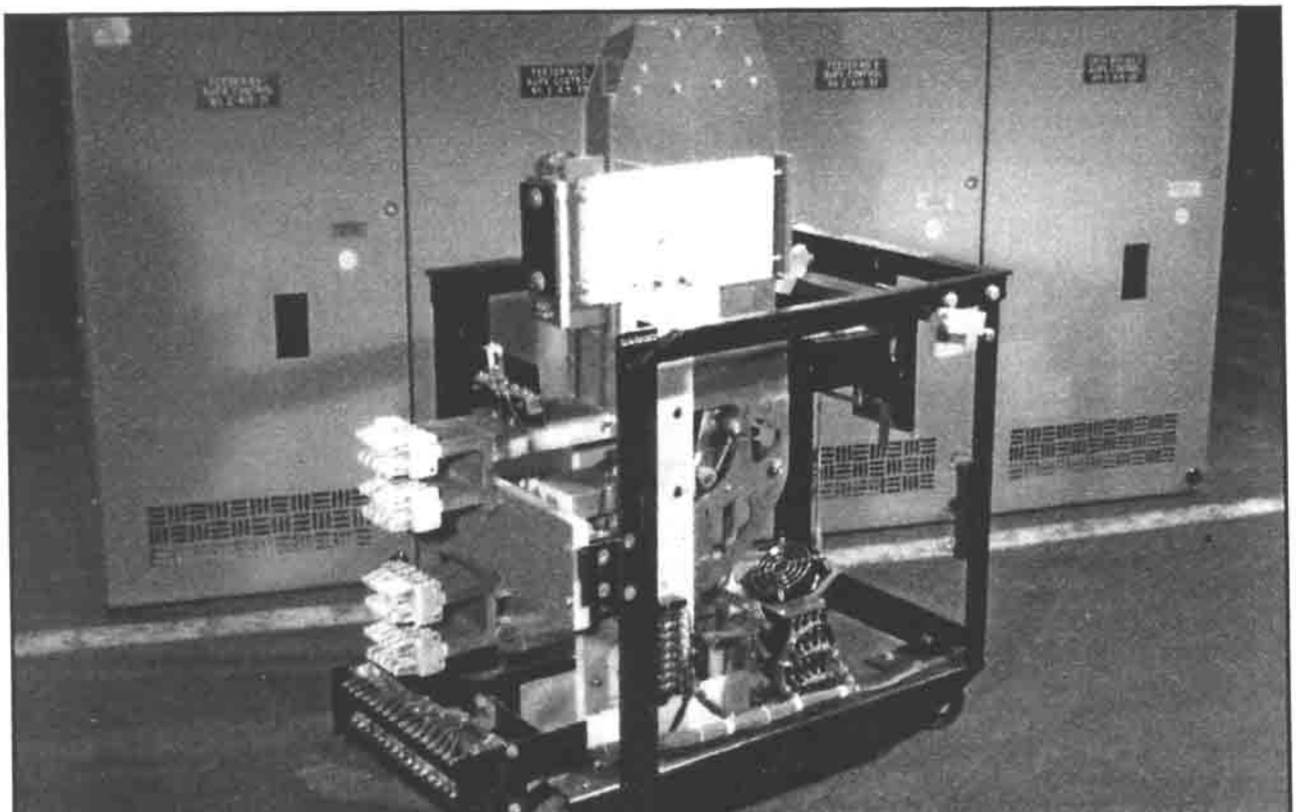
GENUINE
WESTINGHOUSE
D.C.
POWER CIRCUIT
BREAKER
APPLICATION
GUIDE

LOW VOLTAGE D.C. POWER CIRCUIT BREAKER APPLICATION GUIDE



LOW VOLTAGE

DC

POWER CIRCUIT

BREAKERS

GENERAL INFORMATION

INTRODUCTION

Low voltage ac power circuit breakers, such as the Westinghouse type DB, are used in large quantities (several thousand per year) and have been widely publicized as to ratings, dimensions, coordination, limitations, etc. Therefore, the application has become familiar to most users of switchgear. In contrast, dc breakers are used in much smaller quantities (in hundreds rather than thousands). Their applications are often rather special and little published data is available. Hence, application engineers and ultimate users of dc switchgear often need more information about how to choose and apply these breakers. The purpose of this article is to review the general characteristics of dc breakers, list the specific Westinghouse types, and discuss the applications of each type.

THE INTERRUPTION OF DIRECT CURRENT

The interruption of direct current is distinctly different from the interruption of alternating current and is generally more difficult at comparable voltages and currents. An ac breaker usually interrupts at or very near normal current zero. Ideally, an ac interrupter does not need to develop much arc voltage drop (during the current part of the cycle) but must develop the ability to withstand voltage very quickly after the instant of current zero. In contrast to this, a direct current interrupter must develop an arc voltage greater than the applied circuit voltage <u>while current is flowing</u> in order to force the current to zero. Hence, the dc interrupter usually must absorb much more energy than an ac interrupter for comparable voltages and currents. Therefore, a given contact structure and arc-chute will have a lesser voltage and current interrupting capacity on direct current than on alternating current.

CLASSIFICATION OF DC BREAKER TYPES

DC breakers may be classified in several ways, such as, speed, voltage, continuous current, and special applications. General purpose breakers are not specifically designed to be very fast and usually do not limit the maximum fault current except in very slowly rising current. General purpose breakers are often identical in design to standard ac breakers but they are given different ratings when they are applied on dc. Usually with breakers designed for ac service but used on dc, the continuous current carrying ability will be higher due to the absence of skin effect, eddy currents, and hysteresis; but the maximum current the breaker can interrupt will be less and the maximum circuit voltage, on which it may be applied, will be much less.

Current limiting breakers are, by standards, put in two classes: high speed and semi-high speed. Both types, when properly applied, act quickly enough to stop the rise of fault current before it reaches the ultimate or E/R value.

