Development of the Westinghouse VCP-W Vacuum Circuit Breaker and VacClad-W Metalclad Vacuum Switchgear

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INTRODUCTION

In August 1971, the Transmission and Distribution Editor of Electrical World reported on the status of the vacuum switch. In a paper entitled "Vacuum Switching — An old technology is coming of age" W. C. Hayes stated:

> Vacuum switching at this stage is like the ingenue understudy waiting in the wings for the established star to tire — it has great potential, but it must be content with bit parts until its growing capability and appeal are too great to be denied.

Now, in 1988, almost 20 years later it can be reported that a new world class star is born. The capability and appeal of vacuum switching has indeed been appreciated and proven with the extensive use of vacuum interrupters in contactors, motor starters, tap-changers, distribution apparatus, and metalclad switchgear.

This paper provides a review of the latest Westinghouse vacuum interrupter. Along with a detailed description of the interrupt performance, development, testing, and design features of the world class VCP-W vacuum circuit breaker used in VacClad-W switchgear.

The VCP-W vacuum circuit breaker, our third generation, presents a marriage of Westinghouse's proven vacuum interrupter technology and its years of experience in the design, production, and application of medium voltage metalclad switchgear, resulting in our VacClad-W switchgear.

VACUUM INTERRUPTERS

Westinghouse has excellent credentials in the field of power vacuum interruption and, since the early 1960's has been a major developer and worldwide supplier of vacuum interrupters. Vacuum interrupters have been designed and provided for such products as circuit breakers (both free-standing distribution equipment and metalclad), reclosers, transformer tap-changers, contactors, motor starters, and general switching devices. Since 1960, Westinghouse has produced a total of over 150,000 units, with excellent field performance.

The internal components of a typical vacuum interrupter are shown in Figure 1. This particular interrupter has an envelope diameter of 4 in. It is equipped with high-purity, gas-free, 2.6 in. diam. copper-chrome electrodes, and can interrupt 25 kA (r.m.s.) at 12 kV. The ambient gas pressure within the evacuated envelope is $\sim$ 10-6 torr.

Under normal circuit conditions the interrupter is closed, and the electrodes butt together. Arcing is established within the interrupter by withdrawing the bellows-electrode from the stationary electrode. This arc burns in the metal vapor evaporated from local hot spots on the electrode surfaces. The metal vapor continually leaves the interelectrode region, and recondenses on the electrode surfaces and the surrounding metal shield. The metal shield is usually isolated from both electrodes, and serves to protect the ceramic envelope from vapor deposition. At current zero, electrode vapor production ceases and the original vacuum condition is rapidly approached. The dielectric strength of the interrupter also increases, and the circuit is interrupted. With the electrodes in the open position, the circuit voltage is isolated internally by the interelectrode gap and externally by the insulating envelope.

The electrode material for vacuum interrupters used in breakers is copper-chrome. Copper-chrome is a semi-refractory material and, as a consequence, the electrode structure is maintained during high current arcing. The electrical conductivity remains high, and the material has a lower weld strength than pure copper.

With respect to the electrode configuration, vacuum interrupter electrodes for breaker applications are designed to provide a component of magnetic field transverse to the arc during high current arcing. This field moves the arc root around the electrode periphery thus minimizing localized electrode temperature and erosion. Furthermore, the arc is controlled and does not bow from the electrodes into contact with the vapor-condensing metal shield. The electrode configuration referred to as "spiral" appears in Figure 2. The opposing electrodes within an interrupter are oriented in such a manner as to provide the transverse magnetic field component.

Switching in vacuum has proved attractive because the devices are reliable, have a long life, and require minimal maintenance. The arcing process is also essentially noise-free, with the operating noise being restricted to the mechanism. The interrupters are also extremely compact with Westinghouse vacuum interrupters having envelope diameters between 4 in. and 7 in. depending on the available circuit fault current, and with the stem diameter determined by the continuous current. An example of vacuum interrupter compactness appears in Figure 3 where a typical VCP-W vacuum breaker is displayed alongside a DHP airbreaker of comparable rating. Of particular importance relative to the overall size of the breaker, is the fact that the maximum electrode stroke need only be a fraction of an inch. Thus, in commercial equipment, the electrode stroke typically varies from ⅜ in. to ½ in. with the longer strokes used for the higher circuit voltages. Such a small stroke results in a compact actuating mechanism.

Prior to discussing the arcing and interruption phenomena which occur in vacuum interrupters during an a.c. wave, it is first necessary to review some of the basic physical properties of cathode and anode spots. During the arcing half cycle, the arc burns in the metal vapor plasma which originates from these localized electrode hot spots. In fact, due to the presence of plasma and the localized hot spots, the overall arc gap is an excellent conductor with an arc voltage of only several tens to several hundreds of volts for arc currents of tens of kiloamperes. At current zero, however, there is an abrupt reduction in overall gap conductivity combined with a reversal of electrode polarity, and tens of kilovolts are then required to reignite the arc within microseconds of the natural a.c. current zero. This rapid change in conductivity is intimately related to the cathode spot properties, and can be adversely affected by the presence of anode spots.

CATHODE SPOTS

For arc currents to several thousand amperes, the vacuum arc can be characterized by a multiplicity of rapidly moving cathode spots, with the number of spots being approximately proportional to the current, a diffuse interelectrode plasma, and a diffuse collection of current at the anode. These cathode spots are essential to the maintenance of the discharge.

Most of the arc voltage drop occurs across a space charge sheath at the cathode, and this cathode fall voltage has been determined for a wide variety of materials. The maximum current conducted by each of the multiple cathode spots varies with the electrode material, and is related to the thermal parameter TBk1/2 of the cathode where TB is the normal boiling point temperature and k the low temperature thermal conductivity of the cathode material. The cathode spot current density at the cathode surface is extremely high, and the overall cathode region is therefore one of high power density. For arcs on copper electrodes, the cathode fall is $\sim$ 18 V, the maximum current per cathode spot is $\sim$ 100 A, and the cathode spot current density at the cathode surface, based on crater sizes, is $\sim$ 108 A/cm2.

The phenomenon of multiple cathode spots results in distributed erosion at the cathode, and examination of the individual cathode spot craters indicates a non-stationary emission process operating on a sub-microsecond time scale. Erosion rates have been determined for a wide variety of materials. Of particular importance is the fact that the cathode spots are regions of intense ionization, with most of the material emitted from the surface spots with a spatial distribution approximating a cosine law. For higher current levels, the ion flux more closely approximates an isotropic distribution. Metal particles also stream away from the cathode spot regions, primarily in a direction parallel to the cathode surface. For copper arcs, the erosion rate is about 10-4 g/C and, in common with most materials, the magnitude of the ion current leaving the cathode spot region is about 10% of the arc current. The ions possess an energy, in eV, which exceeds the arc voltage, and can be considered to migrate away from a localized potential maximum within the cathode fall. For copper, the ions are multiply charged and possess a mean energy $\sim$ 20eV (about 106 cm/s) per unit charge whereas the mean vapor energy is $<$ leV.

The primary cathode spot parameters which influence successful interruption at current zero are (1) the high velocity of the ionized metal vapor away from the cathode surface which leads to a rapid decrease in the interelectrode plasma density and (2) the need to create a high power density spot on the former anode in order to conduct appreciable current in the next half cycle.

ANODE SPOTS

During the arcing half cycle, evaporation always occurs from the cathode electrode. However, for certain arcing conditions, there may also be significant evaporation from the anode electrode due to the formation of a single, grossly evaporating anode spot. This anode spot operates near the normal boiling temperature of the anode material, and can significantly increase the interelectrode plasma density. Furthermore, since the erosion is not distributed, anode spot formation can cause gross melting of the electrode. Finally, the plasma jet from the anode spot can cause the cathode spots to bunch together with resulting gross erosion on the cathode.

Experiments at both low and high currents show that the probability of anode spot formation increases with increasing electrode separation, with increasing circuit current and arc duration, and with decreasing anode area. Furthermore, the probability of spot formation is related to the thermal characteristics of the anode electrode material; increasing with decrease in the anode thermal parameter Tm (kpc)1/2 where Tm is the melting temperature of the anode material, and k, p, and c are the thermal conductivity, density and specific heat. The dependence of anode spot formation on geometric factors such as anode area and electrode spacing suggests that spot formation is associated with ion starvation in the anode region. Thus, for small anode areas and long electrode spacings, when most of the ions in the plasma stream from the cathode spots are no longer incident on the anode, the arc voltage increases due to formation of an anode sheath, and the anode surface is heated. This ion starvation concept is strengthened by observations of anode phenomena in the presence of an axial magnetic field. Here the cathode ions are confined to the interelectrode region, and spot formation is postponed to higher currents. Several investigators have proposed that magnetic constriction also plays an important role in triggering anode spot formation.

The presence of stationary anode spots during the arcing half cycle can adversely affect dielectric recovery due to (1) associated increases in the interelectrode plasma and vapor densities (2) continued evaporation from the localized hot spot following current zero and (3) for the case of refractory materials such as carbon and tungsten, continued thermionic emission of electrons following electrode polarity reversal.

ARCING AND INTERRUPTION IN VACUUM INTERRUPTERS DURING AN A.C. WAVE

Figure 4 depicts the important arcing and interruption phenomena which occur during fault current interruption in vacuum. These phenomena influence the design of the interrupter, and in particular the size, configuration, and material of the electrodes. In this section, arc initiation, high current arc mode, current zero, and dielectric recovery voltage phenomena are discussed in sequence, with distinctions drawn, where necessary, between contactor and breaker applications.

ARC INITIATION

When a vacuum switch is operated, an actuator separates the electrodes a distance of 1/10 in. to 4/5 in. This actuator must first provide sufficient force to break the interelectrode weld. Electrode materials are consequently selected to ensure a relatively low weld strength.

The electrodes are separated at random during the passage of a.c. current. At the last point of contact between the parting electrodes, a metal bridge is formed. This bridge subsequently melts and, at low currents of several thousand amperes, cathode spots then migrate over the cathode surface from the previous bridge location. Essentially, all ionization for this initial interelectrode plasma occurs in these cathode spot regions, with recombination solely at the shield and anode. The phenomenon of spot splitting with increasing arc current results in a desirable distributed erosion at the cathode.

If the current at the instant of electrode separation approaches 10 kA, the bridge melting can lead to formation of a single, high vapor pressure arc column which can remain constricted for one or two milliseconds. For the spiral electrodes of Figure 2, a raised ring is located around the center of the electrodes so that arc initiation occurs off axis. As a result, this columnar arc is driven first towards the periphery of the contact. The current path through the electrode spirals then creates a magnetic field with a strong component transverse to the arc column, and the arc is forced around the electrode periphery. If the current and electrode spacing were to remain constant following arc initiation, the columnar arc would rapidly be replaced by a multiplicity of cathode spots, a diffuse interelectrode plasma, and a diffuse collection of current at the anode.

