1. What is resistance switching?

It is the method of connecting a resistance in parallel with the contact space (arc). The resistance reduces the restriking voltage frequency and it diverts part of the arc current. It assists the circuit breaker in interrupting the magnetizing current and capacity current.

2. What do you mean by current chopping?

When interrupting low inductive currents such as magnetizing currents of the transformer, shunt reactor, the rapid deionization of the contact space and blast effect may cause the current to be interrupted before the natural current zero. This phenomenon of interruption of the current before its natural zero is called current chopping.

3. What are the methods of capacitive switching?

- Opening of single capacitor bank
- Closing of one capacitor bank against another

4. What is an arc?

Arc is a phenomenon occurring when the two contacts of a circuit breaker separate under heavy load or fault or short circuit condition.

5. Give the two methods of arc interruption?

- High resistance interruption: the arc resistance is increased by elongating, and splitting the arc so that the arc is fully extinguished
- Current zero method: The arc is interrupted at current zero position that occurs 100 times a second in case of 50Hz power system frequency in ac.

6. What is restriking voltage?

It is the transient voltage appearing across the breaker contacts at the instant of arc being extinguished.
7. What is meant by recovery voltage?

The power frequency rms voltage appearing across the breaker contacts after the arc is extinguished and transient oscillations die out is called recovery voltage.

8. What is RRRV?

It is the rate of rise of restriking voltage, expressed in volts per microsecond. It is closely associated with natural frequency of oscillation.

Part – B

1. Explain with neat diagram the working of vacuum circuit breaker (N/D-16)

A vacuum circuit breaker is such kind of circuit breaker where the arc quenching takes place in vacuum. The technology is suitable for mainly medium voltage application. For higher voltage vacuum technology has been developed but not commercially viable. The operation of opening and closing of current carrying contacts and associated arc interruption take place in a vacuum chamber in the breaker which is called vacuum interrupter. The vacuum interrupter consists of a steel arc chamber in the centre symmetrically arranged ceramic insulators. The vacuum pressure inside a vacuum interrupter is normally maintained at $10^{-6}$ bar.

The material used for current carrying contacts plays an important role in the performance of the vacuum circuit breaker. Cu/Cr is the most ideal material to make VCB contacts. Vacuum interrupter technology was first introduced in the year of 1960. But still it is a developing technology. As time goes on, the size of the vacuum interrupter is being reducing from its early 1960’s size due to different technical developments in this field of engineering. The contact geometry is also improving with time, from butt contact of early days it gradually changes to spiral shape, cup shape and axial magnetic field contact. The vacuum circuit breaker is today recognized as most reliable current interruption technology for medium voltage switchgear. It requires minimum maintenance compared to other circuit breaker technologies.

Advantages of Vacuum Circuit Breaker or VCB

Service life of vacuum circuit breaker is much longer than other types of circuit breakers. There is no chance of fire hazard like oil circuit breaker. It is much environment friendly than SF$_6$ Circuit breaker. Beside of that contraction of VCB is much user friendly. Replacement of vacuum interrupter (VI) is much convenient.

Operation of Vacuum Circuit Breaker

The main aim of any circuit breaker is to quench arc during current zero crossing, by establishing high dielectric strength in between the contacts so that reestablishment of arc after current zero becomes impossible. The dielectric strength of vacuum is eight times greater than that of air and four times greater than that of SF$_6$ gas. This high dielectric strength makes it possible to quench a vacuum
arc within very small contact gap. For short contact gap, low contact mass and no compression of medium the drive energy required in vacuum circuit breaker is minimum. When two face to face contact areas are just being separated to each other, they do not be separated instantly, contact area on the contact face is being reduced and ultimately comes to a point and then they are finally de-touched. Although this happens in a fraction of micro second but it is the fact. At this instant of de-touching of contacts in a vacuum, the current through the contacts concentrated on that last contact point on the contact surface and makes a hot spot. As it is vacuum, the metal on the contact surface is easily vaporized due to that hot spot and create a conducting media for arc path. Then the arc will be initiated and continued until the next current zero.

![Vacuum circuit breaker](image)

At current zero this vacuum arc is extinguished and the conducting metal vapor is re-condensed on the contact surface. At this point, the contacts are already separated hence there is no question of re-vaporization of contact surface, for next cycle of current. That means, the arc cannot be reestablished again. In this way vacuum circuit breaker prevents the reestablishment of arc by producing high dielectric strength in the contact gap after current zero.

There are two types of arc shapes. For interrupting current up to 10 kA, the arc remains diffused and the form of vapor discharge and cover the entire contact surface. Above 10 kA the diffused arc is constricted considerably by its own magnetic field and it contracts. The phenomenon gives rise over heating of contact at its center. In order to prevent this, the design of the contacts should be such that the arc does not remain stationary but keeps travelling by its own magnetic field. Specially designed
contact shape of vacuum circuit breaker make the constricted stationary arc travel along the surface of the contacts, thereby causing minimum and uniform contact erosion.

2. Explain the phenomenon capacitive current interruption in a circuit breaker (N/D-16)(A/M-15)

The interruption of capacitive current produces high voltage transients across the gap of the circuit breaker.

This occurs when an unloaded long transmission line or a capacitor bank is switched off.

Considering a electrical circuit of a simple power system, $C$ - stray capacitance of the circuit breaker

$C_L$ - line capacitance

At the instant $M$
The capacitive current is 0.
- System voltage is maximum

**If interruption occurs**

Capacitor $C_L$ remains charged at the maximum value of system voltage.

**After the instant $M$**
- Voltage across the breaker gap is the difference of $V_c$ and $V_cL$.

**At the instant $N$**
- The voltage across the gap is twice the maximum Value of $V_c$.

**If the breaker restrikes**
- The voltage across the gap become partially zero.
- Voltage falls from $2V_{c_{\text{max}}}$ to zero.
- A severe high frequency oscillation occurs (about the point $S$)
- Interrupted again. (if restriking current=0)
- The capacitor $C_L$ at the voltage $-3emax$.

