Sulphur hexa fluoride (SF6) extra high voltage circuit breakers and its technical considerations to improve its quality and design.

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ABSTRACT—The Interruption of electric power circuits has always been an essential function, especially in cases of overloads or short circuits when immediate interruption of the current flow becomes necessary as a protective measure. In earliest times, circuits could only be broken only by separation of contacts in air followed by drawing the resulting arc out to such a length that it could no longer be maintained. As the voltage and current capacity of power systems grew, however this means of interruption soon became inadequate and special devices called circuit breakers are implemented .So basically a modern circuit breaker can be defined as an electromechanical device capable of making , breaking and carrying currents under both normal and abnormal conditions.

In this paper we have made a detail study of sulphur hexa fluoride(SF6) type of circuit breaker and also the various testing parameters tests performed for efficient design and functioning of SF6 circuit breaker.

Key words –Sulphur hexa fluoride(SF6) circuit breakers, arc extinction, interruption, faults, Operating mechanism,testing,typesofcircuitbreaker.

INTRODUCTION

Every electric circuit needs a switching device and protective device. Switchgear is a general term which covers a wide range of equipment concerned with switching and protection. In a power system the switch gear serves two purposes: Switching during normal operating conditions for the purpose of operation and maintenance.
Switching during abnormal conditions such as short circuits and interrupting the faulty currents.
Whenever a short circuit occurs a heavy current flows through the equipment causing considerable damage to the equipment and interruption of the service. In order to avoid such a damage every part of the power system is provided with a protective relaying system and an associated switching device. The function of protective relaying system is to cause the prompt removal from the service of any element when it suffers from short circuit which interferes the effective operation. The relaying equipment is aided in this task by circuit breakers.

Circuit Breaker –Its Necessity!

A Circuit breaker is a device that interrupts the abnormal or fault currents and in addition performs the function of a switch. Circuit breakers are essential for circuits operating at higher voltages and equipment that carry large currents. For voltages higher than 3.3 KV isolation is provided by circuit breakers. Circuit breakers preferred where the continuity of service and frequent replacement of a fuse is required.

Principle of operation-

It consists essentially of fixed and moving contacts which are touching each other and the current under normal conditions. In usual when the circuit breakers are closed ,electrodes(current carrying contacts)engage each other under the pressure of spring. To open the circuit breaker a small pressure is required to be applied on the trigger. Whenever the fault occurs on any part of the power system , the trip coils of the breaker get energized and the moving contacts are pulled apart by some mechanism ,thus opening the circuit. The separation of current carrying contacts produces an arc. It not only delays current interruption but also generates enormous heat which may cause damage to the system or to the breaker itself. The main problem of the breaker is to extinguish the arc with in the shortest time possible.

Methods of arc extinction-

High resistance method: In this case the arc is controlled in such a way that its effective resistance increases with the time so that the current is reduced to such a value that the heat produced by it is not sufficient to maintain the arc .The resistance can be increased by

1) *Cooling the arc: it brings about recombination of ionized particles .it is done by bringing the arc in contact with cool air.*
2) *Increasing the length of arc :length of arc can be increased by increasing the gap length between the contacts but it is not practicable.*
3) *Reducing the cross section of arc :the cross section of an arc can be reduced by small area of contacts or by letting the arc pass through a narrow opening.*

4) *Splitting the arc : the resistance of the arc can be increased by splitting the arc into small number of arcs into series.*

Low resistance or current zero interruption :this method is applicable only in ac circuit interruption because there is natural zero of current 100 times in a second for 50Hz three phase supply system. This property of ac circuit is exploited for interruption purposes and the current is not allowed to rise again after a zero occurs.

1) *Lengthening of the gap :the dielectric strength or post zero resistance is proportional to the length of the gap between the breaker contacts. So lengthening by rapid opening of the breaker contacts is an obvious process.*
2) *Increasing the pressure in the vicinity of the arc: by increasing the density pressure of particles constituting the discharge also increases.*
3) *Cooling :if the particles are allowed to cool the natural combination of ionized particles will take place more rapidly which results the increase in dielectric strength of the medium.*
4) *Blast effect: by blowing a stream of air through arc ionized particles between the contacts are swept away and replaced by un ionized particles.*

ROLE OF A CIRCUIT BREAKER

The main duties which a circuit breaker has to perform in addition to satisfying the rated breaking capacities and rated making and breaking times are:

Interruption of small inductive currents (current chopping):

The deionization is an important requirement only if it occurs immediately after current zero. The deionization at any other stage of arc current cycle is disadvantageous and unnecessary .The draw back of deionization is that it causes current chopping. It is the phenomenon of current interruption before the natural current zero is reached.

