 and 200
4160 GrdY/2400	300 and 400	3	75
4800 GrdY/2770	300 and 400	3	75
7200 GrdY/4160	300 and 400	3	75
8320 GrdY/4800	300 and 400	3	75
12 470 GrdY/7200	300 and 400	3	95
13 200 GrdY/7620	300 and 400	3	95
13 800 GrdY/7960	300 and 400	3	95
14 400 GrdY/8320	300 and 400	3	95

*Not applicable to indoor rating.

[†]One bushing.

3.2 Service conditions

3.2.1 Normal service conditions

Capacitors are suitable for operation at their specified rating when

Table 4—Maximum ambient

Mounting arrangement	Ambient air temperature, °C	
	24 h average [*]	Normal annual [†]
Isolated capacitor	46	35
Single row of capacitors	46	35
Multiple rows and tiers of capacitors	40	25
Metal-enclosed or housed equipments	40	25

^{*}The 24 h arithmetic average of hourly readings during the hottest day expected at that location.

[†]As defined in the reports of the U.S. Weather Bureau.

- The ambient temperature is within the limits specified in 3.1.7. (Capacitors may be exposed to the direct rays of the sun.)
- The altitude does not exceed 6000 ft (1800 m) above sea level.
- The voltage applied between terminals does not exceed the rated voltage by more than the tolerance specified in 3.1.2.3.
- The voltage applied between terminals and case does not exceed the insulation class specified in 3.1.5.
- The applied voltage does not contain harmonics in excess of the limits specified in 3.1.2.3.
- The nominal operating frequency is equal to the rated frequency.

3.2.2 Abnormal service conditions

If capacitors are required to operate under abnormal service conditions, such as the following, the application should be brought to the attention of the manufacturer:

- Exposure to damaging fumes or vapors
- Exposure to conducting or explosive dust
- Exposure to abnormal mechanical shock or vibration, including earthquakes
- Exposure to radiated heat from surfaces (other than the sun) that are hotter than the ambient temperature limits for capacitors given in 3.1.7
- Mounting and/or arrangement that prevents adequate ventilation
- Operation in ambient temperatures outside the range specified in 3.1.7
- Altitude higher than 6000 ft (1800 m) above sea level
- Momentary duty exceeding that listed in 3.1.3
- Service conditions other than those listed in 3.2.1

4. Capacitor applications on distribution lines

Shunt power capacitors applied to distribution systems are generally located on the distribution lines or in the substations. This clause deals with those capacitors located on the distribution lines, which may be in pole-mounted racks, pad-mounted banks, or submersible installations. (Substation applications are discussed in clause 5.) The distribution banks often include three to nine capacitor units connected in three-phase