**At the instant $P$**
- The system voltage reaches its positive maximum. (point T)
- Voltage across the gap becomes $4emax$.
- The capacitive current reaches zero again and there may be an interruption.
- The transient voltage oscillates between $-3emax$ and $+5emax$. (point $P$—$Q$)
  - Thus voltage across the gap goes on increasing

3. **Derive the expression for restriking voltage and RRRV (N/D-16)/(A/M-15)**

When the current across the contact of the circuit breaker is zero, a high-frequency transient voltage develops in the whole breaker contact and is produced by the sudden distribution of energy between the electric and magnetic field. This transient voltage is called restriking voltage. The voltage appears
Across the breaker contacts at the moment of final current has a serious influence on the arc extinction process. Under the influence of this voltage, the arc tries to restrike and hence it is named as the restriking voltage.

After the zero current, the arc gets extinguished, if the rate of rising of restriking voltage between the contact is less than the rate at which the dielectric strength of the medium between the contact gains. Immediately after the final current interruption, the voltage that appears across the breaker contacts (transient voltage) superimposed on the power frequency system voltage (recovery voltage).

Considered a simple circuit, having a circuit breaker CB, as shown in the figure below. Let L be the inductance per phase of the system up to the fault point; R be the resistance per phase of the system up to the fault point, and C be the capacitance of the circuit.

\[
\text{Fault and its Equivalent Circuit}
\]

When the fault occurs in the system under fault condition the contacts of the breaker are open, and the capacitance C is short-circuited by the fault, and the short circuit current is limited by the resistance and the inductance.

When the breaker contacts are opened, and the arc certainly quenches at some current zero, a voltage v is suddenly applied across the capacitor and therefore across the circuit breaker contacts. The current i which would flow to the fault is not injected in the capacitor and inductor. Thus

\[
i = i_L + i_C
\]

\[
i = \frac{1}{L} \int vdt + C \frac{dv}{dt} \quad \frac{di}{dt} = \frac{v}{L} + C \frac{d^2 s}{dt^2}
\]

Assuming Zero time at zero currents when \( t = 0 \) and the value of current and voltage before opening of circuit breaker is expressed as
On substituting the above values in equation (1), we get

\[
v = V_{\text{max}} \cos \omega t \quad \quad \frac{di}{dt} = \frac{V_{\text{max}}}{\omega L} \times w \times \cos \omega t
\]

\[
i = \frac{V_{\text{mt}}}{\omega L} \sin \omega t \quad t = 0; \quad \left| \frac{di}{dt} \right| = \frac{V_{\text{max}}}{L}
\]

The solution of the standard equation is

\[
v = V_{\text{max}} \left[ 1 - \cos \left( \frac{1}{\sqrt{LC}} \right) \right] = V_{\text{max}} (1 - 2\pi f_n t) \quad \text{equ}(3)
\]

From the equation,

\[
\frac{1}{\sqrt{LC}} = 2\pi f_n = w_n
\]

The above expression is for restriking voltage where \( V_{\text{max}} \) is the peak value of recovery voltage (phase-to-neutral) \( t \) is time in seconds, \( L \) is inductance in Henrys, \( C \) is the capacitance in farads and \( v \) is the restriking voltage in volts. The maximum value of restriking voltage is \( 2V_{\text{max}} \) and occurs at

\[
t = \frac{\pi}{w} \quad \text{or} \quad t = \pi \sqrt{LC}
\]

Characteristics of Restriking Voltage

The important characteristic of restriking voltage which affects the performance of the circuit breaker is as follows –

**Amplitude Factor** – It is defined as the ratio of the peak of transient voltage to the peak system frequency voltage.

**The rate of Rising of Restriking Voltage** – It is defined as the slope of the steepness tangent of the restriking voltage curve. It is expressed in kV/µs. RRRV is directly proportional to the natural frequency. The expression for the restriking voltage is expressed as
The transient voltage vanishes rapidly due to the damping effect of system resistance, and the normal frequency system voltage is established. This voltage across the breakers contact is called recovery voltage.

\[ RRRV_{max} = \frac{V_{max}}{\sqrt{LC}} \]

The waveforms of recovery and the restricting voltage are shown in the figure above. After the current zero, the voltage appearing across the breaker contacts is composed of transient restriking voltage and power frequency recovery voltage.

4. Explain the construction and working of SF6 circuit breaker (ND-15)

A circuit breaker in which the current carrying contacts operate in sulphur hexafluoride or SF₆ gas is known as an SF₆ circuit breaker. SF₆ has excellent insulating property. SF₆ has high electro-negativity. That means it has high affinity of absorbing free electron. Whenever a free electron collides with the SF₆ gas molecule, it is absorbed by that gas molecule and forms a negative ion. The attachment of electron with SF₆ gas molecules may occur in two different ways, 

\[ SF₆ + e = S Frances₆^- \]

\[ SF₆ + e = SF₅^- + F \]

These negative ions obviously much heavier than a free electron and therefore over all mobility of the charged particle in the SF₆ gas is much less as compared to other common gases. We know that mobility of charged particle is majorly responsible for conducting current through a gas.

Hence, for heavier and less mobile charged particles in SF₆ gas, it acquires very high dielectric strength.

Not only the gas has a good dielectric strength but also it has the unique property of fast recombination after the source energizing the spark is removed. The gas has also very good heat transfer property. Due to its low gaseous viscosity (because of less molecular mobility) SF₆ gas can efficiently transfer
heat by convection. So due to its high dielectric strength and high cooling effect SF₆ gas is approximately 100 times more effective arc quenching media than air. Due to these unique properties of this gas, SF₆ circuit breaker is used in complete range of medium voltage and high voltage electrical power system. These circuit breakers are available for the voltage ranges from 33KV to 800 KV and even more.