Current chopping is a serious drawback as it produces high voltage transient across the contacts of the breaker. Resistance switching is used to overcome the effect of over voltages de current chopping. Oil circuit breakers are used where these kind of interruption occurs because in it the arc control is proportional to the fault current to be interrupted.

Interruption of capacitive currents:

Another cause of excessive voltage transients across the circuit breaker contacts is the interruption of capacitive currents.

Examples – opening of unloaded long transmission lines, unloaded undergrounded cables and disconnecting of capacitor banks employed in the network.

Vacuum, SF6 and air blast circuit breakers are suitable for capacitor current interruption duty.

Interruption of terminal faults:

A fault occurring very near to the terminal of the circuit breaker is known as terminal fault.

It depends upon the source voltage V and source impedance X, as the impedance between the breaker and the fault is negligible.

After the arc extinguishes at natural zero the circuit recovers and a restriking transient voltage or transient recovery voltage (TRV).

Interruption of short line faults (kilo metric faults):

The fault occurring between a distance of few km to few tens km from the circuit breaker are called the short line or kilo metric faults.

Such faults are characterized by high frequency of restriking voltage of the order of 10 to 100kHz.

The transient restriking voltage(TRV)across the breaker terminals is accompanied by a high frequency line side component, whereas the reduction of fault current due to inductance of short circuited line is only slightly less than that of terminal fault.

Asynchronous or phase opposition switching:

Phase opposition may occur when the breaker recloses after fairly long delay during which generators G1 and G2 fall out of synchronism.

When the switch opens the peak value of the TRV is determined by the sum of V1 and V2 and approaches two times that of short circuit or terminal fault interruption.

CLASSIFICATION OF CIRCUIT BREAKERS *Basis of type of current: They may be classified as ac circuit breakers and dc circuit breakers.*

Basis of rated voltages: They are classified as low voltage circuit breakers(below 1,000 V) and high voltage circuit breakers(above 1,000 V).

Basis of location: Circuit breakers are classified as outdoor(air insulated switch gear) and indoor(gas insulated switchgear)breakers.

Basis of medium of arc extinction: They are classified as oil circuit breakers, air blast circuit breakers, sulphur hexafluoride(SF6) circuit breakers and vacuum circuit breakers.

1)Oil circuit breakers: They are the oldest type of the circuit breakers. The separating contacts of the breakers are made to separate within insulating oil which has better insulating properties than air.

Types-

a)Bulk oil circuit breakers- uses large quantity of oil. It also known as dead tank type because the tank is held at ground potential.

b) Low oil circuit breakers -uses small quantity of oil. It is also known as live tank circuit because the oil tank is insulated from the ground.

Advantages-arc energy is absorbed, provides good cooling properties, acts as very good insulator.

Disadvantages-may cause fire hazards, formation explosive mixture with air, periodical maintenance and replacement.

Applications-used up to 12kV,500MVA and metal enclosed switch gear up to 30kV.

2)Air blast circuit breakers: The drawbacks of oil circuit breakers led to the development air blast circuit breakers

which uses mainly nitrogen or carbon dioxide as the arc interrupting medium.

Types-

a)Axial blast air circuit breakers- the flow of air is along the arc. The falling reservoir pressure and short optimum gap result in the following features. The interruption must take place at the first current zero, gives high speed clearance, small contact gap constitute inadequate clearance.

b)Cross blast air circuit breakers-an air blast is directed at right angles to the arc. The principle used in this type of breaker is fundamentally different from axial air blast breaker.

Advantages-high speed of operation, negligible maintenance, elimination of fire hazards , reduced size.

Disadvantages-more complicated construction, higher cost, problem of current chopping , requirement of highly trained personnel.

Applications-suitable for all EHV applications ,also for arc furnace duty.

3)Vacuum circuit breakers : The highest insulating strength and when an ac circuit is opened by separating the contacts of in a vacuum ,interruption occurs at first current zero with dielectric strength building thousand times at faster rate than other breakers.