HIGH CURRENT ARC MODE

In breaker applications, the current and electrode spacing can increase markedly following arc initiation. For example, the electrodes of a 15 kV breaker would typically be separated to a distance of ½ in., and for an interrupter rated at 1000 MVA, the peak asymmetric current at this spacing could approach 100 kA. This combination of high current and long electrode spacing can result in vigorous anode spot activity which, for plain-disk electrodes, can result in destructive heating of the anode. Further, the anode plasma jet could contact the surrounding metal vapor condensation shield, Figure 1. Finally, this jet could also cause cathode spot bunching with resulting gross cathode erosion. One method of minimizing anode involvement is to set the electrode stroke to a minimum value consistent with the particular interruption and voltage requirements. A second method is to increase the electrode areas which also, of course, increases the diameter and cost of the interrupter. A third method is to control the arc so as to (1) prevent shield involvement and (2) minimize localized heating of the electrodes so that, as the current decreases after peak current has been attained, the current will eventually be sufficiently low so that the arc plasma again becomes diffuse. The Westinghouse design combines all three techniques, with arc control being provided by forced arc motion of several rotations around the periphery of "spiral" electrodes.

CURRENT ZERO

As the arc current decreases towards current zero, the arc plasma again becomes diffuse with the electron current being emitted from a declining number of discrete cathode spots. As the current in the final cathode spot approaches the a.c. zero, the arc may become unstable and extinguish spontaneously.

DIELECTRIC RECOVERY AND VOLTAGE WITHSTAND

At current zero, the vapor producing cathode spots extinguish. The residual vapor and plasma within the interelectrode region rapidly condense and recombine on both the shield and electrode surfaces, and the original vacuum condition is rapidly approached. Analysis of the recovery processes directly following current zero is complicated by the non-uniform distribution of the reapplied voltage in the recovering arc gap. In the presence of residual plasma, the circuit voltage is impressed across a narrow space charge sheath at the new cathode. One consequence of this sheath is that the vapor condensation shield, which is in good electrical contact with the interelectrode plasma, initially assumes the potential of the new anode. Then, as the plasma density decays, the shield rapidly assumes mid potential.

The a.c. circuit is successfully interrupted if the instantaneous dielectric strength of the recovering interelectrode gap always exceeds the circuit reapplied voltage. Full recovery can be attained within microseconds or tens of microseconds of current zero. This ultimate breakdown voltage depends on both the spacing and geometry of the internal shields, and also the electric field stress on the external envelope of the interrupter. Further, the ultimate breakdown voltage is critically dependent on the spacing of the electrodes, the condition of the arced electrode surfaces, and the magnitude and duration of the recovery voltage.

Reliability and Testing of the VCP-W Circuit Breaker and VacClad-W Metalclad Switchgear

BACKGROUND

A comprehensive program was undertaken to:

1. Demonstrate the reliability of VCP-W circuit breakers and VacClad-W switchgear with respect to the electrical and mechanical aspects of their primary functional requirements.
2. Ensure that the circuit breaker and switchgear can properly and reliably function under the range of environmental conditions that might be encountered in the field.

The reliability tests were conducted on a variety of different breakers and components. Interruption tests were performed on several versions of the vacuum interrupters until the present interrupters were derived. These final versions were chosen because they consistently meet the very stringent design requirements. For instance, mechanical tests were performed on circuit breakers in several stages of development. These prolonged endurance tests continued to isolate the less reliable components so that continual improvements could be implemented. Eventually, rugged, durable, reliable and high quality components were chosen that meet or exceed the design life and maintenance goals. In fact, in all respects of the test program, the VCP-W breaker and VacClad-W switchgear exceed the requirements of ANSI and IEC Standards.

Compared with existing designs of magnetic air and vacuum breakers, VCP-W breakers and VacClad-W switchgear represent a standardized line of equipment with a common mechanism design for all voltage ratings. Many of the other components such as vacuum interrupters and pole units are common to several ratings. This standardization means fewer total parts for the entire breaker line, which permits more thorough testing and evaluation of each of these components to produce significant improvements in reliability.

A properly structured reliability test program involves subjecting several breakers to life tests that would simulate severe field service for at least 20 years. The series of tests must encompass the entire range of conditions that the breaker will encounter in actual service, from mechanical duty cycle and normal load current carrying to environmental conditions like pressure, temperature and humidity. These tests must also include severe functional or abnormal conditions, such as fault interruption or surge impulse voltage conditions. To test for these factors requires accelerated life tests on breakers and components in all stages of development. Possible failure modes are identified throughout the different tests, so that corrective measures can be taken to eliminate these failure modes.

VAC CLAD-W TEST PROGRAM

The VacClad-W metalclad switchgear including the circuit breaker was designed to meet all the applicable requirements of the ANSI, IEEE, IEC and NEMA Standards. In order to be considered a world class product, the design criteria dictated that all tests demonstrate performance exceeding ANSI and IEC Standards. The ANSI & IEC test series are the basic test criteria and include interruption (over the complete current range), BIL, dielectric, continuous current, mechanical life, and thermal and environmental conditions.

To ensure the highest standard of performance, this complete test program was performed twice; at the prototype stage and repeated in its entirety on the first production units.

Reliability studies of power circuit breakers made by industry groups have found that 75% to 90% of field problems are mechanical in nature. With this in mind coupled with Westinghouse's on going commitment to total quality, this test program is being supplemented by conducting no- load mechanical life tests on selective circuit breakers at four-month intervals.

SELECTION OF VCP-W VACUUM INTERRUPTERS

Since the vacuum interrupter is the heart of the vacuum circuit breaker, it was necessary to conduct an extensive and comprehensive test program to evaluate the vacuum interrupters that were to be chosen for VCP-W vacuum circuit breaker.

Before vacuum interrupters were considered acceptable for three-phase ANSI specified power testing in the Westinghouse High Power Laboratory, they first underwent a very rigorous single-phase prequalification procedure. This procedure required that three identical vacuum interrupters of a given rating be subjected to ANSI C37.09, Table I, Test Duty 13, thirteen times each. (That is a total of 39 tests.) That is almost 20 times more than is required by ANSI, and passing this prequalification procedure means that its interruption reliability is more than 350 percent greater than the ANSI specified tests.

In addition, this prequalification procedure requires that each of the three identical vacuum interrupters be subjected to five single-phase symmetric current tests 50 percent higher than the maximum interruption current required by ANSI (1.5 KI). This allows each interrupter to experience full peak current at 90 percent of full contact spacing. Even though interruption is not required during these tests, interruption does occur in about 50 percent of them, typically 7 or 8 times in 15 tests. The purpose of this procedure is to make sure that the arc does not damage the vapor shield during full asymmetric interruptions. This is verified by X-ray or internal inspection of the three vacuum interrupters after the tests.

ELECTRICAL TESTS

All VCP-W breakers and equipment ratings were subjected to extensive electrical tests required by ANSI and IEC Standards: power interruption, dielectric tests including both one minute withstand and impulse, short circuit momentary and short-time, continuous current, radio influence voltage (R.I.V.) corona, load capacitance current switching, primary and bus bar insulation tests.

POWER INTERRUPTION TESTS

Since one of the major functions of a circuit breaker is to interrupt a fault current on a power system. Each rating of VCP-W circuit breaker located inside the VacClad-W switchgear was subjected to the tests at the Westinghouse High Power Laboratory detailed in ANSI C37.09, Table I. Test Duty 8 (which requires an accumulated 400 KSI of rated interruption current) of this procedure often subjects the VCP-W breaker to about 2000 KSI (20 full fault current interruptions). The IEC ratings for the VCP-W product line were established in the KEMA Laboratories in The Netherlands, with KEMA certificates currently on file.

After each test series, the breaker and equipment were subjected to a 1 minute hi-pot voltage test. This rigorous high power lab testing, along with the vacuum interrupter prequalification program described earlier, demonstrates the VCP-W circuit breaker's ability to interrupt fault current in excess of the requirements defined by both the ANSI and IEC Standards.

DIELECTRIC AND BIL REQUIREMENTS

An extensive design/test/design iterative development scheme was followed to ensure that the VCP-W breaker and VacClad-W switchgear assembly meet the BIL impulse voltage requirements. A procedure was developed to subject the original design to a statistical design test procedure. Each of the 26 terminal test configurations (TTC's) were derived from ANSI Standards and were impulsed by performing 20 tests at the designated BIL voltage (95 kV, corrected for pressure, temperature, and humidity). This was to determine which of the TTC's showed impulse breakdown problems. If the true withstand probability was between 90% to 95%, it would be expected that there would be no more than, two failures out of each series of 20 tests. If any TTC suffered more than two out of 20 failures, this indicated that a design modification was required to reduce the number of failures to two or less. The new design was then subjected to a number of tests much greater than 20. At the conclusion of this iterative process, the goal was reached where there were no more than two failures out of 20 tests at each of the 26 TTC's.

Next, approximately 1,300 tests at 95 kV (designed BIL) were performed, 50 tests at each of the 26 TTC's. An estimate of the true probability (p) of withstanding the applied 95 kV was calculated as the ratio of the number of successes to the total number of tests run. There are two additional advantages to running a larger number of tests (50) at each terminal test condition than are required:

1. To increase the confidence that each terminal test condition did not constitute an impulse breakdown problem.
2. To demonstrate which terminal test condition was marginal in meeting a 95 percent withstand probability.

To demonstrate the true withstand probability of 95 percent, at least 1,235 successes out of 1,300 tests were required.

A procedure similar to this was followed in the initial development design stages. The probability of passing the ANSI 3 x 3 tests can then be determined. If the true probability is 95 percent, then the probability of passing ANSI 3 x 3 is 97.3 percent (failure probability 2.7 percent). This overall procedure has an important benefit of minimizing the number of tests required at the design modification stage of development. Furthermore, to comply with the IEC requirement, impulse testing was performed to the 2 x 15 procedure.

Because this procedure was adopted in the initial design stages, any impulse voltage problem areas were identified early in the development, and the appropriate redesign measures were taken. In this way, quality could be built-in to assure the high reliability of the final design passing the required test requirements.

Final impulse and hi-pot qualification tests performed on the tool-made equipment, were completed in compliance with ANSI Standard C37.20, with complete success.

MOMENTARY AND SHORT-TIME CURRENTS

To ensure that the VacClad-W switchgear equipment, including the VCP-W circuit breaker, can withstand the dynamic loading and thermal effects of a short circuit current, all VacClad-W ratings have been tested to ANSI C37.20 for momentary and short circuit withstand. Suitable configurations of VacClad-W switchgear were subjected to three-phase, short circuit currents with one phase being completely offset, Peak current = 2.70 x Symmetrical RMS, (this exceeds the 2.55 ratio required by the IEC Standard) for the first ¼ cycle and the symmetrical component being held for a duration of 3 seconds.

CONTINUOUS CURRENTS (THERMAL)

Continuous current carrying tests have demonstrated temperature rises and total temperatures below the numbers defined in ANSI C37.20 for all combinations of VCP-W breakers offered in the VacClad-W switchgear line.

CAPACITOR SWITCHING

For capacitor switching, up to 75 tests (more than 3 times the number required by ANSI C37.09) have been performed to:

1. Demonstrate the capability of the VacClad-W to switch isolated capacitor banks with capacitive currents of 630 A (11.1 MVAC).
2. To switch open wire line charging currents of 2 A.

