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Industrial Applications of Circuit Breakers In Electrical Power Transmission and Distribution Systems: A Review

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Abstract **- This paper presents a review on the operations of different types of circuit breakers (CB) used in electric power transmission and distribution. Circuit breakers are majorly classified under direct current(DC) or alternating current(AC) system. It shows that the most suitable way of classifying circuit breakers is on the position of voltage standing which is astronomically grouped under direct current(DC) or alternating current(AC) circuit breakers. still, reviewed literatures didn't easily distinguish the separate operations of the different types of circuit breakers as applied to DC and AC power network. The DC circuit breakers which comprise of mechanical, solid-state and mongrel breakers are substantially applied in domestic and artificial operations that employ the use of direct current(DC) especially in high voltage direct current(HVDC) network system for the protection of electrical bias. AC circuit breakers are grouped in high voltage and low voltage forms. The low voltage CB comprises of atomic and molded case circuit breakers used majorly in domestic and marketable installations. The high voltage circuit breakers are further subdivided into oil andoil-less forms. Theoil-less CB is made up air, vacuum and Sulphur hexafluoride(SF6) circuit combers. These high voltage circuit breakersare majorly applied in high voltage and redundant high voltage transmission systems for protection of power system outfit and electrical machines.**

Keywords**— Low Voltage Circuit Breakers ,Miniature Circuit Breaker(MCB , Molded Case Circuit Breaker (MCCB)),HVDC**

I. Introduction

Circuit Breakers is one of the major power system factors in electric power transmission and distribution. A good circuit breaker must be able of clearing and segregating blamed sections of the power circuit fleetly and easily(Balan etal., 2016). The exploration on circuit breaker is no way ending due to its significance in power system circuits. Circuit breaker is a mechanical device that have the eventuality of interposing fault currents by unyoking divisible connections and reclosing it after faults concurrence, in addition performs the work of a switch. Its purpose is to open and close the network to help the goods of fault and to connect dissociate factors of the electrical grid. It can be employed manually during line conservation while it's operated automatically during fault on the line(Anderson, 1999; Khan, 2008; Umran, 2016; Obi etal., 2021). Under healthy operating conditions, the fixed and portable connections of the combers stay unrestricted and won't automatically operate until unhealthy operating conditions do on the system. During unhealthy(fault) conditions, the relay senses the fault and sends a tripping signal to the circuit breaker for opening of the blamed section. The circuit breaker tripping coils get amped after entering this fault signal and the portable connections are dragged piecemeal by some medium, thereby opening the circuit on which it protects. When the circuit breaker connections are dragged piecemeal under conditions of fault, an electric bow is struck between them. The loftiest value of current that can be intruded by a circuit breaker without any detriment to the system is known as interposing or rupturing current. The circuit breaker rupturing current sustain until the discharge halts. During healthy operating conditions the connections are in unrestricted position, whereas during unhealthy conditions the breaker connections move to intrude the current inflow that give rise to an electric bow between the connections. This bow generated during the separation of the circuit breaker connections produces tremendous heat that can affect to system damage or to the circuit breaker itself as well as delaying the process of current interruption. The conditions of circuit combers are in mega volt-amp(MVA), and heavy- duty circuit combers can break- in some thousand amperes of high short circuit currents(Mehta and Mehta, 2008; Bansal, 2019).

The main functions of circuit combers in power circuit are to sustain fault current without deformation due to glamorous forces under fault conditions, to switch cargo currents, to break fault currents as well as operating current. They're employed in the power system to shield it from any unwanted fault by opening or breaking the circuit to intrude the fault current. They're rated in terms of the number of poles, rated frequency, rated timber capacity, rated voltage and current, short-term standing, and operating duty(Hewitson etal., 2004; Wadhwa, 2012; Alharbi and Habiballah, 2020).