Every medium that has pressure below atmospheric ,which is 760mm of Hg is known as vacuum. The vacuum arc is essential that pressure should be low because only then it approaches ideal arc. It is also known as cold cathode arc

Advantages-does not require filling of gas or oil, rapid recovery of dielectric strength, no emission of gas which makes it pollution free.

Disadvantages-higher technology requirement, vacuum interrupter is costlier, cannot be repaired at the site.

Applications-suitable from 3.6kV to 36kV,preferred for indoor switchgear up to 36kV,750MVA.

5)Sulphur hexa fluoride(SF6)circuit breakers:

In case of air blast and oil circuit breakers, the extinguishing force builds up relatively slowly after the moment of contact separation and hence the arc is usually extinguished after a few cycles of current have passed zero.

Vacuum circuit breakers and SF6 breakers have better properties in regard to the comparison of oil and air blast breakers.

Construction - these type of breaker consists of interrupter unit and the gas system.

Advantages-excellent insulating ,arc extinguishing , physical and chemical properties, gas is non inflammable and chemically stable.

Disadvantages-sealing problems, gas is suffocating to some extent, arced SF6 is poisonous.

Applications-most popular over wide range of voltages from 3.6kV to 760kV.

PROPERTIES OF SULPHUR HEXA FLOURIDE GAS-

The physical, chemical and dielectric properties and arc quenching characteristics of SF6 gas are the following:

- *It is colourless , odourless , non toxic and inflammable gas.*
- *The gas is extremely stable and inert and its density five times that of air.*
- *It has thermal conductivity higher(about 2-2.5 times) than that of air and assists in better cooling properties of current carrying parts.*
- *The gas starts liquefying at certain low temperatures. The temperature at which the SF6 gas changes to liquid state depends on pressure.*
- *The heat content property at temperatures below 6000 degrees is much higher that of nitrogen.*
- *It is chemically stable up to 500 degrees and does not react with its structural material up to 500 degrees.*
- *It has exceptionally low reactivity and does not attack metals, plastics.*
- *It not only possess a good dielectric strength but has unique property of recombination.*
- *The presence of moisture is very harmful to the properties of SF6 gas, hydrogen fluoride is formed.*
- *Dielectric strength of SF6 gas at atmospheric pressure is 2.35 times that of air and 30% less than that of dielectric of oil.*

GENERATIONS OF SF6 GAS

First generation: The first generation of circuit breakers uses the dual pressure principle.

The source of quenching Pressure is a stationary high-pressure receiver, much as in the earlier air blast circuit breakers.

To interrupt the current, gas is blown into the break chamber, collected in a low-pressure receiver and subsequently returned to the high pressure receiver.

The major disadvantage of this approach is that, at the required quenching pressure of 1-1.6 M Pa, SF6 liquefies even at temperatures above freezing temperatures.

For this reason, the high-pressure receivers require extra heating.

Second generation: Second-generation SF6 circuit breakers work on the single pressure principle.

The quenching pressure required for extinguishing the arc, is not generated until the opening movement actually begins.

During the breaking operation, the moving compression cylinder moves against a fixed piston, thus generating required quenching pressure. As the contacts separate, an arc forms between them.

Interrupter design: There are two basic types of interrupter designs available. One is the single flow series piston arrangement with nozzles of insulating material coupled with the moving contact.

In this type, the moving contact tip and the insulating nozzle throat are exposed to arcing for a longer time which gives rise to higher contact burn and nozzle ablation.

The other type is the double flow, fixed nozzles arrangement. In the closed state, the moving contact bridges and the two fixed contact tubes with its spring loaded fingers, which are arranged in a ring. The large cross-section of these tubes and the large number of contact fingers give the interrupter unit a high normal current rating. ***REQUIREMENT OF OPERATING ENERGY FOR PUFFER BREAKERS:***

Analysis of energy requirement for the puffer breaker has shown that puffer type of interrupter has comparably longer

stroke to build up the differential gas pressure and to maintain it through out the interruption process.

In fact the reliability of a puffer circuit breaker primarily depends upon its ability to maintain reasonably high differential pressure throughout the "Arc interruption window" for the interrupter.

Third generation: This design breakers are also called self blast breakers. In this design the energy of the arc is also used for its interruption.