These MVAC numbers refer to maximum three-phase, isolated capacitor bank, nameplate MVAC, including a multiplying factor of 1.35.

PRIMARY AND BUS BAR INSULATION TESTS

To ensure the high performance of the VacClad-W switchgear insulating system, the following series of design tests were performed on the insulating materials:

- ANSI C37.20 flame retardant and track resistance requirements for the glass polyester.
- Accelerated creep tests, including mechanical loading @ 105°C on the glass polyester components.
- Accelerated temperature aging tests on the glass polyester components and adhesives.
- ANSI C37.20 flame retardant, track resistance and thermal cycle requirements for the fluidized epoxy bus bar insulation.
- ANSI C37.20 flame retardant test requirements of the P.V.C. and tape joint coverings.

MECHANICAL ENDURANCE TESTS

In order to minimize field problems caused by mechanical failure, the VCP-W circuit breaker and levering system were subjected to a stringent evaluation program. This program involved the mechanical no-load life testing of several prototype breakers. These prototype breakers were in some cases subjected 30,000 no-load operations. The levering system was subjected to as many as 1,000 operating cycles. This exceeded the high confidence level for the performance of the tool-made units. The first nine production breakers were then run through 15,000 to 30,000 mechanical endurance tests. The first five production levering systems were operated between 500 and 1,000 cycles. This stringent test program ensures that the VCP-W circuit breakers and levering system can qualify for the ANSI Standards requirement of 10,000 (5,000 for high interrupting and continuous current ratings) and 100 operating cycles, respectively.

Furthermore, Westinghouse's continuing commitment to total quality involves conducting a continuing program of life testing. This consists of the testing of at least two breakers at three month intervals.

ENVIRONMENTAL TESTS

The following environmental tests were performed on VCP-W breakers and VacClad-W switchgear.

- Thermal cycle tests from −30°C to 105°C were conducted on the circuit breakers. During the thermal cycle test, the breakers were subjected to 10 mechanical operations.
- Outdoor water tests in accordance with ANSI C37.20 were conducted on both the aisleless and sheltered aisle configurations.

PRODUCTION TESTS

Circuit Breaker

- Each breaker drawout unit is checked for alignment with a master cell fixture that verifies all interfaces and interchangeability.
- All circuit breakers are operated over the range of minimum to maximum control voltage.
- Interrupter contact gap is factory set.
- One-minute dielectric test is performed on each breaker per ANSI Standards.
- Final inspection and quality check.

Housing

- Master breaker fixture is inserted into each breaker cell to ensure alignment.
- One-minute dielectric test per ANSI Standards is applied to both primary and secondary circuits.
- Operation of wiring, relays, and other devices is verified by an operational sequence test.
- Final inspection and quality check.

SURGE PROTECTION

The VCP-W vacuum circuit breaker in the VacClad-W metalclad switchgear is applied over a broad range of circuits, and is one of the many components in the circuit protection system. The distribution system can be subject to voltage transients caused by lightning or switching surges. The Westinghouse VCP-W vacuum circuit breaker uses vacuum interrupters that have fast dielectric recovery rates and low chop currents, so they are much less prone to generating high overvoltages than earlier vacuum breakers. Recognizing this phenomenon and the complex interaction of the power system parameters, a set of surge protection guidelines have been developed for application of VCP-W circuit breakers and VacClad-W switchgear.

These application guidelines for VacClad-W metalclad switchgear were established after extensive analysis of medium voltage power systems. To achieve this, a computer program has been developed, and this incorporates inputs for the power system; the load, the vacuum circuit breaker, and surge protection means (if any). All program inputs correspond to, and are verified against, practical data. In order to insure that these computed results are realistic, several thousand tests were performed on the vacuum interrupters used in the VCP-W breaker.

Extensive computer analysis has been performed to insure that the most critical transformer and motor applications were encompassed in the study.

This computer analysis approach, by virtue of its capability to analyze a broad range of circuits, assures a significantly higher degree of confidence in the surge data, rather than relatively few representative practical tests.

START-UP PROGRAM

This extensive VacClad-W reliability test program has been supplemented by a field follow-up program being coordinated by the Quality Assurance Department. This program was initiated to assure customer satisfaction for the first ten switchgear installations. It was felt that an organized program was desirable to identify and eliminate problems as early as possible during installation. An audit team consists of Design Engineering, Customer Order Engineering, Manufacturing, Quality Control and Shipping functions along with the local Electric Service engineer. Members of this team review and inspect those installations prior to energization to ensure smooth start-up.

Furthermore, there has been an organized program to train the Field Electric Service people with training schools at the factory, providing them with a complete set of drawings, service manuals and instruction books.

Design Features and Advantages of the VCP-W Circuit Breaker and VacClad-W Switchgear

OVERVIEW

Westinghouse VacClad-W metalclad switchgear provides the time-honored advantages of metalclad switchgear; flexibility, quality and economy. Plus the benefits of Westinghouse vacuum interruption; reliability, less maintenance, reduced size, less weight and longer life.

The product has been designed to meet power system needs in the following important areas:

- Safety
- Performance
- Maintenance
- Space Utilization
- Application Flexibility
- Reliability

VacClad-W vacuum metalclad switchgear (Figure 5) offers for both indoor and outdoor applications, a total design concept of cell, breaker and auxiliaries to meet the user needs. This design consists of a two-high arrangement of circuit breaker, cable and auxiliary components for added application freedom and significant floor space savings.

In addition, a single, basic unit size is used for all switchgear ratings, functions and circuit configurations — a valuable asset in planning and laying out switchgear installations. In many situations, total required floor space may be reduced by as much as 50% compared to conventional switchgear — as shown in Figure 6. Furthermore, VacClad-W switchgear incorporates standardized, highly tooled modular construction, utilizing a minimum number of parts to provide maximum product quality. The most modern manufacturing techniques and facilities are used to produce this switchgear, which include computer-aided drafting, manufacturing information systems, numerical controlled machines, process equipment and order follow.

Using the ANSI Standards, the VCP-W circuit breaker ratings basically encompass:

Voltages of 2.4 kV through 15 kV.

Continuous currents of 1200 amperes, 2000 amperes and 3000 amperes. Interrupting classes from 250 MVA through 1000 MVA. Short circuit r.m.s. interrupting current and short-time current capabilities through 49 kA and momentary (close and latch) asymmetric current capabilities through 78 kA.

Using the IEC Standards, the VCP-W circuit breaker ratings basically encompass:

Voltages of 3.6 kV through 17.5 kV.

Rated normal currents of 630 amperes, 1250 amperes and 2000 amperes. Rated short circuit breaking currents of 25 kA, 31.5 kA and 40 kA. Short circuit making currents of 64, 81, and 102 kA peak.

The VCP-W breaker characteristics based on symmetrical current ratings are shown in detail in two figures. The first figure (Figure 7a) is per ANSI Standards, the second figure (Figure 7b) is per IEC Standards.

SWITCHGEAR DESCRIPTION AND FEATURES

The circuit breaker and auxiliary drawer positions are among the most flexible in the industry, and provide ten different configurations. A new exclusive configuration allows a 3,000 amp breaker to be located in the upper compartment, with either a PT or Fuse drawer located in the lower compartment. Figure 8 shows the available configurations, and Figure 9 shows the side view graphical representations of these arrangements. Furthermore, the outdoor version of VacClad-W (Figure 10) is identical to the indoor design, with the addition of suitable weather proofing extensions for both aisleless and sheltered aisle (single and double row) designs.

Some of the unique features and major components of a typical VacClad-W assembly are:

Hinged Front Door

The door provides space for mounting of relays, meters, and instruments in a standardized arrangement. These designs have been pre-engineered to provide ease of selection of control and protection functions, and are incorporated in a computer-aided design program. By standardizing the arrangements, complete mechanical drawings and Bill of Material can be provided with the proposal in sufficient detail that they constitute drawings for approval. This procedure shortens the total cycle time, assuring the shortest possible delivery.

Breaker/Cell Interface

Reliable operation and ease of inspection and maintenance is achieved by an innovative grouping of functions in this assembly (see Figure 11). These functions include:

- A single screw-type levering system, which incorporates in one assembly the safety interlocks and breaker latching device.
- Ground stab assembly for grounding the circuit breaker in all positions.
- Secondary disconnect assembly which has automatic, self-aligning sliding type contacts. The secondary mechanism is easily operated from the front of the switchgear to engage the "test" position.

- Additional circuit breaker auxiliary switches (MOC switch).
- Breaker position switches (TOC switch).

Horizontal Drawout Circuit Breaker

Type VCP-W circuit breaker (Figure 12, 2-4) is a horizontal drawout design, which provides connect, test, and disconnect positions with the door closed. The stored energy mechanism is on the front of the breaker so inspection and minor maintenance can be done with the breaker on the removable extension rails without the need for a separate lifting device. The auxiliary drawers can also be withdrawn on these same extension rails for inspection and minor maintenance without the need for a separate lifting device.

Automatic Shutter

The grounded steel shutters (Figure 12, 5) operate automatically, when the circuit breaker is withdrawn, to protect the operator from accidental contact with the stationary primary contacts. The shutters are located behind a glass polyester CT barrier.

Frame and Housing

A modular housing provides for maximum rigidity and flexibility.

Main Bus System

The main bus is flame retardant and track resistant fluidized bed epoxy insulation with plated joints and constant pressure washers.

Ring-Type Current Transformers

The CTs are easily accessible from the front, with space for a maximum of 4 current transformers per phase. (Figure 11)

Primary and Secondary Contacts

All moving breaker contacts are self-aligning, have positive action, and are silver-plated.

Metal Compartment Barriers

All compartments (Figure 12, 9) are enclosed by grounded metal barriers.

Removable Insulation Barrier

The insulation barrier (Figure 12, 10) is breaker mounted. This provides easy access to compartment when breaker is removed.

Breaker Wheels

Breaker (Figure 12, 11) can be rolled on floor when removed from the structure.

Auxiliary Compartment Shutter

As an added safety feature, the auxiliary compartment shutters operate automatically when the auxiliary drawer is withdrawn. This is to protect the operator from accidental contact with the stationary primary contacts.

Cable Space

Ample cable space (Figure 13, 13) is provided for cables, potheads, and other related components. Top or bottom cable entry is available.

Potential Transformers

Potential transformers are drawer-mounted (Figure 13, 14) for front accessibility and can be completely withdrawn on the same removable rail extensions used for the VCP-W breaker.

Control Power Transformers

Drawer mounting (Figure 13, 15) makes control power transformers accessible. They can be completely withdrawn the same as the potential transformer.

VCP-W VACUUM CIRCUIT BREAKER DESCRIPTION AND FEATURES

The new VCP-W vacuum breaker developed by Westinghouse is a high performance, compact device, only 29 inches high, 29 inches wide and 30 inches deep and is significantly smaller than conventional medium voltage drawout circuit breakers. Not only is it small, but it's light weight, too. Breakers' weights range from 350 to 525 pounds.

