Westinghouse Electric Corporation
Distribution Apparatus Division
Bloomington, Indiana 47401

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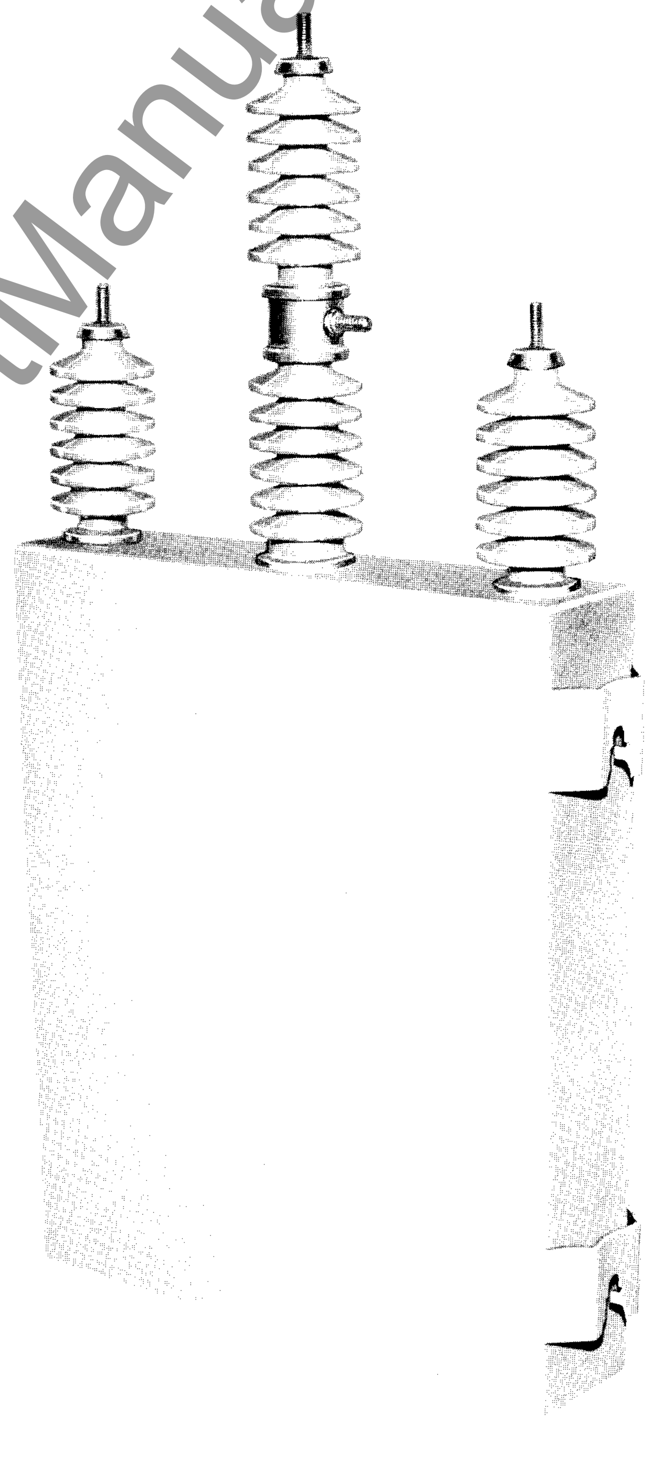
New Information
E, D, C/2001, 2002/DB

Corona Ring Design
Single and Three Phase
2400 Volt to 24940 Volt

High Voltage Capacitor Units Mark V and Mark VI



Mark V and Mark VI Description, Bill-of-Material, and Ratings

Description – Mark V Power Capacitor

A standard Mark V power capacitor unit is defined as a capacitor unit that can be completely described by the assigned style number and the customer can order the capacitor by that style number with no further description and/or explanation of the bill-of-material. The Mark V power capacitor meets all requirements of NEMA CP-1, 1976, ANSI C55.1-1968, and IEEE Standard No. 18. Refer to 39-310 P WE A for style numbers and list prices.

Description – Mark VI Power Capacitor

A standard Mark VI power capacitor unit is defined as a capacitor unit that can be completely described by the assigned style number and the customer can order the capacitor by that style number with no further description and/or explanation of the bill-of-material. The Mark VI power capacitor meets all requirements of NEMA CP-1, 1976, ANSI C55.1-1968, and IEEE Standard No. 18. In addition the Mark VI power capacitor will receive a final terminal-to-terminal overpotential test at 6.25 times rated voltage DC for 10 seconds. Refer to 39-310 P WE A for style numbers and list prices.

All power capacitors built by Westinghouse receive a power factor test at 100°C prior to shipment.