There blast cylinder will be divided into two parts of 70:30 ratio in which the 30% of the cylinder will be fixed and arc energy will raise pressure in this chamber for its interruption.

The rest 70% will be compressed by the piston as in case of puffer mechanism or second generation breakers.

These third generation circuit breakers require very less operating energies hence breaker cost have come down rapidly with the introduction of this design

OPERATING MECHANISM –TYPES

Spring mechanism: These type of mechanism is commonly found in high/extra high voltage outdoor type circuit breakers and practically in all medium voltage indoor type breakers.

These mechanisms used with Minimum Oil Circuit Breakers (MOCBs) and later adapted for SF6 breakers also.

This mechanism is stored in the closing springs.

The stored energy is available for closing the circuit breaker upon command following the release of a closing latch.

Pneumatic mechanism: This type of mechanism is best suited for air blast circuit breakers because the pressurized air is already used for insulating and interrupting. An piston is used to drive the opening linkages and to charge a set of closing springs.

To close the circuit breaker, high-pressure air is applied to the underside of the piston by opening a three-way valve, the piston moves downwards transmitting the opening force through a toggle arrangement.

In addition to opening the contacts, the mechanism charges a set of closing springs and once the contacts are opened a close latch is engaged to hold the breaker in the open position.

Hydraulic mechanism: They are in reality only a variation of the pneumatic operation.

The energy in most cases is stored in a nitrogen gas accumulator and the incompressible hydraulic fluid becomes a fluid operating link that is interposed between the accumulator and a linkage system

They operate at much higher pressures than do pneumatic cylinders. Leakage is an important factor because the fluid is conserved and recycled.

Hydraulic mechanism moving parts are totally immersed in hydraulic fluid and is a completely sealed system and protects the components from corrosion.

CIRCUIT BREAKER USED IN BHEL (420kV):

Circuit Breaker manufacturing was started in 1960s, at Hyderabad BHEL which works in collaboration with Alsea Sweden.The collaboration was for ABCBS up to 400 kV, later this was extended to MOCBs up to 400 kV. In 1980s SF6 breakers were introduced by BHEL in technical collaboration with Siemens Germany. Presently BHEL is manufacturing SF6 circuit breakers with Hydraulic mechanism of 145kV, 245kV, 420 kV and 800kV Voltage ranges. They manufacture only outdoor breakers and are of live tank design.

We have made an effort to study about the 420 kV BHEL circuit breaker which is furnished in this report.

Constructional features: The 420kV circuit breaker consists of the following as its constructional features

Breaker base-Its poles are mounted on breaker base. These inter poles comprises of

two interrupt units: provides a double break feature per pole.

Bell crank mechanism: converts the vertical movement of operating rod into linear horizontal movement of moving parts.

Grading capacitors: ensures uniform voltage distribution in open position.

Pre insertion resistors also part of the breaker base.

Accumulator - The operating energy is produced by compression of nitrogen in the accumulator, which is mounted horizontally on base unit of each pole.

A pressurized oil pipe runs from the accumulator to the operating mechanism of the associated pole.

Two more pipes run from the accumulator to the control unit; one to pump and the other to the hydraulic monitoring unit.

Mechanism housing- connects the piston rod of the operating mechanism to the operating rod through the driving rod.

It is not pressurized and can be opened by detaching a cover plate, for inspection or manual operations.

On/off indicator- these auxiliary switches and a terminal strip are accommodated in a box. It is bolted to the mechanism housing.

The auxiliary switch S1 are actuated via driver , bolted to the lower coupling flange connecting the piston rod & driving rod.

Interrupter unit:The gas tight interrupter unit consists of a porcelain insulator , the contact tube , the guide tube , the moving contact tube, the blast cylinder, and the blast piston.

The current flows from the terminal plate through contact support , contact tube , contact fingers (arranged in a circle in the moving contact tube), guide tube and flange.

The flanges of two interrupter units are connected by conductors in order to bridge the housing.

Contact tube and guide tube are fitted with arc quenching nozzles and made of arc resistant material, graphite.

These nozzles keep the erosion to a minimum.

Each interrupter is provided with one filter sump at the terminal flange end.

Bell crank mechanism is the moving contact tube and the blast cylinder form an integral assembly.