Westinghouse's commitment to world class products that can compete in a global market, has resulted in a new measure of standardization. All breakers, regardless of voltage or interrupting capability, are the same basic size. Not only that, but most parts of the frame, primary conductors and disconnects, mechanism and interrupter assemblies are identical throughout the breaker product line. This new level of standardization means a higher quality product through high volume parts production with fewer parts to stock. Training time for operating and maintenance personnel is also reduced, as is repair time.

Figures 14-17 show various views of the Type VCP-W vacuum circuit breaker, with some of the major components and features highlighted:

Chassis

A rugged steel frame which contains the front mounted operating mechanism supports the vacuum interrupter pole units. When the breaker is in the withdrawn position on the removable extension rails, it can be lifted off by any suitable lifting means via the lifting yoke. However, a portable lifting device is available as an accessory if no other suitable means is available.

Front Panel

An 11 G steel panel fits to the front of the chassis and provides a "lap" joint with the switchgear when in the connected position. Thus, with the breaker in the connected position, the compartment picture frame and the VCP-W breaker together form a complete barrier between an operator and high voltage. This front panel of the chassis has been designed with the operator in mind, with the controls and indicators attractively grouped on a functional control panel. As added safety two dead front shields (including the front cover) and the operating mechanism are always between the operator and high voltage.

Mechanism

The breaker is equipped with a spring stored energy mechanism vertically mounted in front of the breaker. When the breaker is withdrawn on the removable extension rails, easy access for inspection and minor maintenance is possible without removing the breaker from the switchgear. Consequently, inspection and minor maintenance, such as lubrication, can occur in a timely fashion without the dependence of a unique lifting device. Furthermore, the front mounted design of the mechanism is such as to provide easy access to the low voltage control devices, such as coils, relays, auxiliary switches and charging motor, enabling simple replacement. (Figure 15)

Vacuum Interrupter Mounting

Rugged track resistant and flame retardant glass polyester stand offs support each vacuum interrupter and its associated primary conductors. This assembly provides a self-contained, self-aligning housing, which can be removed as a complete unit. The vacuum interrupter within is supported in such a manner, that during operation, all mechanical loading is transmitted through the molding and not through the envelope and seals of the interrupter.

Contact Erosion Indicator

To facilitate the contact erosion inspection procedure, the VCP-W breaker has a visible direct reading contact erosion indicator. The vacuum interrupters are marked to indicate the permissible contact wear in casechecking of the contacts is desired. (Figure 16)

VCP-W Non-Sliding V-flex Current Transfer

The VCP-W circuit breaker incorporates a patented feature for transferring current from the moving vacuum interrupter stem to the primary disconnect conductors. (Figure 17, 18) The system is unique in two respects. First, low thermal and electrical resistance are achieved by using a multi-point contact. Secondly, the V-flex system eliminates a sliding action resulting in a maintenance free system due to lack of wear, resulting in long life. (Figure 18)

This patented current transfer system consists of a series of .040 inch thick tin-plated, high conductivity copper leaf conductors. The number of leaves depends upon the current rating; e.g., 20 for the 3000 ampere rating. Each leaf has a hole to connect to the vacuum interrupter stem. However, the circumference of this hole has a series of radial slots to provide an 8 discrete segment configuration, these segments are then set-up or raised, the inside diameter coinciding with the stem diameter.

The action of connecting each leaf conductor to the vacuum interrupter stem initiates a flattening operation of the segments, in turn, each segment is swagged into intimate contact with the stem. Therefore, each separate leaf provides a multi-point connection.

Motion of the vacuum interrupter stem is accomplished by providing a long cantilever length. This is enhanced by the "V" configuration of the flexible leaf conductors. As the stem moves up and down the V configuration and the long cantilever length flex, eliminating the common sliding action, this lack of wear results in a maintenance free system.

This current transfer system has two advantages over conventional spring-loaded sliding contacts: 1) very long life, no sliding action to produce wear; and 2) very low electrical and thermal resistance, because of the multi-points. This patented system provides excellent electrical and thermal transfer, and is also maintenance free.

Field Tested Components

To enhance the reliability of the circuit breaker, field proven components from existing Westinghouse products have been utilized. These components include ratchet, cam and trip systems in the mechanism, and primary disconnect finger assemblies.

SUMMARY

The VCP-W vacuum breaker and VacClad-W metalclad switchgear have been designed, tested and manufactured to meet the global needs in the areas of performance, safety, maintenance, space utilization, application flexibility and reliability. The design criteria are in full compliance with ANSI, IEC, IEEE and NEMA Standards. Conformance to these industry standards assures a high level of performance and a total quality product.

Figure 1 — Vacuum interrupter cutaway.

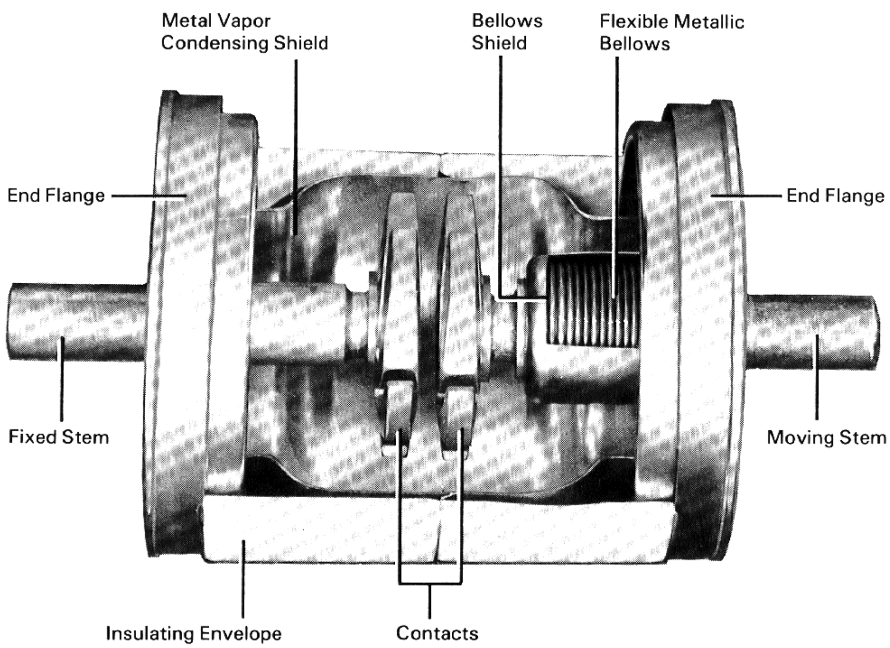


Figure 2 — "Spiral" electrode configuration.

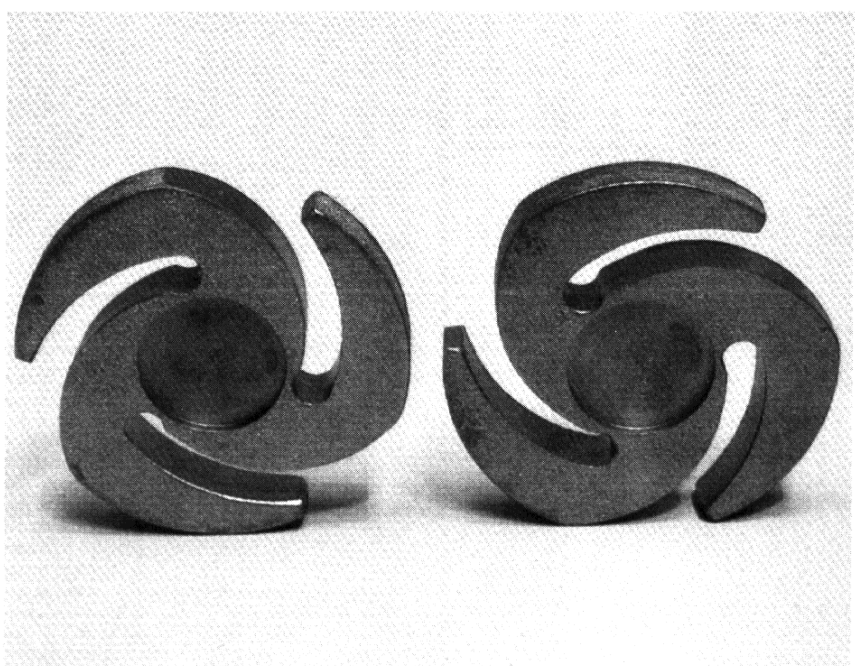
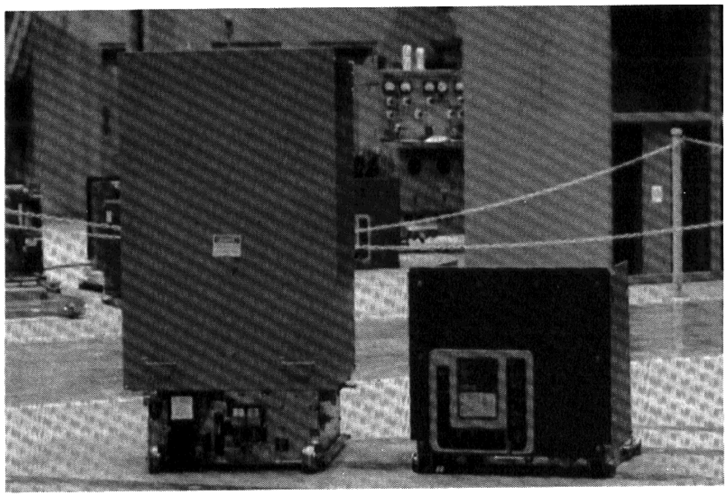


Figure 3—VCP-W breaker alongside a comparable DHP air breaker.



DHP VCP-W

Figure 4—Interruption in vacuum.

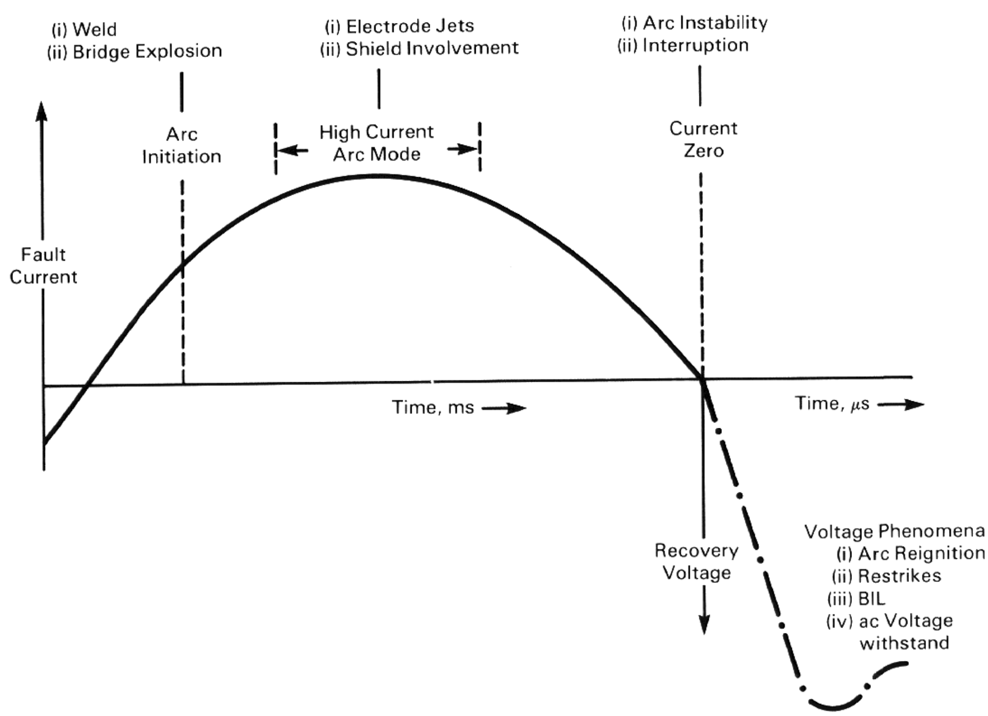


Figure 5 — Upper breaker in withdrawn position on removable extension rails.