Voltage classes recognized by ANSI are: 300, 325, 800, 1000, 1600, 3200 max. volt for application on systems having nominal voltages of 250, 275 for mining, 750, 850, 1500, and 3000. (ANSI Std. C37.14 1992).

Frame size current ratings range from 225 to 12,000 amperes. Note, however, all classifications do not cover the complete ranges of speed, current, and voltage classes. See attached Tables: 8, 9, 10, 11, 11A, 12 and 14 which are taken from ANSI C37.14-1992.

GENERAL PURPOSE BREAKERS

For many applications on lower voltage and lower powered circuits, the maximum possible fault current will be so low that all the equipment on the circuit can withstand the maximum current for about 0.20 second (200 milliseconds), and a so-called general purpose or slow-speed breaker may be used. These breakers are not fast enough to do much current limiting except when the current rises very slowly, and, therefore, must be so chosen that they can interrupt the maximum current (with maximum voltage) that can exist in the circuit. On older type breakers which have no arc-chutes (such as the CL, CH and CHM) or have simple barrier type arc-chutes (such as the HS or CHR), the arc energy is largely dissipated in the wide-open free air space always provided above and/or around these breakers types. Hence, these breakers are not very sensitive to arc energy. When inductance and current are high, energy ($1/2\ L\ i^2$) will be high and a larger, more persistent ball of fire (ionized gas) will be thrown high above the breaker, but the interruption will be completed. When these breakers are applied on higher-powered circuits, it is essential that adequate clear space be provided above the breaker. Before applying these breakers, the general outline drawings should be studied (these show the gas clearance space required) or the Engineering Department should be consulted.

Other general purpose dc breaker types (such as the DA and the DB), which have arc-chutes that constrict the arc in a relatively small space, have upper limits on the amount of arc-energy they can absorb. Therefore, these types have an interrupting current rating which is dependent upon the circuit inductance. For higher voltages, (500-600-750) older, slow speed, general purpose types, such as the CH or CHM, may sometimes be used. (The CHR may be used up to 1500 volts). The general trend is to use semi-high speed breakers (Types DR or DMD) or the high speed breakers (Types DM-2F and DM-2R) on circuits of 500 volts or higher This is because the higher voltage usually results in higher rates-of-rise and such high ultimate currents that some current limitation is desirable even though not absolutely necessary.

CURRENT LIMITING BREAKERS

On higher powered circuits, especially at the higher voltages, the value of the fault current may increase to the point that damage may result to the equipment or the breaker may be unable to interrupt the fault current. It is uneconomic to operate under these conditions, and it becomes necessary to slow down the rise of fault currents and interrupt them.

The manner in which the current builds up in a dc circuit depends on the supply circuit. If the supply circuit is true dc such as is produced by a battery or a dc generator the current will build up along the well-known exponential curve that is characteristic of a resistance-inductance circuit. Tests "b", "c", and "d" of the ANSI Standard Tables 11A and 12 are representative of the classic rate-of-rise curves normally associated with these supply circuits. If the supply circuit is ac, as in the case with power rectifiers, the current can build up with a peak occurring during the first cycle of the ac supply frequency and then drop to some sustained value. The early peak is caused by the offset in the ac phase currents. This early peak means that, except for high speed dc breakers which part contacts in a time short enough to prevent the peak from being reached, a dc breaker on such a circuit can be subjected to the mechanical stresses of currents that can be appreciably higher than the current it will have to interrupt. If the breaker mechanical and interrupting rating are the same current level, the first cycle peak current will determine the application limit, not the smaller sustained current that must be interrupted. Test "a" of Standard Tables 11, 11A and 12 represents this type of rate-of-rise supply circuit.

A simple rough estimate of the first cycle peak can be made. A short circuit on the dc terminals of the rectifier can be considered as an extension of a three phase short circuit on the ac side. A maximum asymmetry factor, which gives the highest current in the ac supply (by multiplying the factor by the steady-state ac fault current), can be calculated for a three phase short circuit as a function of the X/R ratio of the circuit to the terminals of the rectifier and then find the maximum asymmetry factor from the curve in Fig. 1. The steady state fault current is calculated from the impedance to the terminals of the rectifier. This value is then multiplied by the maximum asymmetry factor to approximate the first cycle peak.

SEMI-HIGH SPEED BREAKERS (Refer to ANSI Std. C37.14-1992, Tables 11A & 12)

The standards define the semi-high speed circuit breaker as one which during interruption does not limit the current peak of the available (prospective) fault current on circuits with minimal inductance (Test"a" of Tables) but which does limit current to a value less than the sustained current available on higher inductance circuits (Test "b", "c", and "d" of Tables). This breaker requires a peak, a short-time and a short-circuit rating. For this application, the Types DR and DMD breakers are available. The Type DR breaker will handle about 150,000 amperes electrically and mechanically and the DMD will handle about 100,000 amperes electrically and mechanically.

On an ac supplied dc circuit, the first cycle peak must be given consideration. This peak must not exceed the mechanical limit of 150,000 amps. for the DR breaker or 100,000 amps. for the DMD breaker. For this type of circuit, the peak current can get higher than the current that is finally interrupted, so the breaker and all other series components must be able to withstand the higher current. This type of circuit gives an appreciably higher rate-of-rise for the same KW rating. The breaker must not be subjected to any current higher than its peak current rating.

The DMD breaker is of more modern design and is somewhat faster than the DR. In those applications where currents in excess of the peak current rating of the DMD breaker are encountered, it is recommended that the type DM-2F high speed breaker be used rather than the DR. Use of the DM-2F makes short circuits easier on the breaker and other equipment in the circuit.