Mark V and Mark VI Power Capacitor Ratings KVAC Rating

Mark V and Mark VI power capacitors are available in the following KVAC ratings:

Single Phase-KVAC	Three Phase-KVAC
50	150①
100	300
150	400
200	

① Mark V Design Only

Voltage Rating

Mark V and Mark VI power capacitors are available in the following voltage ratings:

Single Phase Capacitor Units

KVAC	Voltage Ratings (Volts)
50	2400 - 14400
100, 150, 200	2400 - 24940

Three Phase Capacitor Units

KVAC	Voltage Ratings (Volts)	Connection
150	12470/7200	Grounded WYE
	13280/7620	Grounded WYE
300, 400	4160/2400	Grounded WYE or
	24940/14400	Ungrounded WYE

Mark V and Mark VI Bill-of-Material

Overvoltage Capability

All Mark V and Mark VI power capacitors are designed with 110% overvoltage capability.

KVAC Rating

All Mark V and Mark VI power capacitors are designed to yield specified KVAC at rated voltage.

Capacitor Bushings and Bushing BIL

All Mark V and Mark VI power capacitors are supplied with extra creep bushings.

Voltage Range (Volts)	No. of Phases	BIL (KV)	Creep (Inch)	No. of Bushings
2400-4800	1	95	12	1 or 2
4800-14400	1	95	18	2
4800-14400	1	125	18	1
17200-24940	1	150	22	1
17200-24940	1	200	28	1
4160/2400-24940/14400	3	125①	18	3
4160/2400-24940/14400	3	95②	18	3

① Grounded WYE connection
② Ungrounded WYE connection

Case Material and Paint

All Mark V and Mark VI power capacitors are supplied with #409 Stainless Steel cases painted with one coat of zinc chromate primer and one coat of oven-cured acrylic enamel ASA-70 (Munsell #5 BG7.0/0.4).

Discharge Resistor

All Mark V and Mark VI power capacitors are supplied with a discharge resistor connected internally between terminals. Resistors are sized by Westinghouse to reduce the residual voltage to 50 volts within 5 minutes.

Connectors

All Mark V and Mark VI power capacitors are supplied with clamp type parallel grove connectors which accommodate one or two conductors from AWG #12 to AWG #1 stranded.

Nameplate

All Mark V and Mark VI power capacitors are shipped with nameplates listing style number, serial number, KVAC, rated voltage, frequency, number of phases, and BIL.

Frequency

All Mark V and Mark VI power capacitors are rated for 60 Hertz.

Tests

All Mark V and Mark VI power capacitors receive all tests specified in NEMA CP-1 with the exceptions:
All Mark V and Mark VI power capacitors receive a 100°C power factor test.

The Mark VI power capacitor receives a 6.25 times rated voltage DC overpotential test for 10 seconds.

Dimensions

Refer to 39-310 P WE A for dimensions of Mark V and Mark VI power capacitors.

Capacitor Design, Manufacturing, Testing – Improvement

Until the Westinghouse Mark V and Mark VI power capacitor, design methods, manufacturing technique and final testing have been subjects by themselves. The technology required to design, manufacture and test power capacitors is well known and well documented in the technical literature.

What is not well known and presents a constant problem to capacitor manufacturers is . . . "How to design, build and test a capacitor on an assembly line basis that will provide good field reliability."

The Westinghouse Mark V and Mark VI Power Capacitors are the first power capacitors to be introduced that fully integrate design, manufacturing technique, and final testing.

Capacitor Design – Improvement

Capacitor designers are familiar with the fact that the foil edge is the weak spot of any high voltage capacitor. Laboratory overvoltage tests conducted on various configurations of high quality dielectric material always yield the same result – failure at the foil edge.

The laboratory fact can be explained by examining a typical capacitor voltage stress diagram:

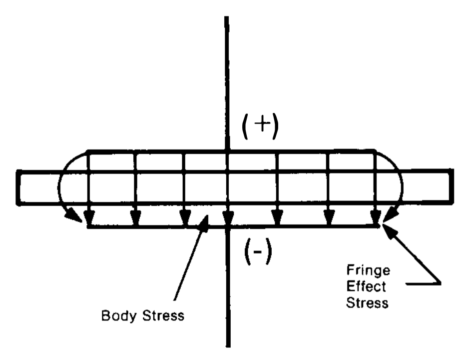


Figure 1

The voltage stress is higher at the foil edge than within the body due to "fringing effects" of the electric field.

For a given voltage stress within the body of a capacitor the stress on the foil edge is always considerably higher in the conventional capacitor.

This is the reason that overvoltage testing in the laboratory always yields the same result – failure at the foil edge.

Capacitor Manufacturing – Improvement
Capacitor manufacturing engineers know that voltage stress increases at the foil edge proportional to the misalignment of one plate in relation to the other plate and that it is not possible to wind a capacitor with the foil edges in perfect alignment.