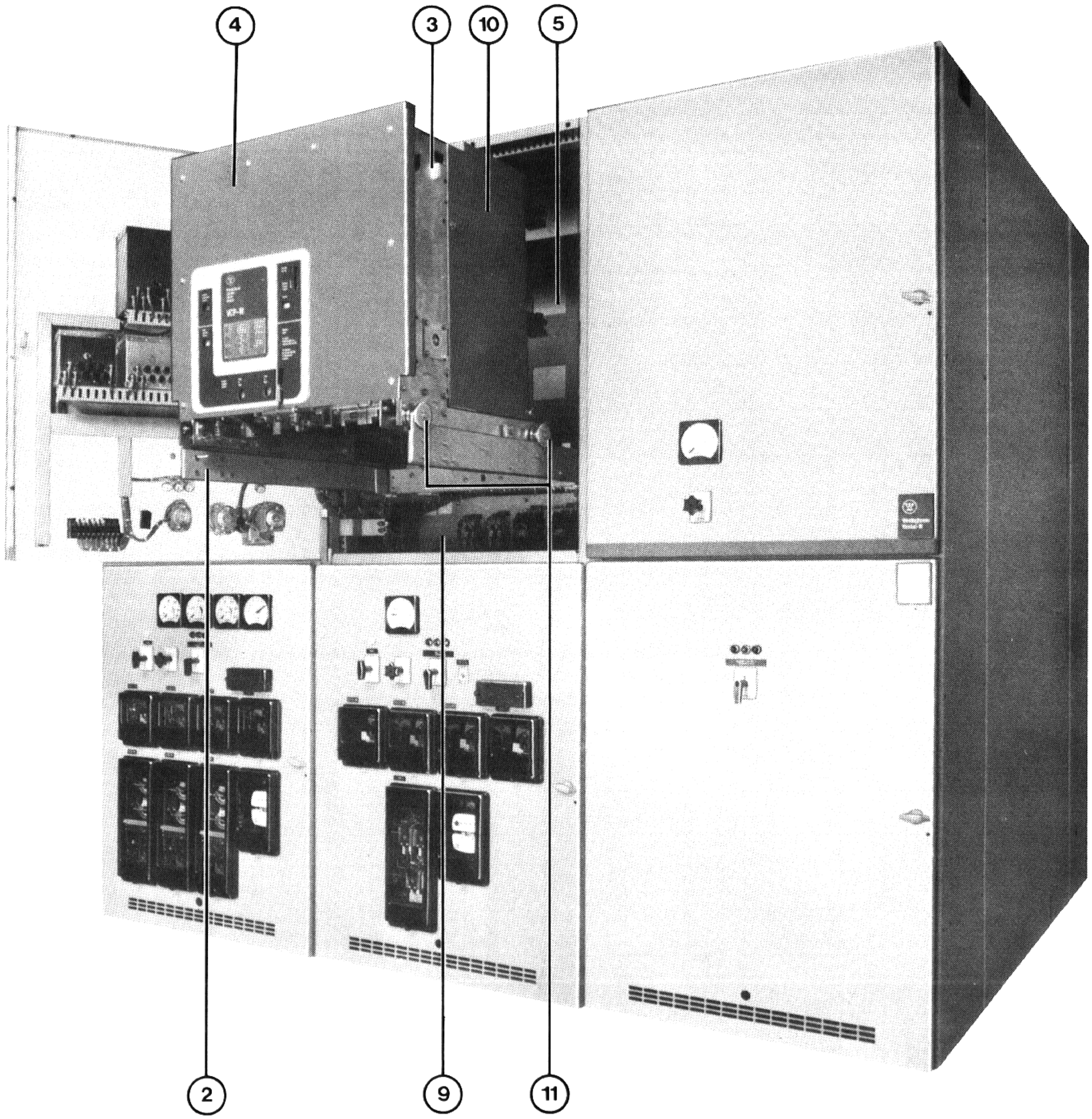
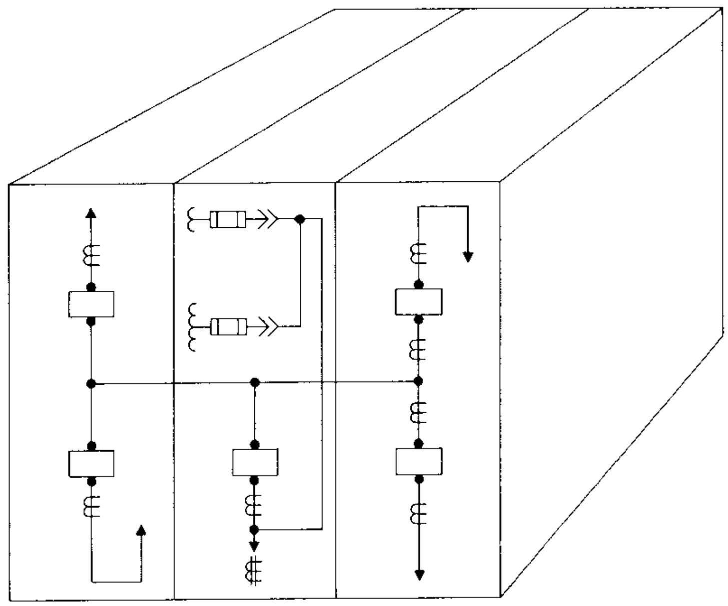
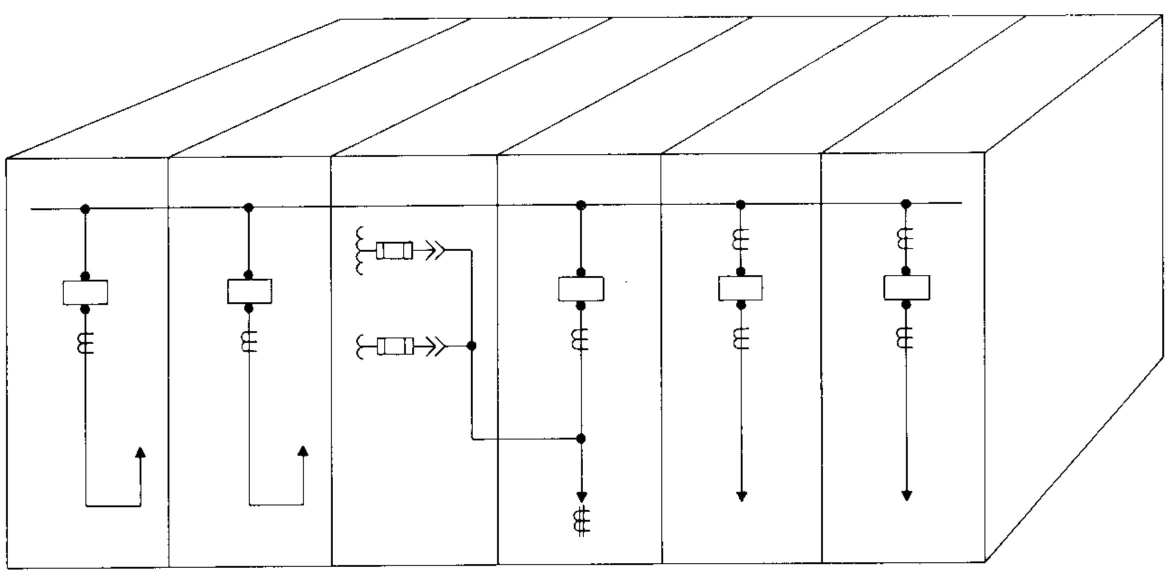


Figure 6 — Comparision of VacClad-W and conventional switchgear.



VacClad-W



Conventional Switchgear

Figure 7A — Available breaker types rated on symmetrical current rating basis, per ANSI Standards.

Identification: Circuit Breaker Type	Nominal Voltage Class (kV Class)	Nominal 3-Phase MVA Class (MVA Class)	Rated Values: Voltage: Rated Max. Voltage E (kV rms)	Rated Voltage Range Factor ② K	Insulation Level: Rated Withstand Test Voltage: Low Frequency (kV rms)	Impulse (kV Crest)	Current: Rated Continuous Current at 60 Hz (Amperes)	Rated Short Circuit Current (at rated Max. kV) ② I (kA rms)	Rated Interrupting Time (Cycles)	Rated Permissible Tripping Delay ② Y (Sec.)	Related Required Capabilities②: Rated Max. Voltage Divided By K E/K (kV rms)	Current Values: Maximum Sym. Interrupting Capability — K Times Rated Short Circuit Current② KI (kA rms)	3 Sec. Short-Time Current Carrying Capability — K Times Rated Short Circuit Current② KI (kA rms)	Closing and Latching Capability (Momentary) ① — 1.6 K Times Rated Short Circuit Current (kA rms)
VCP-W Vacuum Circuit Breaker														
50 VCP-W 250	4.16	250	4.76	1.24	19	60	1200 2000 3000	29	5	2	3.85	36	36	58 78①
50 VCP-W 350	4.16	350	4 76	1.19	19	60	1200 2000 3000	41	5	2	4.0	49	49	78
75 VCP-W 500	7.2	500	8.25	1.25	36	95	1200 2000 3000	33	5	2	6.6	41	41	66
150 VCP-W 500	13.8	500	15	1.30	36	95	1200 2000 3000	18	5	2	11.5	23	23	37 58①
150 VCP-W 750	13 8	750	15	1.30	36	95	1200 2000 3000	28	5	2	11.5	36	36	58 77①
150 VCP-W 1000	13.8	1000	15	1.30	36	95	1200 2000 3000	37	5	2	11.5	48	48	77

① Non-standard circuit breakers with high momentary rating available for special applications.
② Consult Westinghouse Application Data 32-265 or Descriptive Bulletin 32-255 for further information.

Figure 7B — Available breaker types rated on symmetrical current rating basis, per IEC Standards.