**Disadvantages of SF₆ CB**

The SF₆ gas is identified as a greenhouse gas, safety regulation are being introduced in many countries in order to prevent its release into atmosphere. Puffer type design of SF₆ CB needs a high mechanical energy which is almost five times greater than that of oil circuit breaker.

**Types of SF₆ Circuit Breaker**

There are mainly three types of SF₆ CB depending upon the voltage level of application-

1. Single interrupter SF₆ CB applied for up to 245 KV(220 KV) system.
2. Two interrupter SF₆ CB applied for up to 420 KV(400 KV) system.
3. Four interrupter SF₆ CB applied for up to 800 KV(715 KV) system.

**Working of SF₆ Circuit Breaker**

The working of SF₆ CB of first generation was quite simple and it is some extent similar to air blast circuit breaker. Here SF₆ gas was compressed and stored in a high pressure reservoir. During operation of SF₆ circuit breaker this highly compressed gas is released through the arc in breaker and collected to relatively low pressure reservoir and then it is pumped back to the high pressure reservoir for re utilize.
The working of SF₆ circuit breaker is little bit different in modern time. Innovation of puffer type design makes operation of SF₆ CB much easier. In buffer type design, the arc energy is utilized to develop pressure in the arcing chamber for arc quenching.

Here the breaker is filled with SF₆ gas at rated pressure. There are two fixed contact fitted with a specific contact gap. A sliding cylinder bridges these to fixed contacts. The cylinder can axially slide upward and downward along the contacts. There is one stationary piston inside the cylinder which is fixed with other stationary parts of the SF₆ circuit breaker, in such a way that it cannot change its position during the movement of the cylinder. As the piston is fixed and cylinder is movable or sliding, the internal volume of the cylinder changes when the cylinder slides.

During opening of the breaker the cylinder moves downwards against position of the fixed piston hence the volume inside the cylinder is reduced which produces compressed SF₆ gas inside the cylinder. The cylinder has numbers of side vents which were blocked by upper fixed contact body during closed position. As the cylinder move further downwards, these vent openings cross the upper fixed contact, and become unblocked and then compressed SF₆ gas inside the cylinder will come out through this vents in high speed towards the arc and passes through the axial hole of the both fixed contacts. The arc is quenched during this flow of SF₆ gas.
During closing of the circuit breaker, the sliding cylinder moves upwards and as the position of piston remains at fixed height, the volume of the cylinder increases which introduces low pressure inside the cylinder compared to the surrounding. Due to this pressure difference SF$_6$ gas from surrounding will try to enter in the cylinder. The higher pressure gas will come through the axial hole of both fixed contact and enters into cylinder via vent and during this flow, the gas will quench the arc.

**Advantages of SF6**

Due to the superior arc quenching properties of sulphur hexaflouride gas (SF$_6$) gas, the sulphur hexaflouride gas (SF$_6$) circuit breakers have many advantages over oil or air circuit breakers. Some of them are listed below:

1. Due to the superior arc quenching property of sulphur hexaflouride gas (SF$_6$), such circuit breakers have very short arcing time.

2. Since the dielectric strength of sulphur hexaflouride (SF$_6$) gas is 2 to 3 times that operation due unlike of air, such breakers can interrupt much larger currents.

3. The sulphur hexaflouride gas (SF$_6$) circuit breaker gives noiseless operation due its closed gas circuit and no exhaust to atmosphere unlike the air blast circuit breaker.

**5. Explain the construction and working of minimum oil circuit breaker (ND-15)**

Mineral oil has better insulating property than air. In oil circuit breaker the fixed contact and moving contact are immerged inside the insulating oil. Wherever there is a separation of current carrying contacts in the oil, the arc in circuit breaker is initialized at the moment of separation of contacts, and due to this arc the oil is vaporized and decomposed in mostly hydrogen gas and ultimately creates a hydrogen bubble around the arc. This highly compressed gas bubble around the arc prevents re-striking of the arc after current reaches zero crossing of the cycle. The oil circuit breaker is the one of the oldest type of circuit breakers.

**Minimum Oil Circuit Breaker**

As the volume of the oil in bulk oil circuit breaker is huge, the chances of fire hazard in bulk oil system are more. For avoiding unwanted fire hazard in the system, one important development in the design of oil circuit breaker has been introduced where use of oil in the circuit breaker is much less than that of bulk oil circuit breaker. It has been decided that the oil in the circuit breaker should be used only as arc quenching media not as an insulating media. Then the concept of minimum oil circuit breaker comes. In this type of circuit breaker the arc interrupting device is enclosed in a tank of insulating material which as a whole is at live potential of system. This chamber is called arcing chamber or interrupting pot. The gas pressure developed in the arcing chamber depends upon the current to be interrupted. Higher the current to be interrupted causes larger the gas pressure developed
inside the chamber, hence better the arc quenching. But this put a limit on the design of the arc chamber for mechanical stresses. With use of better insulating materials for the arcing chambers such as glass fiber, reinforced synthetic resin etc, the **minimum oil circuit breaker** are able to meet easily the increased fault levels of the system.

**Working Principle or Arc Quenching in Minimum Oil Circuit Breaker**

**Working Principle of minimum oil circuit breaker or arc quenching in minimum oil circuit breaker** is described below.

In a **minimum oil circuit breaker**, the arc drawn across the current carrying contacts is contained inside the arcing chamber. Hence, the hydrogen bubble formed by the vaporized oil is trapped inside the chamber. As the contacts continue to move, after its certain travel an exit vent becomes available for exhausting the trapped hydrogen gas. There are two different types of arcing chamber is available in terms of venting are provided in the arcing chambers.

One is axial venting and other is radial venting. In axial venting, gases (mostly Hydrogen), produced due to vaporization of oil and decomposition of oil during arc, will sweep the arc in axial or longitudinal direction. Let's have a look on **working principle Minimum Oil Circuit Breaker** with axial venting arc chamber.