Relative Voltage Stress at Foil Edge Vs. Foil Edge Displacement

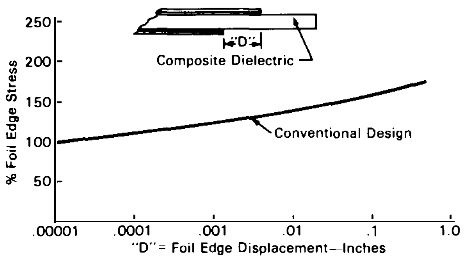
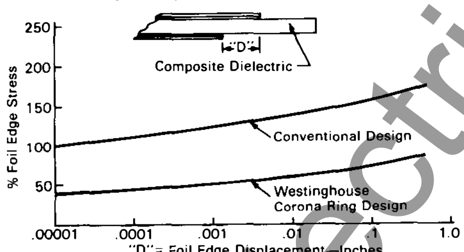


Figure 2

This fact means that the maximum voltage stress on a conventional capacitor is actually determined at the time the individual capacitor section is wound – not by the capacitor design engineer.

The Mark V and Mark VI power capacitors are designed to solve this problem. The Mark V and Mark VI capacitor foil edge voltage stress is reduced to values less than can be obtained with a conventional capacitor with the plates in perfect alignment by the addition of corona rings to one plate.

Relative Voltage Stress at Foil Edge Vs. Foil Edge Displacement



Westinghouse Capacitor Unit

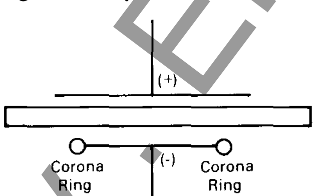


Figure 4

The manufacturing engineer is no longer concerned with misalignment of foil edges during the winding process. The design engineer is no longer concerned with manufacturing tolerance as it relates to overvoltage capability and foil edge stress.

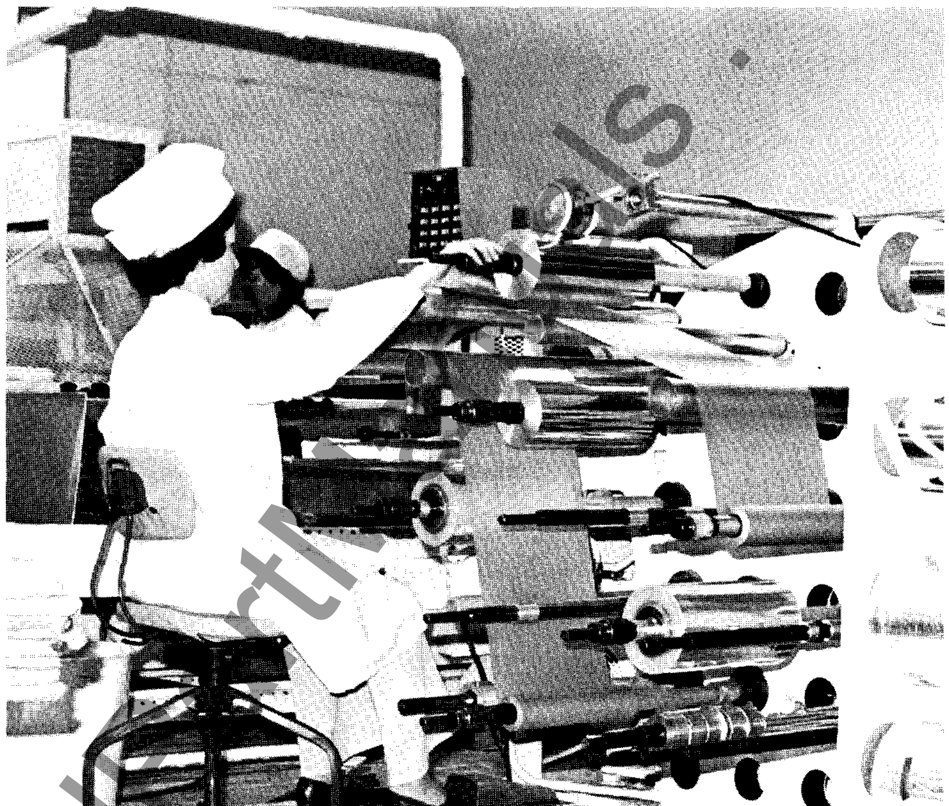


Figure 3

Dielectric Strength – Improvement
The addition of corona rings to one plate of a conventional capacitor will improve the dielectric strength without any other changes in the dielectric system.

Capacitor Design	AC Breakdown ①	DC Breakdown ②
Conventional Capacitor	1.00	1.00
Corona Ring Added to Conventional Capacitor	1.21	1.24

① 500 VAC/15 Sec. Rate of Increase
② 1000 VDC/Sec. Rate of Increase

Figure 5

Dielectric Loss – Improvement
The addition of corona rings to one plate of a conventional capacitor will reduce the dielectric loss without any other changes in the dielectric.