Some authors have worked on the circuit combers and its operations to the operation of power system. In Rao and Gajjar(2008), Mayr bow model with steady time parameter and cooling power is applied to develop SF6 breaker model in(PSCAD). It's observed from their results that for the effective interruption of an electric bow, the position of fault should be within the critical length, cooling power should be optimal for the given fault vicinity and the presence of the capacitances across the circuit breaker is needed. In Jing and Bing(2014), the characteristics of glamorous immediate amusement trip in typically low voltage moldered case circuit combers(MCCB) are anatomized using finite element system. The simulation result demonstrates that MCCB has good prospect in optimizing the design and protection performance. Gao etal.(2017) compared DC semiconductor circuit breaker and Sulphur hexafluoride(SF6) circuit breaker with transverse glamorous field(TMF) for DC transmission. Their results showed that semiconductor combers have presto breaking speed, while semiconductor switches may be connected in series and parallel with the high voltage circuit combers. Different types of circuit combers and their operations were reviewed by Goh etal.(2017) which include Sulphur hexafluoride(SF6), oil painting, vacuum, air, and DC combers which made up of solid- state DC and cold-blooded DC breaker. Chen and Ke(2018) bandied modeling and simulation circuit breaker operated on high voltage system with the aid of power system computer backed(PSCAD). From their results, the current and voltage when the circuit breaker cuts current inflow in different positions are primarily harmonious as grounded on the introduced model of the circuit breaker. Liang etal.(2018) delved on a new synthetic test of direct current(DC) vacuum circuit breaker. They anatomized the breaking process of DC circuit breaker, the introductory principle of AC synthetic test and parameters analysis, and also presented a new synthetic test circuit topology of the breaker. Al Mashakbeh(2019) presented a check on the significance of electrical circuit protection bias which showed that utmost diligence use circuit combers and fuses as the electrical circuit protection bias for guarding their circuits from different dangerous conditions. Fatigue assessment and ductilemulti-body dynamic analysis of 550 kV high voltage circuit breaker was performed by Kim(2019) to prognosticate fatigue life of the circuit breaker. Sedhuraman etal.(2019) estimated the performance of smart intelligent circuit breaker(SICB). Their results showed that SICB can reduce and amend thepre-fault by itself without human interface. introductory bracket of different types of circuit breaker in power system transmission and distribution are reviewed by Alharbi and Habiballah(2020). They classified them grounded on their operation, voltage position and packaging, and this helps in guarding power system outfit and bias from dangerous fault current. Yang etal.(2020) presented the specialized growth, substantially the topology, test technology, and technology of protection and control of high voltage direct current(HVDC) circuit breaker and their operations in voltage source motor high voltage direct current(VSC- HVDC) transmission design. Shah et.al.(2020) presented simulation of cold-blooded high voltage direct current(HVDC) circuit breaker with super-conducting fault current limiter(SFCL) for fault current limiting with the aid of MATLAB software.From their given results, the current limiting bysuper-conducting fault current limiter(SFCL) particularly repressed the DC denounce current and specially reduced the current interruption stress for superconducting DC circuit breaker factors. From the reviewed literatures, it's seen that the review of different types of circuit combers as applied to dc and ac power networks were lacking in their analysis. As a result, different types of circuit combers were distributed under dc and ac networks. Their current carrying capacities and voltage situations as well as their operations to power system network are also noted down.

II. Materials

A.Groups of Circuit Breakers used in Electrical Power Transmission and Distribution

There are colorful classes of circuit combers as applied to power system. They're astronomically classified as DC and AC circuit combers which are grounded on the type of current they operate on in the power network. In AC circuit combers, they're classified grounded on the position of operating voltage, by the position of installation, by means of interruption and by its external design.

As grounded on the position of voltage operation, circuit combers are classified as low voltage circuit combers with operating voltage up to 1 kV and high voltage circuit combers with operating voltage beyond 1 kV. The high voltage circuit combers are subdivided into circuit combers with operating voltage of 70 kV and below, and those with operating voltage of 132 kV and over. All high voltage circuit combers are distributed in two main orders which are oil painting andoil-less circuit combers(Gupta, 2015).

As grounded on position of installation, circuit combers can be classified as out-of-door and inner circuit combers. The major distinction between the two is on the enclosures, covering, and the place of installation. The inner type circuit combers are specified to be installed in defended enclosures similar as in structures or defended containing for protection against rainfall conditions. While the out-of-door type circuit combers don't demand any shielding, protection or covering. They've stronger quadrangle arrangements as compared to the inner type(Wadhwa, 2012).