The moving contact has just been separated and arc is initiated in MOCB. The ionized gas around the arc sweep away through upper vent and cold oil enters into the arcing chamber through the lower vent in axial direction as soon as the moving contact tip crosses the lower vent opening and final arc quenching in **minimum oil circuit breaker** occurs. The cold oil occupies the gap between fixed contact and moving contact and the **minimum oil circuit breaker** finally comes into open position. Where as in case of radial venting or cross blast, the gases (mostly Hydrogen) sweep the arc in radial or transverse direction.
The axial venting generates high gas pressure and hence has high dielectric strength, so it is mainly used for interrupting low current at high voltage.

On the other hand, radial venting produces relatively low gas pressure and hence low dielectric strength so it can be used for low voltage and high current interruption. Many times the combination of both is used in minimum oil circuit breaker so that the chamber is equally efficient to interrupt low current as well as high current. These types of circuit breaker are available up to 8000 MVA at 245 KV.

Advantages:

- Increased degree of carbonisation due to a smaller quantity of oil.
- The dielectric strength of oil decreases due to a high degree of carbonisation.
- Difficulty in removal of gases from the contact space-time


Air blast circuit breaker used compressed air or gas as the arc interrupting medium. In the air blast, circuit breaker compressed air is stored in a tank and released through a nozzle to produce a high-velocity jet; this is used to extinguish the arc. Air blast circuit breakers are used for indoor services in the medium high voltage field and medium rupturing capacity. Generally up to voltages of 15 KV and rupturing capacities of 2500 MVA. The air blast circuit breaker is now employed in high voltage circuits in the outdoors switchyard for 220 KV lines.
Though gasses such as carbon dioxide, nitrogen, freon or hydrogen are used as the arc interrupting medium, compressed air is the accepted circuit breaking medium for gas blast circuit breakers. The reasons are given below.

The circuit breaking capacities of nitrogen are similar to compressed air and hence no advantage of using it. Carbon dioxide has the drawback of its being difficult to control owing to freezing at valves and other restricted passages. Feron has high dielectric strength and good arc extinguishing properties, but it is expensive, and it is disintegrated by the arc into acid-forming elements. The desirable features to be found in air blast circuit breaker are

**High-Speed Operation** – It is very necessary on large interconnected networks so that the system stability can be maintained. This is achieved in circuit breaker because the time interval between the discharge of triggering impulse and contacts separation are very short.

**Suitability for frequent operation** – Repeated switching by an air blast circuit is possible simply because of the absence of oil, which rapidly carbonizes with the frequent operation and because there is an insignificant amount of wear and tear at the current-carrying contact surfaces. But it must be remembered that if frequent switching is anticipated, then the maintenance of a sufficient air supply is essential.

**Negligible Maintenance** – The ability of the air blast circuit breaker to deal with repeated switching also mean that negligible maintenance is required.

**Elimination of Fire Hazard** – Because of the absence of oil the risk of fire is eliminated.

**Reduced Size** – The growth of dielectric strength is so rapid in air blast circuit breakers that final gap required for arc extinction is very small. This reduces the sizes of the devices.

**Principle of Arc Extinction in Circuit Breaker**

The air blast needs an additional compressed air system which supplies air to the air receiver. When opening air is required, compressed air is admitted to the arc extinction chamber. It pushes away the moving contacts. In doing so, the contacts are pulled apart, and the air blast moves away the ionized gas along with it and assists arc extinction.

Air blast extinguishes the arc within one or more cycles, and the arc chamber is filled with high-pressure air, which prevents restrikes. The air blast circuit breakers fall under the category of external extinguishing energy type. The energy supplied for arc quenching is achieved from the high-pressure air, and it is free from the current to be interrupted.

**Axial blast Air Circuit Breaker** – In the air blast circuit breaker, the flow of air is longitudinal along the arc. Air blast circuit breaker may be a single blast or double blast. Breaking employing double blast
arrangement are sometimes called radial blast circuit breakers as the air blast flows radially into the nozzle or space between the contacts.

![Radial Blast](image)

The essential feature of air blast circuit breaker is shown above. The fixed and moving contacts are kept in a closed position by spring pressure under normal operating conditions. The air reservoir tank is connected to the arc chamber through an air valve, which is opened by a triple impulse.

![Axial Blast](image)

When the fault occurs, the tripling impulse causes opening of the air valve connecting the reservoir to the arcing chamber. The air entering the arc chamber exerts pressure on the moving contacts which moves when the air pressure exceeds the spring force.

The contacts are separated, and an arc is developed between them. The air flowing at a great speed axially along the arc cause removal of heat from the edge of the arc and the diameter of the arc reduced to a very small value at current zero.
Thus, the arc is interrupted, and the space between the contact is flushed with fresh air flowing through the nozzle. The flow of fresh air removes the hot gasses between the contact space and rapidly build up the dielectric strength between them.

Cross Blast Air Circuit Breaker – In such breaker, an arc blast is directed at right angles to the arc. The schematic representation of the cross principle of cross blast air circuit breaker is given in the figure below. A moving contact arm is operated in close spaces to draw an arc which is forced by a transverse blast of air into the splitter plates, thereby lightening it to the point when it cannot restrike after zero current.
Resistance switching is not normally required as the lightening of arc automatically introduces some resistance to control the restriking voltage transient but if extra resistance is thought desirable. It is possible to introduce it by connecting it in the section across the arc splitter.