They are coupled with coupler of cross head via two connecting rods and rocker. The counter acting blast piston is fixed to supporting ring is connected with coupler of cross head via a fork and levers.

Arc interruption: When an opening operation is initiated, the blast cylinder moves towards the bell-crank mechanism. The counter acting blast piston is pushed in the opposite direction for rapid compression of the trapped SF6 gas to the required pressure.

At the instant of contact separation, arc strikes between the front end of the arc-quenching nozzle of the contact tube and arcing ring of the moving contact tube.

The compressed gas in the blast cylinder is released into the gap radially as the contacts separate. As the moving contact tube moves further, the arc between front end of the moving contact tube, is transferred from the arcing ring to the nozzle of guide tube by the gas flow.

The arc is further elongated by the gas flow axially into the nozzles and gets extinguished. The technical data is categorized into electrical and operating data.

TESTING OF CIRCUIT BREAKERS

These tests are conducted on first few prototype circuit breakers of each type for the purpose of proving the capabilities and confirming the rated characteristics of the circuit breaker of that design.

To check the making ,breaking capacity, short time rating current and operating duty.

Type test:

Type tests are design validation test and are conducted only for particular design get revised. but the routine tests are to be conducted on every breaker being manufactured to ensure the breaker is manufacture per design. These tests ensures that design and the manufacturing is strictly in line with requirement and it will perform well in the power system.

1) *Dielectric tests- To check characteristics of Circuit breaker for Dry, wet, power frequency, Lightning impulse voltage ,Switching impulse voltage (applicable for 420kV CB and above).*
2) *Radio Interference voltage test- To determine RIV on CB pole in both close & open position.*
3) *Resistance of the main circuit- To record circuit resistance during temp. rise test at 20^0 C*
4) *Temp. rise test- To ensure capability of contacts to carry rated normal current within specified temp rise limits.*
5) *Short-time withstand current & peak withstand current- To check the ability of the circuit to carry the maximum rated short-circuit withstand current (2.5 times the RMS value) at 50 Hz in close position during the specified short-term duration of 1 or 3 sec.*
6) *Mechanical operation test at ambient temperature- To check the characteristics of the breaker for 2000 operations on each pole.*
7) *Short-circuit current making/ breaking tests- To check ability of the CB to clear the current on different tests in symmetrical & asymmetrical conditions as per provisions of IEC.*
8) *Capacitive current charging tests- To check withstand capability of the CB for no load transient lines, cables , and capacitor banks.*

Routine tests: They are also performed as per the recommendations of standards and in manufacturer's premises. It includes power frequency voltage (to determine the voltage drops within the current path of the break mechanism) and milli volt drop test and operational test(performs on the breaker by simulating its tripping by artificially closing the contact of the relay).

1) *Dielectric test on main circuit- To check the dielectric's withstand capability of live terminals to live terminals and to earth in both close & open condition of CB*
2) *Dielectric test on auxiliary & control circuit-To check the dielectric's withstand capability of auxiliary & control circuit of CB subject to short duration (60 sec) voltage withstand test for 2 KV.*
3) *Design identification test - Verifies the CB for compliances in terms of language of name plate, identification of aux. Equipment, colour & quality of paint etc.*
4) *Mechanical operating test - Includes -5 open-close operations at max. rated and minimum control voltage ,5 close-open operation at rated control voltage, records opening & closing times at the rated operating pressure & voltage.*
5) *Measurement of resistance of main circuit-To record contact resistance of CB for mechanical operations to be within specified limits*

CONCLUSION

The above mentioned circuit breaker are being practiced at BHEL Hyderabad and the circuit breakers have qualified the type tests and routine tests as per the design and operational requirements. These circuit breakers have proven to be suitable for operation in high stress environments. These circuit breaker meet the increasing demands of quality and quantity. Quality

Demands for all electrical and electronic parts for automotive industries and high voltage applications

The technical solutions described above have demonstrated these capabilities It shows cost effective increase in quality of the protection. These SF_6 circuit breakers proved to be very robust in construction and it's hydraulic mechanism caters to the huge energy requirements of the breaker .So far large amount of SF_6 breakers in both high/extra high voltages have been in use and working continuously since 20 years without any problem in the Indian grid. So far around 800 numbers of 420 kV breakers are supplied by BHEL and all are catering to the needs of the power system.

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