As grounded on the means of interruption of fault current on the line, circuit combers can be classified as oil painting, air- break, air- blast, vacuum, and Sulphur hexafluoride(SF_6) circuit breaker(Alharbi and Habiballah, 2020).

As grounded on the design of external structure, circuit combers can be classified as dead tank and live tank circuit combers. These are also set up to be types of out-of-door circuit combers. The live tank circuit combers have its enclosures and interrupters mounted above the ground position, while the dead tank circuit combers have its enclosures and interrupters mounted on the ground(Choonhapran, 2007).

B.Types of AC Circuit Breakers used in Electrical Power Transmission and their operations

There are different orders of circuit combers used in the transmission and distribution of electrical power.

C. Low Voltage Circuit Breakers

These types of circuit combers are extensively applied in domestic settings as well as in artificial and marketable operations. They include moldered case circuit breaker(MCCB) and atomic circuit breaker(MCB)(Pierre and Jean- Jacques, 2009; Norazizah and Noramalina, 2019).

1)Miniature Circuit Breaker(MCB):

The MCBs as shown in Figure 1 are substantially applied for domestic and marketable installations, with operating voltage between 220 and 400 V and current range from 6 Amps to 63 Amps. The current to intrude cannot be advanced than 100 Amp and the interruption characteristics aren't generally malleable. Generally, they're handed with thermal or magneto- thermal bias and the casing cannot be opened to develop any conservation of the device(Lucius, 2016).

Figure 1: Miniature circuit breaker (JW Tech, 2017)

2)Molded Case Circuit Breaker(MCCB):

The MCCB as shown in Figure 2 is used in distribution of electric power. It's designed principally to cover electrical circuits and outfit that operates on low voltage below 600 V. It can intrude currents up to 2500 Amp. also, this device allows to acclimate the interruption current. The functional principle is also thermal or magneto- thermal and the factors are located inside a separating moldered case. These biases are designed in order not to be opened for conservation, so the connections cannot be replaced. All MCCBs are presto enough to circumscribe the volume of the prospective current let- through, and some are presto enough to be designated as current- limiting circuit combers. They can be used in heavy duty operations similar as welding machines, guarding creators, guarding motors, guarding affluents and guarding capacitor banks(Das, 2012; Aio, 2013).

Figure 2: Molded case circuit breaker (Global Sustainable Energy Solutions, 2017)

D.High Voltage Circuit Breakers

High voltage circuit combers are specified and designed to intrude current inflow at natural current zero and hold out against the pressure and pressure bring about by dielectric on the procedure of interruption. They're applied in high voltage and extra-high voltage transmission systems. They're extremely classified as oil painting and oil-less circuit combers. The oil painting circuit combers are subdivided into minimum or low oil painting circuit combers and bulk oil painting circuit combers. The oil-less circuit combers are sub-categorized as air-break, air blast, vacuum, and Sulphur hexafluoride(SF6) circuit breaker(Suwanasri etal., 2013; Umran, 2016; Obi etal., 2021).

1) Oil Circuit Breaker(OCB):