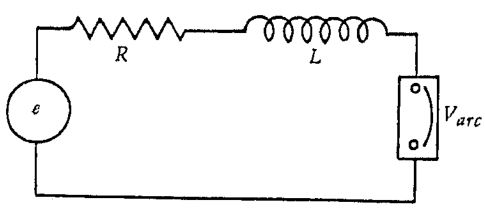
HIGH SPEED BREAKERS - (Refer to IEEE Std. C37.14-1992 Tables 11, 11A & 12)

The standards define the high speed circuit breaker as one which during interruption limits the current peak to a value less than the available (prospective) fault current (Test "a" of Tables). This breaker requires a short-time rating and a short-circuit current rating. For this application the Types DM-2F and DM-2R are available. These breakers have been tested in circuits having 217.5KA peak current availability. The short-time rating is 75KA and the short circuit rating is 139KA.

The short time in which a dc high speed breaker must act to be current limiting necessitates the use of mechanisms with a small amount of mass, and usually requires a mechanism that has a holding coil type latch rather than a mechanical type latch which would require time to disengage and accelerate. The presently available high speed breakers for metal enclosed dc circuits up to 1000 volts are modifications of the type DM basic pole unit. The attached tabulations show what characteristics are available in high speed breakers.

CIRCUIT STUDIES FOR NEW APPLICATIONS

When a dc circuit breaker is being considered for a new or unusual application, the following circuit factors must be reviewed: voltage, resistance, inductance, and circuit arrangement. In addition to the circuit constants, parallel sources of power and feed-back from driven apparatus must be considered. As with ac breaker application, a complete circuit or system diagram is essential. This diagram should include the electrical characteristics of all components which may affect any possible switching or fault interrupting conditions to be imposed on the breaker. Not only rotating machine voltages but also super-imposed ac voltages, (from rectifier circuits) battery voltages, and counter e.m.f.'s. from electro-chemical cells. In higher powered circuits, all resistance, inductances, and parallel sources should be carefully estimated. For simplicity, it is often convenient or even necessary to reduce a complex multi-unit circuit to an equivalent simple series circuit, consisting of source voltage (or source voltages), resistance, inductance and the breaker in question.



* e = total Instantaneous Voltage

R = total Circuit Resistance

L = total Circuit Inductance

*May include several sources and sometimes ac super imposed on the DC

When a fault occurs, but before the breaker begins to open the initial rate-or rise equation is:

$$di/dt = e/L$$

In high powered circuits, it is important to get a good estimate of this initial di/dt. After the breaker starts to open, arc voltage begins to develop and affect the current according to the general relation:

$$di/dt = \frac{e - iR - Varc}{L.}$$

From this equation, it is apparent that the voltage, resistance, and inductance must be known, at least approximately before the performance of a breaker in a new circuit can be predicted.

ARC ENERGY ABSORPTION

Those breaker types which have arc-chutes that constrict the arc in a relatively small space, (such as the Types DA, DB, DL, DM, DM-2F, DM-2R, DR and DMD) dissipate much of the arc-energy in heating the materials of the arc chute. Therefore, breakers of this design have very definite limits as to how much arc-energy they can absorb. When an arc-chute becomes too hot, the breaker arc voltage drop becomes too small to force the current to zero. The interrupting time will prolong to ultimate failure. The amount of energy that a specific arc-chute can absorb and still be expected to interrupt the fault current successfully is expressed in watt-seconds.

The importance of knowing the circuit inductance, at least approximately, cannot be overstressed. In addition, to setting the initial rate-of-rise ($di/dt = e/L$), inductance affects the energy initially stored in the circuit ($1/2\ L\ i^2$). This, plus energy from the source during the interrupting interval, must all be dissipated in the arc-chute.

ACCESSORY DEVICES

In order that a circuit breaker may properly perform its primary protective functions of interrupting faults or overloads in the main circuit, and in some cases provide routine switching of the main circuit, various accessory and secondary control circuit devices are usually required to be mounted on the breaker. Not all devices listed below are applicable to all breaker types. Furthermore, the number of devices that can be mounted simultaneously, on a single breaker, may be limited.

1. Series Overcurrent Trip Devices

   a) *Dual long delay and Instantaneous
      (Sometimes called ITL trip)

   b) *Long delay and Short delay

   c) Instantaneous only

   *Note: These are very seldom used on dc breakers except for tie feeders or very special application.s

2. Reverse current trips

3. Shunt trips

4. Undervoltage trips

   a) Instantaneous

   b) Delayed - See Note * above

5. Impulse Trips

   a) Bucking Bar

   b) Electronic Trips

      Usually mounted in cell or on bus bar.

6. Rocking Beam Relay; operates thru Electronic trip or shunt trip.

7. Manual Trip

8. In addition to the above trip devices, the following auxiliaries may be supplied.

   a) Automatic trip indication switch

   b) Lock-out attachment

   c) Operation counter

   d) Auxiliary switches

   e) Position indicators

   f) Key interlocks

9. Most high speed breakers do not have mechanical latches (in the ordinary sense) to hold them closed but use some of magnetic latch with a holding coil. They are also usually tripped by an impulse system.

10. The controls for semi-high speed types, such as the Types DR or DMD, are similar to the controls used for electrically operated low voltage ac breakers. They will have electrically operated closing devices and some form of electrically operated tripping devices.

    The controls for high-speed breakers are special. They may or may not be equipped with any of the accessories listed above. See later discussions of these types and always refer requests for these to headquarters for analysis of the application.

APPLICATION

For this discussion, breaker applications will be divided into two general categories: the type of service and the breakers used for each service:

AUXILIARY POWER SUPPLIES

The most commonly used service is for auxiliary power in factories and mills. Usually, power for this service is supplied at a nominal voltage of 250 volts dc. In the past, the source of this dc was from M-G sets or from rotary converters. From about 1935 to 1960, the multi-anode rectifier and later the single anode rectifier was used. Today, for this type of service, the silicon diode rectifier is almost universally used.