Voltages above rated cause an increase in the dielectric loss due to the non-linear effect of foil edge loss in relation to losses within the body of the capacitor.

100°C Power Factor Vs. % Rated Voltage

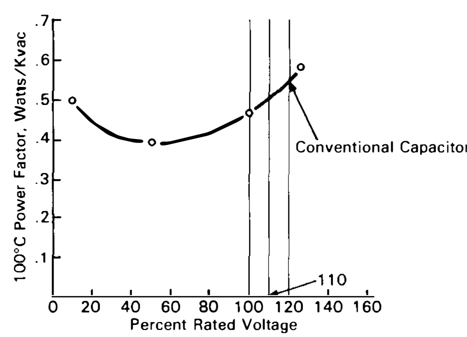


Figure 6

The addition of the corona rings reduce the overall dielectric loss, because the rate of increase of loss at the foil edge due to overvoltage is reduced.

100°C Power Factor Vs. % Rated Voltage

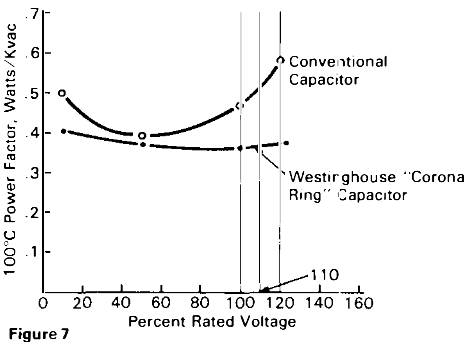


Figure 7

Production Line Final Overvoltage Testing – Improvement

Present NEMA CP1-1976 Standards require a terminal-to-terminal overvoltage test on all units produced. The DC test voltage specified is 4.3 times rated voltage for 10 seconds. The Mark V corona ring capacitor is designed to meet this test requirement.

The Mark VI corona ring capacitor is designed to exceed the present NEMA Standard CP1-1976. All Mark VI corona ring design capacitors will receive a final DC overvoltage test of 6.25 times rated voltage for 10 seconds.

100% Power Factor Testing at 100°C – Improvement

NEMA Standard CP1-1976 states that a power factor test must be made – statistical sampling methods may be used. NEMA Standard CP1-1976 does not specify the dielectric temperature at the time of the statistical test.

A practical way for a manufacturer to meet the CP1 requirement is to measure the power factor of the capacitor used for the thermal stability test, allow the unit to cool to room temperature and then re-measure the power factor. The room temperature measurement would then become the basis for the statistical test limit on all production.

Power Factor Vs. Dielectric Temperature

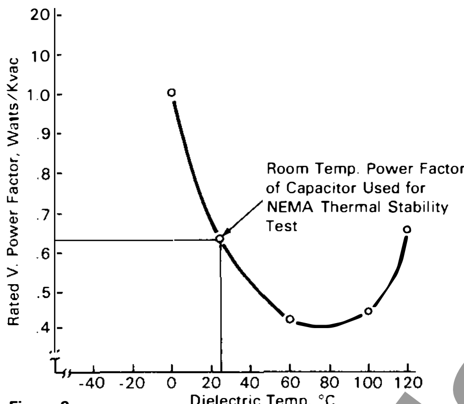


Figure 8

The reason NEMA CP1 Standards allow statistical testing of power factor is because it is assumed that impregnation is a batch process in which all units experience the same manufacturing variables.

By experience, Westinghouse has determined this is not the case. During the manufacturing process many variables can be present that would cause a statistical test to be invalid.

Figure 9 indicates that units with various manufacturing errors will pass a room temperature power factor test but not a power factor test at 100°C.

Power Factor Vs. Dielectric Temperature

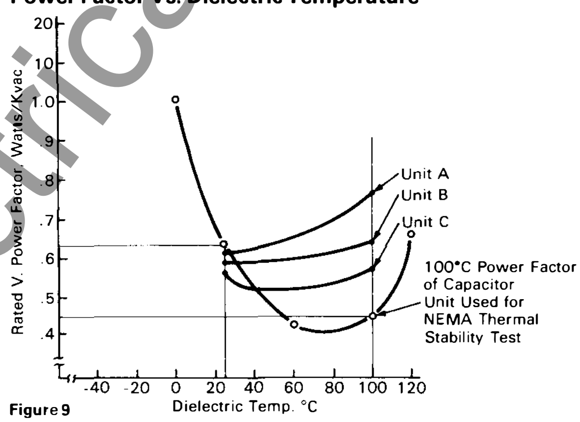


Figure 9

Unit A – Not Fully Impregnated
Unit B – Excess Solder Flux
Unit C – Packaging Grade Film

This is the reason Westinghouse has chosen to power factor test all capacitors at 100°C.

Further Information

39-310 PWEA
SA 214

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