Circuit Breaker Type	Voltage Class	Insulation Level kV: Power Frequency	Insulation Level kV: Impulse Withstand	Rated Normal Current Amps	Rated Short Circuit Breaking Current kA rms	Short Time Current, kA rms 3 sec.	Short Circuit Making Current kA peak
36 VCP-W25	3.6	10	40	630, 1250, 2000	25	25	64
36 VCP-W32	3.6	10	40	1250, 2000	31.5	31.5	81
36 VCP-W40	3.6	10	40	1250, 2000	40	40	102
72 VCP-W25	7.2	20	60	630, 1250, 2000	25	25	64
72 VCP-W32	7.2	20	60	1250, 2000	31.5	31.5	81
72 VCP-W40	7.2	20	60	1250, 2000	40	40	102
120 VCP-W25	12	28	75	630, 1250, 2000	25	25	64
120 VCP-W32	12	28	75	1250, 2000	31.5	31.5	81
120 VCP-W40	12	28	75	1250, 2000	40	40	102
175 VCP-W25	17.5	38	95	1250, 2000	25	25	64
175 VCP-W32	17.5	38	95	1250, 2000	31.5	31.5	81
175 VCP-W40	17.5	38	95	1250, 2000	40	40	102

③ Interrupting time is 3 cycles at 50/60 Hz.
Rated operating sequence 0-3 min-CO-3 min-CO.
Consult Westinghouse for KEMA certificates on file.

Figure 8 — Available configurations.

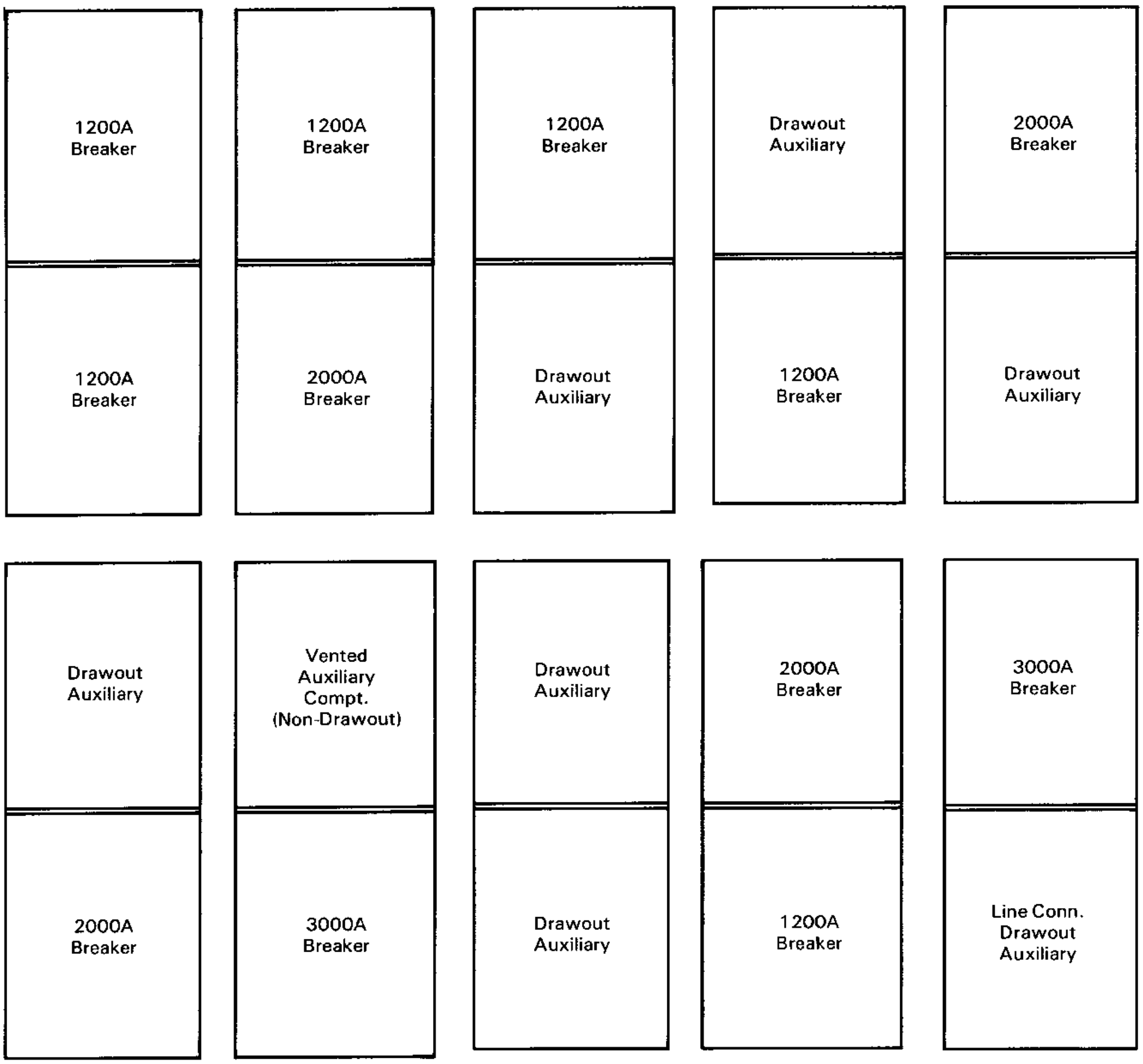
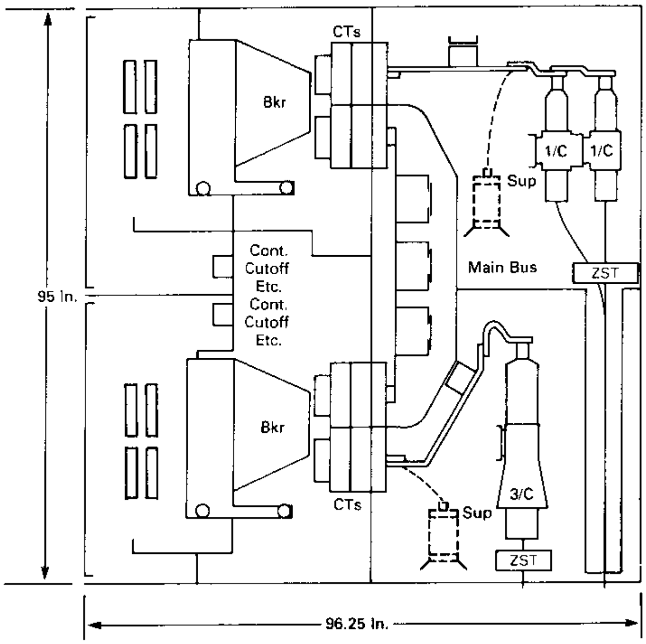
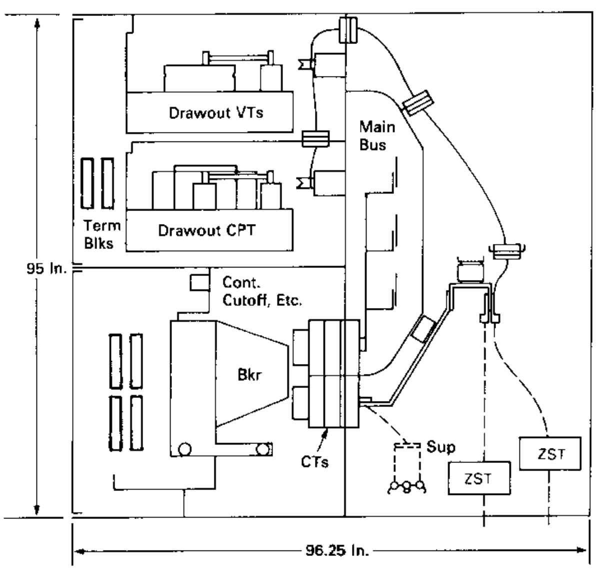


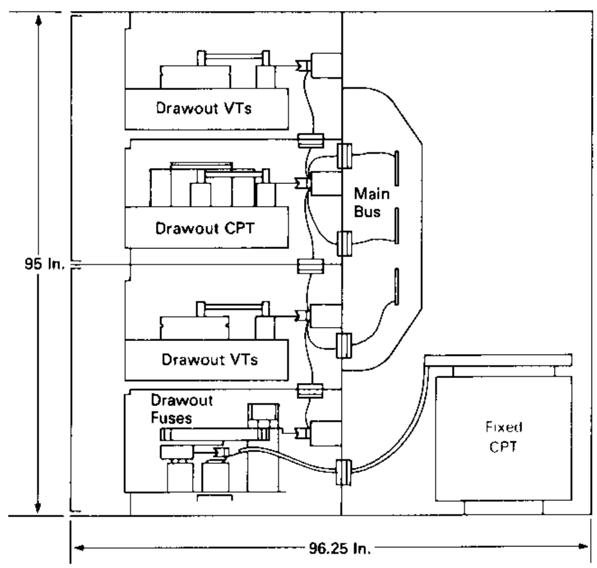
Figure 9—Typical vertical sections.