The output of the converting apparatus is fed to the distribution bus through the machine breaker (in the case of the rectifier this is called the cathode breaker). Feeder breakers connect the utilization apparatus to the distribution bus. When two sources of power are available, the distribution busses are usually connected together without a tie breaker. In this case, the installation become equivalent to a single source of larger capacity. Also, in this case, it is most economical to connect the power sources to opposite ends of the distribution bus as, under this condition, the bus size will only be of sufficient capacity to carry the output of the largest source. The standard output rating of conversion equipment, today, is 100% continuously, 125% for 2 hours, and 200% for one minute. The machine breaker should be rated to carry the 125% for 2 hours. An example: For a 1000 KW - 250V. dc source, the full load current will be 4000 amperes with 5000 amperes for 2 hours. The breakers must be rated 5000 amperes. The breaker must also be able to interrupt the short-circuit output current of the source. For most conversion equipment, the maximum short-circuit output current is about 10-12 times the continuous rated current, so that, in this example the breaker must be able to interrupt 50,000 amperes.

MAIN MILL DRIVES

The power supplies for dc main mill drives may be M-G sets, variable voltage rectifiers or thyristors (SCR's). The most common configuration, today, is to have an individual power supply for each motor. Some of the smaller mills may have a common supply that feeds all the main drive motors.

The motors for the smaller mills, such as merchant mills, bar mills, and rod mills range in horsepower from 500 to 2500 for each mill stand or group of stands. (A few have had multiple motors on a group of stands up to 5000 HP from 1 power supply). On cold strip mills and on the finishing stands on hot strip mills, (roughing stands are usually synchronously driven), the motor will range from 2500 HP to 12,000 HP per stand. In almost all cases, there is an individual power supply for each stand.

The dc voltage for these drives is almost always in the 600V. to 700 volt range although a few have been designed for higher or lower voltages.

Machine Breakers - Thyristors (SCR's)

When thyristors are used as the main power source, a thyristor section is supplied for the mill rolling operation and a second section (called the inverter section) is used to slow the mill down to threading speed. The rolling operation will require a thyristor to supply the full capacity continuously. The inverter section duty cycle is such that breakers of much reduced capacity (continuous current) may be used. The interrupting duty on the rolling section requires the application of high speed breakers protect the thyristors. The duty on the inverter sections is even more severe in case of an inverter fault as the breaker has imposed on it not only the dc voltage but the ac voltage as well. A special very high speed breaker has been developed for this application. Special arc-chutes have also been developed for these breakers as all thyristors have a maximum PRV (Peak Reverse Voltage) that can be applied across them without damage to them. For the normal mill operating voltage, the thyristors will have a maximum PRV of above 2400 volts. The arc voltage is limited to about 2200 volts.

TRACTION SERVICE

The power supplies for traction service may be M-G sets, rotary converters, mercury arc rectifiers or silicon rectifiers. The last named, silicon, is used almost exclusively, on all new installations, today. The most common operating voltage is 600V. Although some of the latest heavy duty installations, for high speed rapid transit service, will operate at 1000 volts. Breakers are supplied for the cathode. This connects the output of the rectifier to the bus. Track breakers (feeder breakers) which connect the power source to the track feeders and "gap" breakers, which isolate the track between stations, are also used.

Rectifiers, for this service, have a 2-hour overload rating of 150% instead of 125% which is standard for most other applications. They may also have overload ratings of 300% for 1 or 5 minutes and 400 or 450% for a very short time, such as 15 seconds. When breakers are applied, the very short time ratings of 300 or 450% are not considered. The breakers are applied on the basis of 150% of the converter rating.

It is common practice, in order to insure continuity of service, to install more than 1 converter in a station. Multiple units are also used to supply the necessary capacity. Great care must be taken to insure that the interrupting capacity of the breakers is not exceeded. If the system voltage is not above 750 volts and the maximum current cannot exceed 150,000 amperes (taking into consideration the AC offset in the first cycle) the DR breaker may be used. If the current will not exceed 100,000 amperes, the DMD breaker should be considered. If the system parameters will permit maximum currents in excess of the above, the high-speed breakers, Types DM-2F and DM-2R must be used.

Voltages above 750 volts (up to 1500 volts) require the use of the DM line of breakers.

The machine breakers should be equipped with reverse current trips (may also have undervoltage releases and/or shunt trips) and the feeder or c "gap" breakers should have instantaneous, (non-polarized) trips. These may also have undervoltage release and/or shunt trips.

Westinghouse Breakers applicable to this service.

Type DR - DMD - DM-2F - DM-2R

Note: See attached sheets for the breaker parameters.

BREAKER CHARACTERISTICS

Type DR - Semi-High Speed Breaker

1) Current Ratings

   a) 2000A, 3000A, 4000A, 5000A, 6000A, 8000A, 10,000A

2) Voltage Rating

   a) Nominal - 750 volts DC - Maximum - 800 volts

3) Maximum Ratings:

Peak	-	150,000 amperes
Short Time	-	90,000 amperes
Short Circuit	-	150,000 amperes

   a) Per ANSI Std. C37.14-1992 Table 11, 11A and 12
   Note: That on circuits having inductances higher than those given in the above standard the maximum interrupting capability will be lower. The limiting factor is the ability of the arc-chute to absorb the circuit energy. The maximum capability of the chute used on the DR Breaker is approximately 300 kilowatt seconds. Where the duty may be above the stated values, refer the application to the Homewood Plant in Pittsburgh for evaluation.

4) Accessories

   a) Trip units - overcurrent

      1) Instantaneous only (100% to 200% calibration)
      2) Inverse time delay. This becomes instantaneous at about 5 times trip setting.

   b) Shunt trip
   c) Undervoltage trip (release)
   d) Reverse current trip

   Note: Reverse current trip and overcurrent trip <u>cannot</u> both be mounted on the same breaker as the magnetic circuits occupy the same physical space. Alarm contacts can be supplied for the reverse current trip. Can be set for about 15% of the breaker rating.

   e) Closing Device

      1) Electric only
      2) Manual closing lever is supplied for maintenance only

f) Auxiliary switch - 7 pole Std., 9 Pole & 11 Pole available (2-11 pole on stationary mounted breakers)

5) a) Fixed

a1) Open Switchboard on Glastic panel
b1) Metal Enclosed

b) Drawout

a1) Metal Enclosed - truck mounted

Note: One breaker per cell either with or without negative disconnect.