Drawback of Air Blast Circuit Breaker

In the air blast circuit breaker, it is necessary that the compressed air at the correct pressure must be available all the times, involving in the largest installation of a plant with two or more compressors. The maintenance of this plant and the problem of air leakages at the pipe fittings are some factors which operate against air blast circuit breaker and it costly for low voltage as compared to oil or air break circuit breaker

7. Why SF6 is used in circuit breakers?(A/M-15)

Reasons for using Sulphur hexafluoride in Circuit Breakers

Sulphur hexafluoride possesses very good insulating and arc quenching properties. These properties are

- It is colourless, odourless, non-toxic, and non-inflammable gas.
- SF6 gas is extremely stable and inert, and its density is five times that of air.
- It has high thermal conductivity better than that of air and assists in better cooling current carrying parts.
- SF6 gas is strongly electronegative, which means the free electrons are easily removed from discharge by the formation of negative ions.
- It has a unique property of fast recombination after the source energising spark is removed. It is 100 times more effective as compared to arc quenching medium.
- Its dielectric strength is 2.5 times than that of air and 30% less than that of the dielectric oil. At high pressure the dielectric strength of the gas increases.
- Moisture is very harmful to SF6 circuit breaker. Due to a combination of humidity and SF6 gas, hydrogen fluoride is formed (when the arc is interrupted) which can attack the parts of the circuit breakers.

SF6 has excellent insulating property. SF6 has high electro-negativity. That means it has high affinity of absorbing free electron. Whenever a free electron collides with the SF6 gas molecule, it is absorbed by that gas molecule and forms a negative ion. The attachment of electron with SF6 gas molecules may occur in two different ways,
These negative ions obviously much heavier than a free electron and therefore over all mobility of the charged particle in the SF$_6$ gas is much less as compared to other common gases. We know that mobility of charged particle is majorly responsible for conducting current through a gas. Hence, for heavier and less mobile charged particles in SF$_6$ gas, it acquires very high dielectric strength.

Not only the gas has a good dielectric strength but also it has the unique property of fast recombination after the source energizing the spark is removed. The gas has also very good heat transfer property. Due to its low gaseous viscosity (because of less molecular mobility) SF$_6$ gas can efficiently transfer heat by convection. So due to its high dielectric strength and high cooling effect SF$_6$ gas is approximately 100 times more effective arc quenching media than air. Due to these unique properties of this gas, SF$_6$ circuit breaker is used in complete range of medium voltage and high voltage electrical power system.

8. Explain different testing schemes of circuit breaker (A/M-14)/(N/D-14)

Short-circuit tests are conducted to prove the ratings of the circuit-breakers.

The following short-circuit tests are conducted on circuit-breakers;

1. Breaking capacity test
2. Making capacity
3. Duty cycle test
4. Short Time Current Test

Short-circuit tests can be performed either by direct testing or indirect testing methods.

**Direct Testing:**

IEC Standards definition of direct test is as follows: “A test in which the applied voltage, the current and the transient and power frequency recovery voltages are all obtained from a circuit having a single power source, which may be a power system or special alternators as used in short-circuit testing stations or a combination of both. A direct test is one where a three phase circuit-breaker is tested, on a three phase system, and at a short circuit MVA level equal to its full rating. In other words this is a test where a three phase circuit-breaker is tested on a 3-phase circuit at full current and full voltage. It should be obvious that testing a circuit-breaker under the same conditions at which it is going to be applied is the ultimate demonstration for its capability and naturally, whenever possible, this should be the preferred method of test. In direct testing, the circuit-breaker is tested under the conditions which actually exist on power systems and it is subjected to transient recovery voltage (TRV) which is expected in practical situations. In direct testing, the short circuit tests are conducted in short circuit
testing stations and are mainly to prove the ratings of the circuit breaker. There are two types of short circuit testing stations:

**Field type testing station** In this, the tests are conducted taking power directly from the system.

**Laboratory type testing stations** It has short-circuit generators to supply power for the short-circuit testing.

The short-circuit testing stations consists of the following equipments/components: (i) Short circuit generator (ii) Short-circuit transformer (iii) Master circuit-breaker (iv) Making switch (v) Capacitors (vi) Resistors and reactors. In direct testing, the circuit-breaker is tested under the conditions which actually exist on power systems. It is subjected to restriking voltage which is expected in practical situations. Fig. below shows an arrangement for direct testing. The reactor L is to control short-circuits current. C, R1 and R2 are to adjust transient recovery voltage.

![Circuit arrangement for direct testing](image)

**Indirect Testing Methods:**

The Indirect testing methods can be classified as Unit testing and synthetic testing. Unit Testing The IEC standards definition of unit testing is as follows: “The test made on a making or breaking unit or group of units at the making current or the breaking current, specified for the test on the complete pole of a circuit-breaker and at the appropriate fraction of the applied voltage, or the recovery voltage, specified for the test on the complete pole of the circuit-breaker”

Unit testing means testing one or more units separately. Generally, high voltage circuitbreakers are designed with several arc interrupter units in series. Each unit can be tested separately. From the test results of one unit, the capacity of the complete breaker can be determined.

The unit testing method is used in laboratory to test Extra and ultra high voltage circuit-breakers at present. With this method, interrupting units are tested at a part of rated voltage of the complete
breaker. This method is recognized by the IEC standard, but one major problem remains, namely the influence of the post-arc conductivity on the voltage distribution across the units.

The trend of increasing the interrupting capability of a single interrupting unit will result in it being impossible to test a single unit in the high power laboratory. Synthetic Testing Method Synthetic testing is an alternative equivalent method for testing of high voltage circuit-breakers and is accepted by the various standards. In synthetic testing, there are two sources of power supply for the testing:

(i) Current source (ii) Voltage source

The current source is a high current, low voltage source. It supplies short-circuit current during the test. The voltage source is a high voltage, low current source. It provides transient recovery voltage.