36 inch Wide Typical Breaker/Breaker Vertical Section

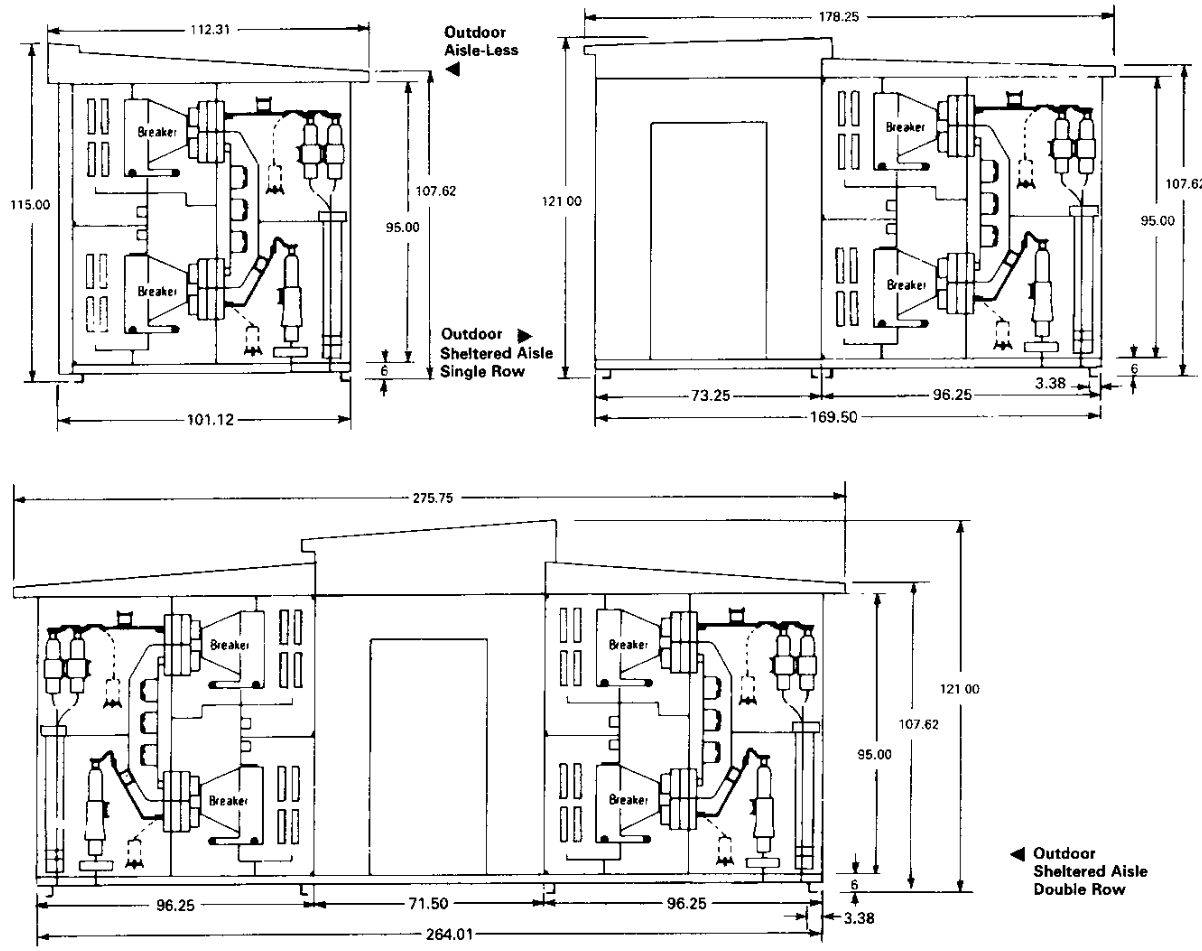


36 inch Wide Typical Auxiliary/Breaker Vertical Section



36 inch Wide Typical Auxiliary/Auxiliary Vertical Section

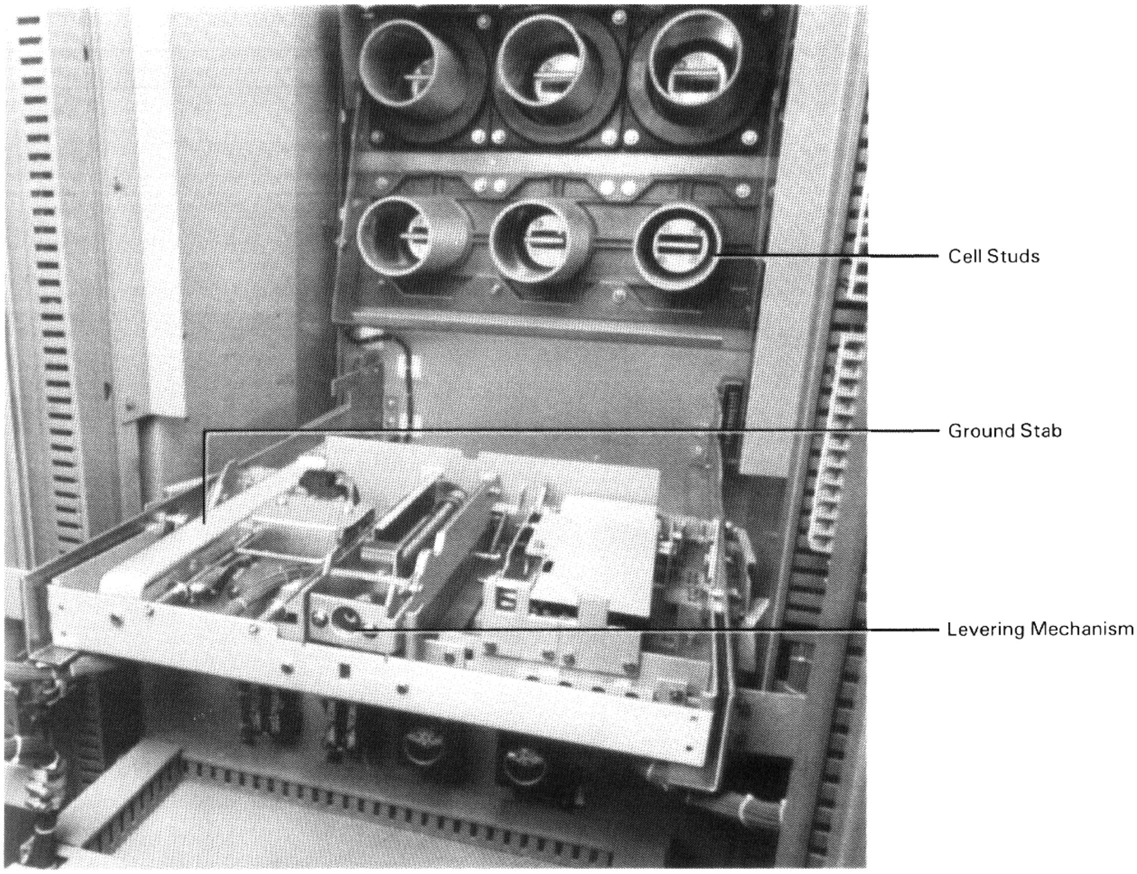
Figure 10—Outdoor versions of VacClad-W.



Dimensions, Inches

Note: Dimensions not to be used for construction. These shown are for reference only. Consult Westinghouse for exact dimensions.

Figure 11—Breaker cell interface.



Note: Shutters should be removed or forced into the open position only when the unit is de-energized. Shutters are shown in the open position for illustrative purposes only. CT barrier has also been removed for clarity.

Figure 12—Upper breaker in withdrawn position on removable extension rails.

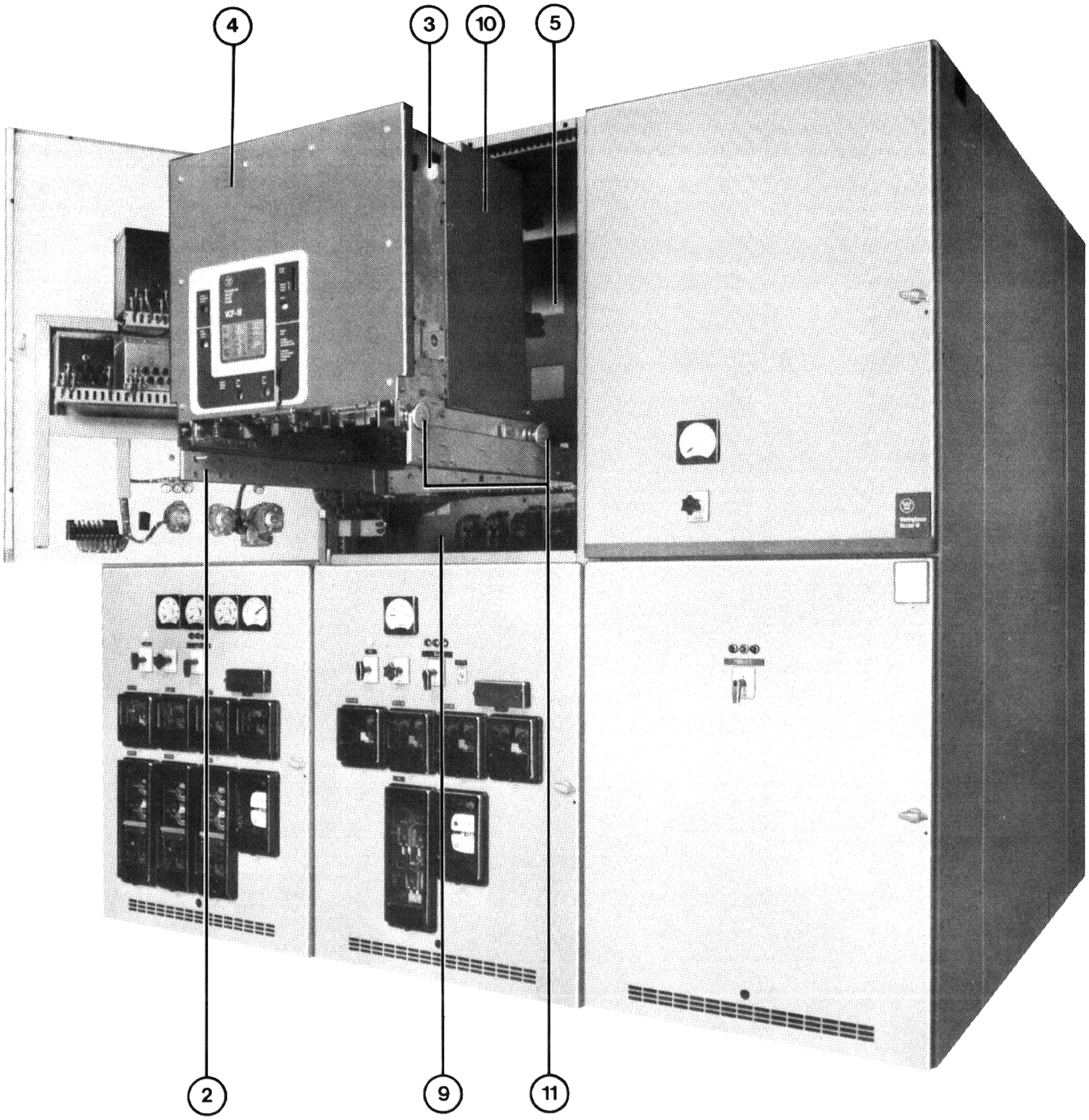


Figure 13—VacClad-W features.