For additional information on the DR Breaker, refer to I.B.35-260.

Type DMD - Semi-High Speed Breaker

1) Current Rating

a) 4000 amperes - single pole

Note: 2 poles can be operated in parallel provided a specific bus configuration is used to insure equal current division thru the 2 parallel poles.

2) Voltage Rating

a) 750 volts, 1000 volts, and 1500 volts

b) Developed Arc Voltage

1) For 750 volt service 2300 volts max.
2) For 1000 volt service 3000 volts max.
3) For 1500 volt service 5000 volts max.

3) Maximum current interrupting rating

a) Per ANSI Std. C37.14-1992

Note that on circuits having inductances higher than those given in the above standard the maximum interrupting capability will be lower. The limiting factor is the ability of the arc-chute to absorb the circuit energy, the maximum capability of the chute used on the DMD breaker is approximately 200 kilowatt seconds. Where the duty may be above the stated values, refer the application to the Homewood Works at Pittsburgh for evaluation.

4) Accessories

   a) Trip Units

      1) Instantaneous
      2) Shunt Trip
      3) Undervoltage Trip (Release)

   b) Closing Device

      1) Electric only
      2) Manual closing for maintenance only

   c) Auxiliary Switches - 8 mechanism activated plus 4 pole activated

5) a) Fixed

      1) Floor mounting
      2) Switchboard pedestal mounting

   b) Drawout

      1) Metal Enclosed on drawout truck

         a1) Single pole
         b1) Single pole with negative disconnect
         c1) 2 pole (without negative disconnect)

For additional information on DMD breakers refer to I.B. 32-410-1 together with the supplement for the DMD breakers.

TYPE DM-2F, DM-2R HIGH SPEED BREAKERS

1) Current Rating

   a) 4000 amperes; DM-2F and DM-2R
   b) 6000 amperes; DM-2F and DM-2R

2) Voltage Rating

   a) 750 volts, 1000 volts and 1500 volts

3) Short-Time Rating - 75,000 amps
   Short Circuit Rating - 139,000 amps

4) Accessories

a) Trip Unit

1) Reverse Current Trip-By Bucking Bar DM-2R only.
2) Forward Current Trip-By Bucking Bar DM-2F only.
3) Definite Value Trip Rocking Beam relay and Trip Coil.
4) Electronic trip unit with trip coil, DM-2R and DM-2F.
Note: The electronic trip and the bucking bar trip are polarized and will trip only on current in a specific direction. The rocking beam relay is not polarized.
5) Undervoltage release (inherent by de-energizing the holding coil).

b) Closing Device

1) Electric only
2) Manual closing for maintenance only

c) Auxiliary Switches - 8 mechanism activated plus 4-pole activated switches.

5) Mounting

a) Fixed

1) Floor mounting
2) Pedestal mounting

b) Drawout

1) Metal enclosed on a drawout truck

a1) Single pole

For additional information, refer to I.B.32-410-1.

Numbered notes indicate breaker use.

Application	Notes
1 - Machine or Cathode Breakers	A, C, D, G, H, J, M & O
2 - Feeder Breakers	B, C, E, G, H, K & O
3 - Tie Breakers	B, C, F, G, H, L & N

Lettered notes indicate breaker characteristics

A - The minimum current rating of the breaker shall be the two-hour rating of the equipment. For auxiliary power supplies and main mill drives, this shall be 125% of the full load continuous rating. For transportation power supplies this shall be 150% of the full load continuous rating. The one minute or ten second rating, etc. shall be disregarded when the application is made.

B - The minimum current of the utilization equipment. For a tie breaker, it shall be the maximum continuous current that may be transferred between busses.

C - The breaker shall be suitable for the maximum voltage that may be applied to the breaker. In addition, the maximum arc-voltage that the breaker may develop should be specified for those applications where possible high arc voltages may damage the equipment. An example is the application of breakers on thyristor power supplies.

D - The breaker should be specified on the maximum current from the source or in the case of multiple units, the maximum reverse current that is available for a fault within the source. With rectifiers the first 1/2 cycle peak should be considered when semi-high speed breakers are used to insure that the current is not above the mechanical capability (peak rating) of the breaker.

E - The breaker shall be suitable for interrupting the maximum output current of the source or sources.

F - The breaker shall be suitable for interrupting the maximum current that may be transferred between busses.

G - The closing mechanism must be electrical but will have mechanical means for maintenance only.

H - All breakers shall be equipped with a shunt trip mechanism. Optional when undervoltage release is supplied. High speed breakers have an inherent undervoltage release and do not have shunt trips.

I - Optional except for cathode breakers with reverse current trips. On cathode breakers, the coil of the reverse current trip mechanism and the undervoltage release shall be in series except when high speed breakers are used.

J - Machine breakers, unless there are no feeders, shall trip from the AC side thru the use of relays with time delay, and the shunt trip. They shall be equipped with reverse current trip mechanisms (or relays) to detect internal machine faults. No time delays shall be used. When there are no feeders, they become equivalent to feeders and should have instantaneous trips.

K - Feeder breaker should have instantaneous trips only. Time delay trips should almost never be used as most utilization equipment is not capable of interrupting short circuit currents. The small contactors used to control motors, etc., can interrupt normal overloads but their ability to interrupt short circuits is limited. As an example, 100 ampere contactors are limited to about 1000 amperes, (10 times) higher currents may destroy or damage them. The opening time of these contactors is about 7 to 10 cycles (on a 60 cycle basis) where-as, the opening time of a breaker used for this service, is 2 to 5 cycles. Therefore, a breaker, without any intentional time delay, can open fast enough to protect the auxiliary equipment.