**Principle and Advantages of Synthetic Testing:**

Figure below shows the basic circuit for testing circuit-breaker. When switch S is closed, short-circuit current I flows through the breaker B and when the test breaker B begins to open an arc voltage Va appears across the breaker terminal as shown in Fig.2.3. At current zero when the arc is extinguished a transient voltage Vtr appears across the breaker, whose form is determined by the generator characteristics and the circuit constants L and C. The breaker has to withstand this transient recovery voltage if it is to clear the circuit. So in actual practice, during the period of main short circuit current flow, there is comparatively small arc voltage appears across the breaker and that during the period of transient recovery voltage very little or no current flows through the breaker. Therefore there is no need to use a single high power source. Instead, the current can be supplied by a comparatively low voltage source, since the arc voltage is usually very small, 1 to 3% of the rated voltage of the breaker, and the voltage can be applied from low energy high Voltage, low current source at the point of current zero to simulate transient recovery voltage.
Types of synthetic test circuits:

Several synthetic testing methods have been developed and their performances have been studied in the past forty years. If the source of energy during the interaction interval is used to classify the methods adopted, they can be distinguished by two basic methods: (i) Cuirefit injection and (ii) Voltage injection method.

Depending on whether voltage circuit or source is switched on before or after current zero, the type of synthetic testing is known as current injection or voltage injection respectively. Further the current injection method can be classified as parallel current injection and series current injection method. In parallel current injection method, the voltage circuit is inserted in parallel with the test breaker, while in series current injection method, it is inserted in series.

The parallel current injection type synthetic testing is popular in Germany and is known as Weil-Dobke circuit. The series current injection type synthetic test circuit was suggested by Kaplan Bashatyr (U.S.S.R) and is known as Russian circuit. In voltage injection method, the voltage source is switched on after the current zero. This method was suggested by Siemens, Germany.

Current Injection Methods

In a synthetic test circuit using current injection, the superposition of the currents takes place shortly before the zero of the power-frequency, short-circuit current. A current of smaller amplitude but higher frequency, derived from the voltage circuit, is superimposed either in the test circuit breaker or in the auxiliary circuit-breaker.

These methods can be described in terms of general principles as follows:

• The current from the voltage circuit is superimposed on the power frequency current through the test circuit-breaker prior to the interaction interval;

• An auxiliary circuit-breaker interrupts the current from the current circuit prior to the interaction interval. During the interaction interval, the test circuit-breaker is exposed to the voltage of the voltage circuit having an impedance which is representative of the reference system conditions. This explains the validity of current injection methods.

Several current injection methods are known but Parallel current injection is used by the majority of the test laboratories.

The following conditions shall be met: (a) TRV wave shape circuit • The shape and magnitude of the prospective TRV shall comply with the specified values • The combination of the stray and lumped capacitance Cd in parallel with Zh gives rise to the delay time $t_a = Zh \times C^*$ (b) Frequency of the injected current and the injection timing • The frequency of the injected current shall preferably be of the order of 500Hz with a lower limit of 250Hz and an upper limit of 1000 Hz.
The initiation of the injected current shall be adjusted such that the time, during which the test circuit-breaker is fed only by the injected current, is not more than a quarter of the period of the injected current frequency with a maximum of 500ps.

**Voltage Injection Method:**

Voltage injection circuit with the voltage circuit in parallel with the auxiliary circuit-breaker (Series circuit) Fig. below shows the simplified diagram of a voltage injection circuit with the voltage circuit connected in parallel with the auxiliary circuit-breaker. The current circuit supplies the entire short-circuit current stress. A capacitor of suitable value is connected in parallel with the auxiliary circuit breaker. After the current zero of the power-frequency short-circuit current, this capacitor transmits the entire transient recovery voltage of the current circuit to the test circuit-breaker, passing the necessary energy for the post-arc current.

About the time of the first peak of this transient voltage, the voltage circuit will be switched in and from this moment onwards the transient recovery voltages of both circuits are added together to form the transient recovery voltage across the test circuit-breaker. The auxiliary circuit-breaker is stressed only by the voltage of the voltage circuit. Both components of the voltage across the test circuit-breaker are superimposed to produce the transient recovery voltage, the wave shape of which can be adjusted by varying \( C_h \) and \( C_i \) in conjunction with additional components.

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9. **Explain about selection of circuit breakers**

A typical circuit breaker operating time is given in Fig. 6.11. Once the fault occurs, the protective devices get activated. A certain amount of time elapses before the protective relays determine that there is overcurrent in the circuit and initiate trip command. This time is called the detection time. The contacts of the circuit breakers are held together by spring mechanism and, with the trip command, the spring mechanism releases the contacts. When two current carrying contacts part, a voltage instantly appears at the contacts and a large voltage gradient appears in the medium between the two contacts. This voltage gradient ionizes the medium thereby maintaining the flow of current. This current generates extreme heat and light that is called electric arc. Different mechanisms are used for
elongating the arc such that it can be cooled and extinguished. Therefore, the circuit breaker has to withstand fault current from the instant of initiation of the fault to the time the arc is extinguished.

![Diagram of circuit breaker operation](image)

**Fig. Typical circuit breaker operating time.**

Two factors are of utmost importance for the selection of circuit breakers. These are:

- The maximum instantaneous current that a breaker must withstand and
- The total current when the breaker contacts part.

In this chapter, we have discussed the calculation of symmetrical sub transient fault current in a network. However, the instantaneous current following a fault will also contain the dc component. In a high power circuit breaker selection, the sub transient current is multiplied by a factor of 1.6 to determine the rms value of the current the circuit breaker must withstand. This current is called the momentary current. The interrupting current of a circuit breaker is lower than the momentary current and will depend upon the speed of the circuit breaker. The interrupting current may be asymmetrical since some dc component may still continue to decay.

Breakers are usually classified by their nominal voltage, continuous current rating, rated maximum voltage, $K$-factor which is the voltage range factor, rated short circuit current at maximum voltage and operating time. The $K$-factor is the ratio of rated maximum voltage to the lower limit of the range of the operating voltage. The maximum symmetrical interrupting current of a circuit breaker is given by $K$ times the rated short circuit current.

The following factors should be considered before selecting a circuit breaker:

**Voltage Rating**

The overall voltage rating is calculated by the highest voltage that can be applied across all end ports, the distribution type, and how the circuit breaker is directly integrated into the system. It is important to select a circuit breaker with enough voltage capacity to meet the end application.