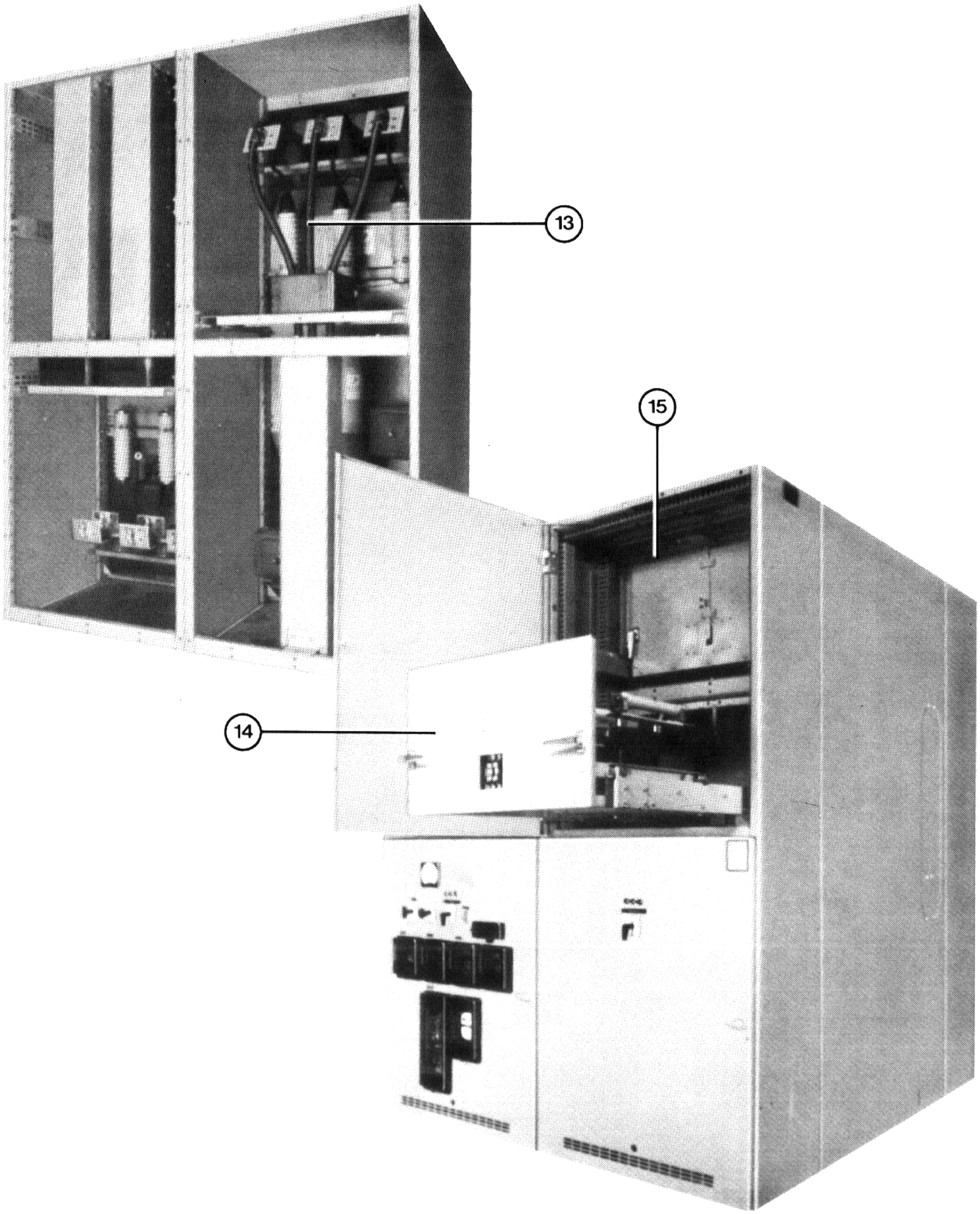
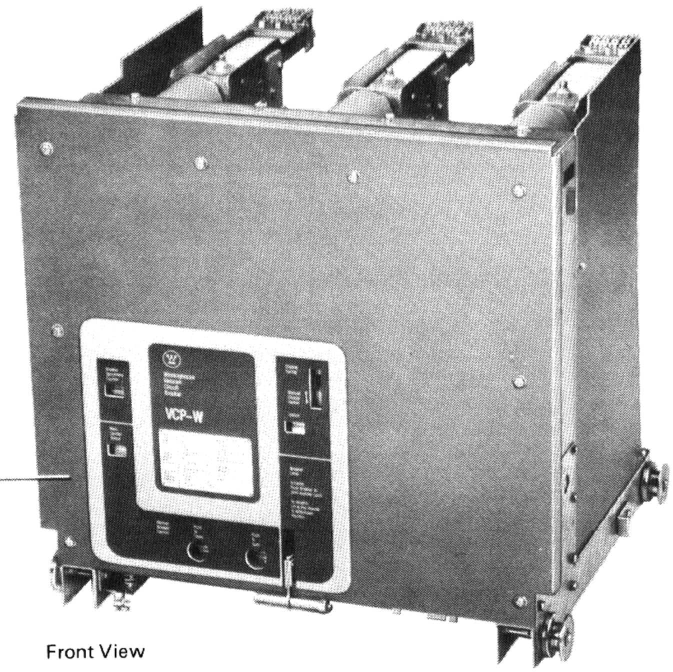
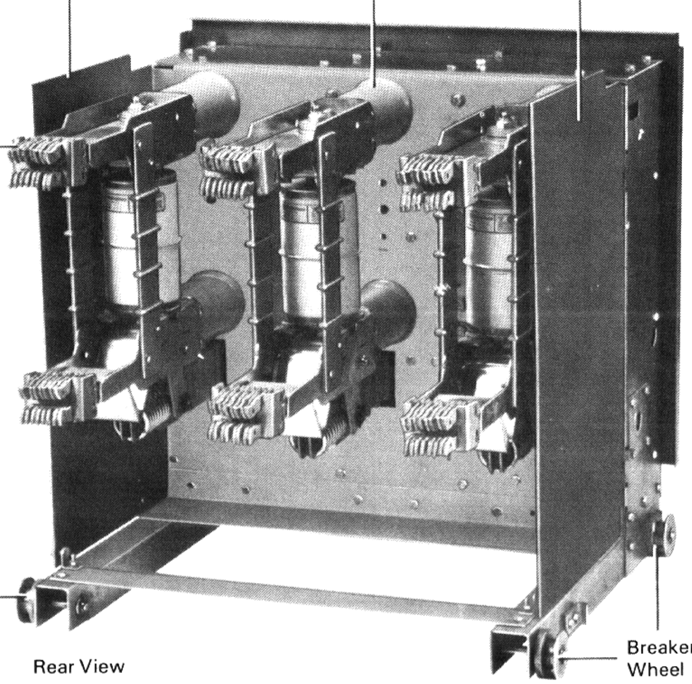


Figure 14—Various views of the VCP-W vacuum circuit breaker.



Front View



Rear View

Figure 15 — VCP-W breaker with front cover removed.

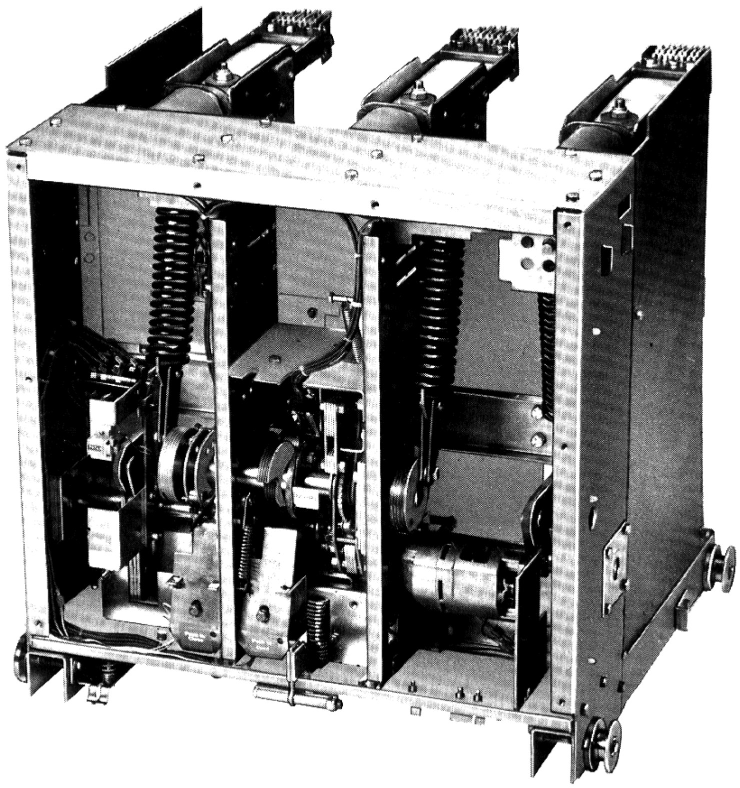
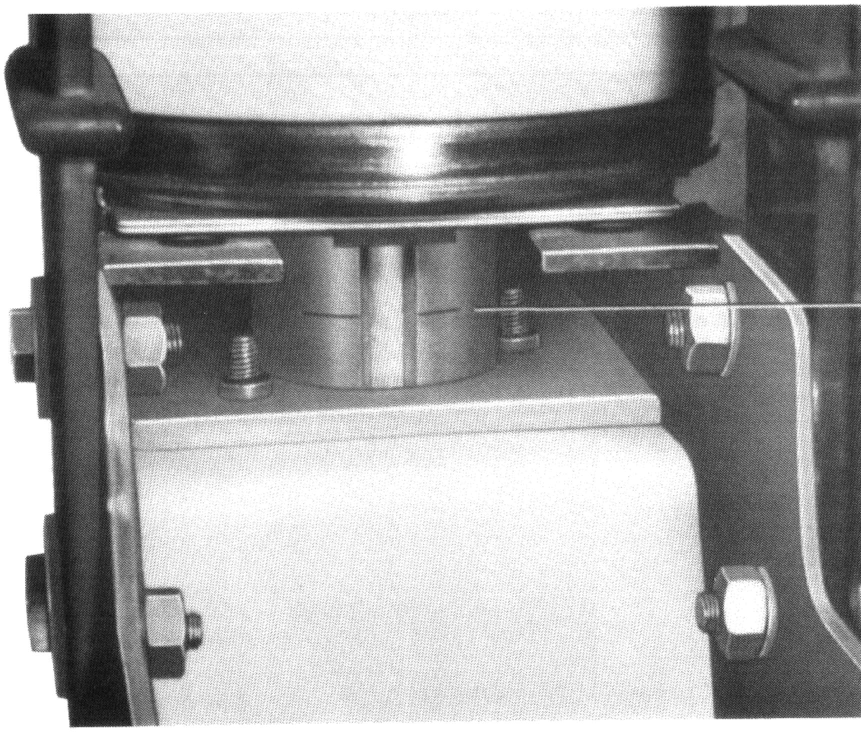
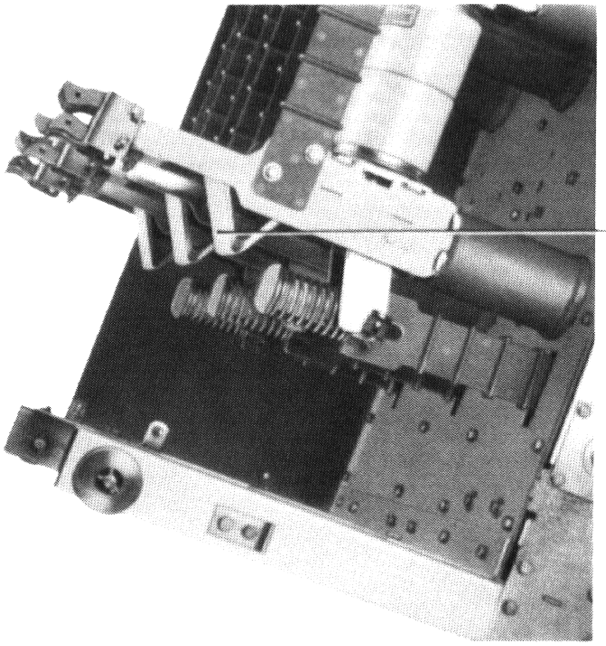


Figure 16—Direct reading contact erosion indicator.



Vacuum interrupter contact wear indicator. Clearly visible, wear-gap (contact erosion) indicators require only an occasional check.

Figure 17 — Patented V-flex current transfer system.



Vacuum Interrupter Current Transfer Conductor

The stiff-flexible current transfer from the vacuum interrupter moving stem to the breaker main conductor is a non-sliding design – thus eliminating the maintenance required with sliding type transfer arrangements.

Reduced Maintenance

Due to the inherent long life characteristics of the vacuum interrupter and the reliable stored-energy mechanism, the type VCP-W breaker requires minimum maintenance.

Figure 18—Current transfer design.