L - Tie breakers may be applied 3 ways.

1. Tie adjacent busses together.
2. Tie remote busses together.
3. Tie remote busses together and also be used as a feeder.

In Case 1, they may or may not be equipped with overcurrent trips. If they are so equipped, they should have time delay to permit the feeders to trip before the tie breaker trips so that the whole system is not de-energized.

In Case 2, they should be equipped with time delay overcurrent trip to protect the tie cables in case of a fault on the cable and also permit a feeder breaker to clear if the fault is on a feeder from the remote bus.

In Case 3, the tie breaker should have instantaneous trips only to protect the utilization equipment.

M - Machine (or cathode) breakers should have reverse current trips. For rectifiers, the reverse current trip can be a part of the breaker.

N - Tie breakers are not equipped with reverse current trips unless it is desired to feed power in one direction only.

o – All breakers should be equipped with the auxiliary equipment that is required for the proper application or safety requirements for the specific application. These consist of auxiliary switches, cut off switches, secondary contacts, mechanical interlocks, key interlocks, etc. The section on breakers should be consulted for the auxiliaries available on each breaker type.

Figure 1 Average and Maximum Asymmetry Factors

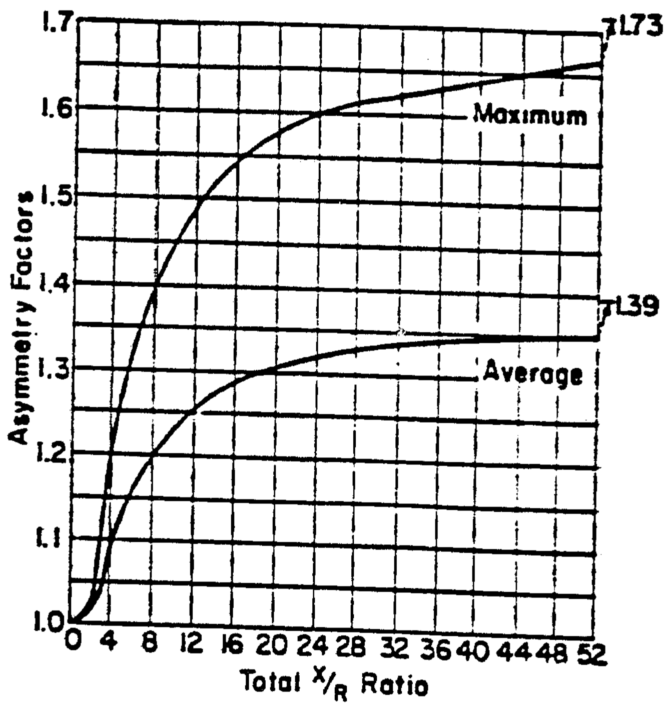


Table 8

Preferred Ratings for General-Purpose Low-Voltage DC Circuit Breakers
with or without Instantaneous Direct-Acting Trip Elements
(See ANSI/IEEE C37.14-199X For the Basis of Ratings)

Line No	Circuit-Breaker Frame Size (amperes)	System Nominal Voltage (volts)	Rated Maximum Voltage (volts)	Rated Peak Current (amperes)*	Rated Maximum Short-Circuit Current or Rated Short-Time Current (amperes)1, 2	Maximum Inductance for Full Interrupting Rating (microhenries)3	Load Circuit Stored-Energy Factor W (kilowatt seconds)3	Range of Trip-Device Current Ratings (amperes)**
	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8
1	600/800	250	300	41000	25000	160	50	40-800
2	1600	250	300	83000	50000	80	100	200-1600
3	2000	250	300	83000	50000	80	100	200-2000
4	3000	250	300	124000	75000	50	140	2000-3000
5	4000	250	300	165000	100000	32	160	4000
6	5000	250	300	165000	100000	32	160	5000
7	6000	250	300	165000	100000	32	160	6000

1. A circuit breaker whose coils have a continuous-current rating lower than those listed for the breakers under a particular interrupting rating shall be given an interrupting rating corresponding to the greatest interrupting rating under which the coil rating is listed.

2. Rated short-time current is applicable only to circuit breakers without instantaneous direct-acting trip elements (short-time-delay element or remote relay).

3. If the expected inductance to the point of fault exceeds the value given in column 5, obtain the reduced interrupting rating from the formula:

$$I = 10^4 \sqrt{\frac{20W}{L}}$$

where
W = the value in column 7
L = actual inductance in microhenries

** For preferred trip-device current ratings, see Table 22. Note that the continuous-current-carrying capability of some circuit-breaker-trip-device combinations may be higher than the trip-device current rating. See ANSI/IEEE C37.13-199X, 9.1.3.

NOTE: The above values apply to one pole of the circuit breaker, except where specifically required for use on insulated systems, battery installations, etc., where the tests apply to two poles.

* The peak current rating is only applicable for circuit breakers for use on solid-state rectifier applications.

Table 9

Test–Circuit Values for General–Purpose Low–Voltage DC Circuit Breakers
(See ANSI/IEEE C37.14–199X For Basis of Ratings)

Line No.	Circuit–Breaker Frame Size (amperes)	Test	Rated Maximum Voltage (volts)	Rated Peak Current (amperes)*	Test Circuit Current (amperes)	Test Circuit Resistance (ohms)	Test Circuit Inductance (microhenries)	Load Circuit Stored–Energy Factor W (kilowatt seconds)
	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8
1	600/800	a	300	41000	25000	0.012	160	50
		b	300	–	9000	0.033	1200	50
2	1600 & 2000	a	300	83000	50000	0.006	80	100
		b	300	–	13000	0.023	1200	100
3	3000	a	300	124000	75000	0.004	50	140
		b	300	–	15000	0.020	1200	140
4	4000	a	300	165000	100000	0.003	32	160
		b	300	–	17000	0.018	1200	160
5	5000	a	300	165000	100000	0.003	32	160
		b	300	–	17000	0.018	1200	160
6	6000	a	300	165000	100000	0.003	32	160
		b	300	–	17000	0.018	1200	160

* The peak current rating is only applicable for circuit breakers for use on solid–state rectifier applications.