**Frequency**

Circuit breakers up to 600 amps can be applied to frequencies of 50-120 Hz. Higher than 120 Hz frequencies will end up with the breaker having to derate. During higher frequency projects, the eddy
currents and iron losses causes greater heating within the thermal trip components thus requiring the breaker to be derated or specifically calibrated. The total quantity of deration depends on the ampere rating, frame size as well as the current frequency. A general rule of thumb is the higher the ampere rating in a specific frame size the greater the derating needed.

All higher rated breakers over 600 amps contain a transformer-heated bimetal and are suitable for 60 Hz AC maximum. For 50 Hz AC minimum applications special calibration is generally available. Solid state trip breakers are pre-calibrated for 50 Hz or 60 Hz applications. If doing a diesel generator project the frequency will either be 50 Hz or 60 Hz. It is best to check ahead of time with an electrical contractor to make sure calibration measures are in place before moving forward with a 50 Hz project.

**Maximum Interrupting Capacity**

The interrupting rating is generally accepted as the highest amount of fault current the breaker can interrupt without causing system failure to itself. Determining the maximum amount of fault current supplied by a system can be calculated at any given time. The one infallible rule that must be followed when applying the correct circuit breaker is that the interrupting capacity of the breaker must be equal or greater than the amount of fault current that can be delivered at the point in the system where the breaker is applied. Failure to apply the correct amount of interrupting capacity will result in damage to the breaker.

**Continuous Current Rating**

In regards to continuous current rating, molded case circuit breakers are rated in amperes at a specific ambient temperature. This ampere rating is the continuous current the breaker will carry in the ambient temperature where it was calibrated. A general rule of thumb for circuit breaker manufactures is to calibrate their standard breakers at 104° F.

Ampere rating for any standard application depends solely on the type of load and duty cycle. Ampere rating is governed by the National Electrical Code (NEC) and is the primary source for information about load cycles in the electrical contracting industry. For example lighting and feeder circuits usually require a circuit breaker rated in accordance with the conductor current carrying capacity. To find various standard breaker current ratings for different size conductors and the permissible loads consult NEC table 210.24.

**Atypical Operating Conditions**

When selecting a circuit breaker it is crucial to have in mind the end user location. Each breaker is different and some are better suited for more unforgiving environments. Below are a few scenarios to
keep in mind when determining what circuit breaker to use:

• **High Ambient Temperature:** If standard thermal magnetic breakers are applied in temperatures exceeding 104°F, the breaker must be derated or recalibrated to the environment. For many years, all breakers were calibrated for 77°F which meant that all breakers above this temperature had to be derated. Realistically, most enclosures were around 104°F; a common special breaker was used for these types of situations. In the mid-1960s industry standards were changed to make all standard breakers be calibrated with 104°F temperature in mind.

• **Corrosion and Moisture:** In environments where moisture is constant a special moisture treatment is recommended for breakers. This treatment helps resist mold and/or fungus that can corrode the unit. In atmospheres where high humidity is prevalent the best solution is the usage of space heaters in the enclosure. If possible, breakers should be removed from corrosive areas. If this is not practical, specifically manufactured breakers that are resistant to corrosion are available.

• **High Shock Probability:** If a circuit breaker is going to be installed in an area where there is a high probability of mechanical shock a special anti-shock device should be installed. Anti-shock devices consist of an inertia counterweight over the center pole that holds the trip bar latched under normal shock conditions. This weight should be installed so that it does not prevent thermal or magnetic trip units from functioning on overload or short circuit scenarios. The United States Navy is the largest end user of high shock resistant breakers which are required on all combat vessels.

• **Altitude:** In areas where the altitude is over 6,000 feet, circuit breakers must be derated for current carrying ability, voltage and interrupting capacity. At altitude, the thinner air does not conduct heat away from the current carrying components as well as denser air found in lower altitudes. In addition to overheating, the thinner air also prevents the of building a dielectric charge fast enough to withstand the same voltage levels that occur at normal atmospheric pressure. Altitude issues can also derate most used generators and other power generation equipment. It is best to speak with a power generation professional before purchasing.

• **Resting Position:** For the most part, breakers can be mounted in any position, horizontally or vertically, without affecting the tripping mechanisms or interrupting capacity. In areas of high wind it is imperative to have the breaker in an enclosure (most units come enclosed) on a surface that sways a bit with the wind. When a circuit breaker is attached to an inflexible surface there is a possibility of disrupting the circuit when exposed to high winds.

### Maintenance and Testing

When selecting a circuit breaker the user must decide to either buy a unit that is UL Tested (Underwriters Laboratories) or not. For overall quality assurance it is recommended that customer
purchase circuit breakers that have been UL Tested. Be aware that non UL Tested products do not
guarantee correct calibration of the breaker. All low voltage molded case circuit breakers which are UL
listed are tested in accordance with UL Standard 489 which is divided up into two categories: factory
testing and field testing.

- **UL Factory Testing**: All UL standard molded case circuit breakers undergo extensive product and
calibration testing based upon UL Standard 489. UL certified breakers contain factory sealed calibrated
systems. The unbroken seal guarantees that the breaker is correctly calibrated and has not been subject
to tampering, alteration and that the product will perform accordingly to UL specifications. If the seal
is broken the UL guarantee is void as well as any warranties.

- **Field Testing**: It is quite normal for data obtained in the field to vary from published information.
Many users become confused to whether field data is flawed or published information is out of sync
with their particular model. The difference in data is that test conditions in the factory vary
considerably than in the field. Factory tests are designed to produce consistent results. Temperature,
alitude, a climate controlled environment and using test equipment designed specifically for the
product being tested all effect the outcome. NEMA publication AB4-1996 is an outstanding guide to
infield testing. The guide gives the user a better variant of what are normal results for infield testing.
Some breakers come with their own testing instructions. Where no instructions are present use a
reliable circuit breaker service company.