Table 10

Preferred Ratings and Test-Circuit Values for
General-Purpose Low-Voltage DC Circuit Breakers for Mining Applications
(See ANSI/IEEE C37.14-199X for Basis of Rating)

Line No.	Circuit-Breaker Frame Size (amperes)	Test	System Nominal Voltage (volts)	Rated Maximum Voltage (volts)	Rated Peak Current (amperes)*	Rated Maximum Short-Circuit Current (amperes)	Test Circuit Current (amperes)	Test Circuit Resistance (ohms)	Test Circuit Inductance (microhenries)	Load Circuit Stored-Energy Factor W (kilowatt seconds)
	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10
1	600-2000	a	275	325	41000	25000	25000	0.013	400	125
		b					9000	0.036	3090	125
2	800-4000	a	275	325	83000	50000	50000	0.007	200	250
		b					13000	0.025	2950	250

NOTES:

(1) The above values apply to one pole of the circuit breaker
(2) For the basis of short-circuit current ratings, see ANSI/IEEE C37.14-199X
(3) If the expected inductance to the point of fault exceeds the value given in colum 9, line a, obtain the reduced interrupting rating from the formula:

$$I = 10^4 \sqrt{\frac{20W}{L}}$$

where
W = the value in column 9
L = actual inductance in microhenries

* The peak current rating is only applicable for circuit breakers for use on solid-state rectifier applications.

TABLE 11
Heavy Duty Traction

Preferred Ratings and Test Circuit Values
High-Speed, Semi-High-Speed and Rectifier Low-Voltage DC Power Circuit Breakers
(Based on Transit Systems with High Frequency Impedance Bonds)
(See ANSI/IEEE C37.14-199X for Basis of Rating)

Line No.	Circuit-Breaker Frame Size (amperes) (Note 2)	Test	Rated Maximum Voltage (volts)	Semi-High-Speed Breaker Rated Peak or High-Speed Breaker Short-Circuit Current (Amperes)	Sustained Current & Semi-High-Speed Breaker Rated Short-Circuit Current (Line 1a) (Avg. Amperes)	Rectifier or Other Breaker-Ratings with Delayed Trip or in Non-Trip Direction (Amperes) Rated Peak	Rectifier or Other Breaker-Ratings with Delayed Trip or in Non-Trip Direction (Amperes) Rated Short-Circuit or Short-Time	Add to DC Circuit-Inductance (microhenries)	Approx. Load Circuit Time Constant (secs)
	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9
1	1200-10000	a	300	125,000	85,000	70,000	42,500	Note 2	—
		b	300	–	46,200	–	–	500	0.053
		c	300	–	13,300	–	–	1000	0.053
		d	300	–	7,300	–	–	2000	0.053
2	1200-12000	a	800	200,000	120,000	149,000	90,000	Note 2	—
		b	800	–	52,600	–	–	450	0.053
		c	800	–	31,200	–	–	1000	0.053
		d	800	–	17,900	–	–	2000	0.053
3	1200-8000	a	1000	158,000	96,000	119,000	72,000	Note 2	—
		b	1000	–	54,250	–	–	500	0.053
		c	1000	–	34,000	–	–	1000	0.053
		d	1000	–	20,700	–	–	2000	0.053
4	1200-6000	a	1600	100,000	60,000	74,000	45,000	Note 2	—
		b	1600	–	44,300	–	–	600	0.066
		c	1600	–	35,000	–	–	1200	0.066
		d	1600	–	25,000	–	–	2500	0.066
5	1200-4000	a	3200	50,000	30,000	37,000	22,500	Note 2	—
		b	3200	–	27,700	–	–	600	0.066
		c	3200	–	25,600	–	–	1200	0.066
		d	3200	–	22,300	–	–	2500	0.066

Notes:
(1) Frame sizes are 1200, 1600, 2000, 2500, 4000, 5000, 6000, 8000, 10000, and 12000 amperes.
(2) No intentional inductance or resistance is to be added on the dc side.
(3) Columns 4, 5, 6 and 7 headings delineate specific ratings for breaker types noted.
(4) The instantaneous trip element shall be set at not more than four times the circuit breaker continuous current rating or the maximum setting below 63.2% of the available sustained current (column 5). See ANSI/IEEE C37.14-199X, 9. 2. 7. 3 (1)(b) and 10. 2. 3. 7.
(5) Tests a, b, c and d represent simulated close-in, intermediate and distant faults.
(6) The circuit breaker must handle all interrupting stored energy of the circuit based on the inherent speed of operation and let-through of current interrupted.
(7) For total performance at other parameters, consult the manufacturer.

TABLE 11A
Heavy Duty Traction

Preferred Ratings and Test Circuit Values
High-Speed, Semi-High-Speed and Rectifier Low-Voltage DC Power Circuit Breakers
(Based on Transit Systems with Low Frequency Impedance Bonds)
(See ANSI/IEEE C37.14-199X for Basis of Rating)

Line No.	Circuit-Breaker Frame Size (amperes) (Note 2)	Test	Rated Maximum Voltage (volts)	Semi-High-Speed Breaker Rated Peak or High-Speed Breaker Short-Circuit Current (Amperes)	Sustained Current & Semi-High-Speed Breaker Rated Short-Circuit Current (Line 1a) (Avg. Amperes)	Rectifier or Other Breaker-Ratings with Delayed Trip or in Non-Trip Direction (Amperes) Rated Peak	Rectifier or Other Breaker-Ratings with Delayed Trip or in Non-Trip Direction (Amperes) Rated Short-Circuit or Short-Time	Add to DC Circuit-Inductance (microhenries)	Approx. Load Circuit Time Constant (secs)
	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9
1	1200-10000	a	300	125,000	85,000	70,000	42,500	Note 2	—
		b	300	-	46,200	-	-	2000	0.21
		c	300	-	13,300	-	-	4000	0.21
		d	300	-	7,300	-	-	8000	0.21
2	1200-12000	a	800	200,000	120,000	149,000	90,000	Note 2	—
		b	800	-	52,600	-	-	1000	0.21
		c	800	-	31,200	-	-	4000	0.21
		d	800	-	17,900	-	-	8000	0.21
3	1200-8000	a	1000	158,000	96,000	119,000	72,000	Note 2	—
		b	1000	-	50,250	-	-	2000	0.21
		c	1000	-	34,000	-	-	4000	0.21
		d	1000	-	20,700	-	-	8000	0.21
4	1200-6000	a	1600	100,000	60,000	74,000	45,000	Note 2	—
		b	1600	-	44,300	-	-	3250	0.34
		c	1600	-	35,000	-	-	6400	0.34
		d	1600	-	25,000	-	-	12800	0.34
5	1200-4000	a	3200	50,000	30,000	37,000	22,500	Note 2	—
		b	3200	-	27,700	-	-	3250	0.34
		c	3200	-	25,600	-	-	6400	0.34
		d	3200	-	22,300	-	-	12800	0.34

Notes:
(1) Frame sizes are 1200, 1600, 2000, 2500, 4000, 5000, 6000, 8000, 10000, and 12000 amperes.
(2) No intentional inductance or resistance is to be added on the dc side.
(3) Columns 4, 5, 6 and 7 headings delineate specific ratings for breaker types noted.
(4) The instantaneous trip element shall be set at not more than four times the circuit breaker continuous current rating or the maximum setting below 63.2% of the available sustained current (column 5). See ANSI/IEEE C37.14-199X, 9. 2. 7. 3 (1)(b) and 10. 2. 3. 7.
(5) Tests a, b, c and d represent simulated close-in, intermediate and distant faults.
(6) The circuit breaker must handle all interrupting stored energy of the circuit based on the inherent speed of operation and let-through of current interrupted.
(7) For total performance at other parameters, consult the manufacturer.

TABLE 12
Light Duty Traction

Preferred Ratings and Test Circuit Values
Low-Voltage DC Power Circuit Breakers
(Based on Transit Systems with High Frequency Impedance Bonds)
(See ANSI/IEEE C37.14-199X for Basis of Rating)

Line No.	Circuit-Breaker Frame Size (amperes) (Note 2)	Test	Rated Maximum Voltage (volts)	Semi-High-Speed Breaker Rated Peak or High-Speed Breaker Short-Circuit Current (Amperes)	Sustained Current & Semi-High-Speed Breaker Rated Short-Circuit Current (Line 1a) (Avg. Amperes)	Rectifier or Other Breaker-Ratings with Delayed Trip or In Non-Trip Direction (Amperes) Rated Peak	Rated Short-Circuit or Short-Time	Add to DC Circuit-Inductance (microhenries)	Approx. Load Circuit Time Constant (secs)
	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9
1	1200-6000	a	800	100,000	60,000	74,000	45,000	Note 2	—
		b	800	-	35,100	-	-	600	0.066
		c	800	-	24,800	-	-	1250	0.066
		d	800	-	15,700	-	-	2500	0.066
2	1200-6000	a	1000	80,000	48,000	53,000	32,000	Note 2	—
		b	1000	-	33,000	-	-	600	0.066
		c	1000	-	25,100	-	-	1250	0.066
		d	1000	-	17,900	-	-	2500	0.066

Notes:
(1) Frame sizes are 1200, 1600, 2000, 2500, 4000, 5000, and 6000 amperes.
(2) No intentional inductance or resistance is to be added on the dc side.
(3) Columns 4, 5, 6 and 7 headings delineate specific ratings for breaker types noted.
(4) The instantaneous trip element shall be set at no less than four times the circuit breaker continuous current rating or the maximum setting below 63.2% of the available sustained current (column 5). See ANSI/IEEE C37.14-199X, 9. 2. 7. 3 (1)(b) and 10. 2. 3. 7.
(5) Tests a, b, c and d represent simulated close-in, intermediate and distant faults.
(6) The circuit breaker must handle all interrupting stored energy of the circuit based on the inherent speed of operation and let-through of current interrupted.
(7) For total performance at other parameters, consult the manufacturer.

TABLE 13
Preferred Ratings for Anode Circuit Breakers
(DELETED FROM THIS EDITION)

TABLE 14
Endurance Requirements for Low Voltage DC Power Circuit Breakers and Field Discharge Circuit Breakers
(See ANSI/IEEE C37.14-199x and ANSI/IEEE C37.18-199X(R1991)

Line No.	Circuit Breaker Frame Size (amperes)	Number of Make-Break or Close-Open Operations: Electrical Endurance	Mechanical Endurance	Total	Between Servicing*
	Col 1	Col 2	Col 3	Col 4	Col 5
1	600/800	1750	9700	11450	1750
2	1200	500	3200	3700	500
3	1600	500	3200	3700	500
4	2000-12000	250	1100	1350	250

*Servicing shall consist of adjusting, cleaning, lubricating, tightening, etc.

TABLE 15
Application Limitatings Relating to Repetitive Duty and Normal Maintenance of Low-Voltage DC Power Circuit Breakers
(See ANSI/IEEE C37.14-199x)

Line No.	Circuit Breaker Frame Size (amperes)	Number of Make-Break or Close-Open Operations: Between Servicing(1)	No-Load Mechanical(2)	Rated Continuous Current Switching(3)
	Col 1	Col 2	Col 3	Col 4
1	600/800	1750	9700	1750
2	1200	500	3200	500
3	1600	500	3200	500
4	2000-12000	250	1100	250

(1) See Appendix, (A).
(2) See Appendix, (A) through (G).
(3) See Appendix, (A), (C), (D), (E), (F), (G), (H), and (J).

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