- **Maintenance**: For the most part, molded case breakers have an exceptional track record of reliability
mostly due to the fact that the units are enclosed. The enclosure minimizes exposure to dirt, moisture,
mold, dust, other containments and tampering. Part of proper maintenance is making sure that all
terminal connections and trip units be tightened to the proper torque value as set by the manufacturer.
Overtime these connections will loosen and need to be retightened. Breakers also need to be cleaned
regularly. Improperly cleaned conductors, the wrong conductors used for the terminal and loose
terminations are all conditions that can cause excessive heating and weakening of the breaker. Breakers
that are manually operated require only that their contacts are clean and that the linkages operate
freely. For circuit breakers that are not used on a regular basis an intermittent startup of the breaker is
required to refresh the systems.

As always, it is best to consult a certified electrician to determine exactly what type of circuit breaker
is right for your generator application. The factors influencing the safe and proper operation of a power
generator and a circuit breaker vary from site-to-site and only a licensed professional can specify the
right equipment.

11. **Explain in detail about air break circuit breaker**

An air break circuit breaker the arc is initiated and extinguish in substantially static air in which the arc
moves. Such breakers are used for low voltages, generally up to 15KV and rupturing capacities of
Air circuit breaker has several advantages over the oil, as an arc quenching medium. These are

- Elimination of risk and maintenance associated with the use of oil.
- The absence of mechanical stress that is set up by gas pressure and oil movement.
- Elimination of the cost of regular oil replacement that arises due to deterioration of oil with the successive breaking operation.

In the air break, circuit breaker the contact separation and arc extinction take place in air at atmospheric pressure. In air break circuit breaker high resistance principle is employed. In this circuit breaker arc is expanded by the mean of arc runners, arc chutes, and arc resistance is increased by splitting, cooling and lengthening.

The arc resistance is increased to such an extent that the voltage drop across the arc becomes more than the system voltage, and the arc gets extinguished at the current zero of AC wave.

Air break circuit breakers are employed in DC circuits and AC circuits up to 12,000 voltages. Such breakers are usually of indoor type and installed on vertical panels or indoor draw out switch gear. AC circuit breakers are widely employed indoor medium voltage and low voltage switchgear.

Plain Break Type Air Break Circuit Breaker

It is the simplest one in which contacts are made in the shape of two horns. The air initially strikes across the shortest distance between the horns and is driven steadily upwards by the convection currents caused by heating of air during arcing and the interaction of the magnetic and the electric fields. The arc extends from one tip to the other when the horns are fully separated resulting in lengthening and cooling arc.

The relative slowness of the process and the possibility of arc spreading of adjacent metal works limits the application of about 500V and too low power circuits.

Magnetic Blow-Out Type Air Break Circuit Breaker

Some air circuit breakers are used in the circuits having voltage up to 11 KV, the arc extinction is accomplished using magnetic field provided by the current in blowout coils connected in series with the circuit being interrupted. Such coils are called blow out the coil. The magnetic field itself does not extinguish the arc. It simply moves the arc into chutes where the arc is lengthened, cooled and extinguished. The arc shields prevent arc spreading to an adjacent network.
It is important to connect the coils at correct polarity so that the arc is directed upwards. As the breaking action becomes more effective with large currents, this principle has resulted in increasing the rupturing capacities of such breakers to higher values.

Arc chute is an efficient device for arc extinction in air and performs the following three interrelated functions:

- It confines the arc within a restricted space.
- It provides magnetic control over the arc movement so as to make arc extinction within the devices.
- It provides for the rapid cooling of arc gasses to ensure arc extinction by deionization.

Air Chute Air Break Circuit Breaker

The normal arrangement of air-chute air break circuit breaker employed for low and medium voltage circuits is shown in the figure below. There are two sets of contacts called the main contacts and arcing or auxiliary contacts. Main contacts are usually of copper and conduct the current in the closed position of the breakers. They have low contact resistance and are silver plated.

The arcing contacts are hard, heat resistant and usually of copper alloy. Arcing contacts are used to relieve the main contacts from damage due to arcing. The arcing contacts are easily renewable when required. The auxiliary and arcing contacts close before and open after the main contacts during the operation.

Here the blowouts consist of a steel insert in the arcing chutes. These are so arranged that the magnetic field induced in them by the current in the arc moves it upwards still faster. The steel plates divide the arc into a number of arcs in the series.
The distribution of voltage along the arc length is not linear, but it is accompanied by a rather large anode and cathode drops. In case the total sum of anode and drops of all the short arcs in series exceeds the system voltage, conditions for the quick extinction of the arc are automatically established.

When the contact has come in contact with the relatively cool surfaces of the steel plants gets rapidly and effectively cooled. The movement of the arc may be naturally or aided by a magnetic blowout. Thus, the arc is extinguished by lightening and increasing the power loss of the arc.

Working Principle Air Break Circuit Breaker

When the fault occurs, the main contacts are separate first, and the current is shifted to the arcing contacts. Now the arcing contacts are separate, and the arc is drawn between them. This arc is forced upwards by the electromagnetic forces and thermal action. The arc ends travel along the arc runner. The arc moves upward and is split by the arc splitter plates. The arc is extinguished by lengthening, cooling, splitting, etc.

Applications of Air Break Circuit Breaker

Air break circuit breaker is suitable for the control of power station auxiliaries and industrial plants. They do not require any additional equipment such as compressors, etc. They are mainly used in a place where there are possibilities of fire or explosion hazards. Air break principle of lengthening of the arc, arc runners magnetic blow-up is employed for DC circuit breakers up to 15 KV.

Drawback of Air Break Circuit Breaker

A drawback of arc chute principle is its inefficiency at low currents where the electromagnetic fields are weak. The chute itself is not necessarily less efficient in its lengthening and deionizing action than at high currents, but the arc movement into the chute tends to become slower, and high-speed interruption is not necessarily obtained.