Oil circuit breakers are the order of high voltage circuit breakers used in transmission of electrical energy which make use of oil painting oil for the extinguishing of arc during the separation of the breaker contact. They correspond of minimum or low oil painting circuit breakers and bulk oil painting circuit breakers. Low oil painting circuit breakers operate with minimum volume of oil painting oil which inhibit the interposing unit in a separating chamber at the live eventuality, and sometimes relate to as the live tank circuit breakers due to the oil painting oil tank is insulated from the ground. While the bulk oil painting circuit breakers uses large amount of oil painting oil as quenching medium and also for separating media between earth corridor of the breaker and current- carrying connections, and occasionally designated as dead tank circuit breakers due to the tank is held at earth eventuality. The contact separation is done under oil painting oil which serves as an insulation between the live corridor due to its high dielectric strength as shown in Figure 3. As the contact is separated underneath the separating oil painting oil, an arc is struck between them. The quenching of an electric arc during contact separation is made possible by two processes. firstly, the hydrogen gasoline has devilish conductivity of heat and cools the electric arc, hence supporting thede- ionization of the medium between the connections. Secondly, the gasoline sets up agitation in the oil painting oil and compels it into the space between connections, thus removing the arcing products from the path of an arc which leads to extinguishing of arc and the circuit current is intruded. The conditions of oil painting oil circuit breakers range from 25 MVA at2.5 kV to 5000 MVA at 230 kV while they are applied for voltage range of 33 kV to 220 kV and breaking capacities of 1500 MVA to 7500 MVA. The graces of oil painting oil as a medium for arc quenching are it has the capability to cool and flow into the space after current zero and electric arc goes out, assimilation of energy by breakdown of oil painting oil, oil painting oil presents a cooling face, while the faults are the high- value of oil painting oil conservation, reduction of dielectric strength of the oil painting oil due to the pollution by carbon patches and high in flammability of the oil painting oil(Hewitsonetal., 2004; Mehta and Mehta, 2008; Alharbi and Habiballah, 2020).

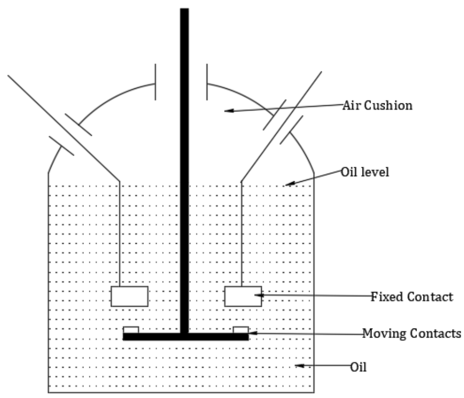

Figure 3: Oil circuit breaker (Bansal, 2019)

2)Air- Break Circuit Breaker:

The air- break circuit breaker is fitted in a chamber that surrounds the connections which is known as bow cascade as shown in Figure 4. It uses air at atmospheric pressure as a means of interposing the fault current, mainly used in low voltage operations with the high interposing current. They are applied on the system that operates on the range of 400 V to

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12 kV and rupturing capacities of 500 MVA(Gupta, 2015).

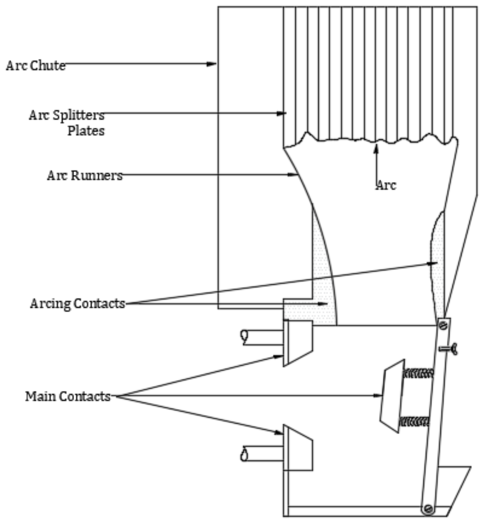

Figure 4: Air-break circuit breaker (Mehta and Mehta, 2008)

3)Air- Blast Circuit Breaker:

This type of circuit breaker as shown in Figure 5 is applied when the system operating voltage is 132 kV and over. They make use of compressed air at pressure of 20 – 30 kg/ cm2 as a means of bow extinguishing during the separation of breaker connections. They have the following graces elimination of fire hazard, the regular charges for oil painting oil relief are avoided, the fault current to be intruded are independent due to the energy demanded for the decimation of an electric arc is gotten from high air pressure, short arcing time, harmonious breaking time, chemical stability of air, small in size and felicity for repeated operation. Their faults are current mincing and restriking voltage, along with high- position noise during the operation and conservation of the air compressor plant, bow extinguishing parcels of the air are inferior, and regular conservation of the compressor plant which gives the air- blast is demanded. Air blast circuit breakers are distributed into cross blast, radial blast and axial blast. Figure 5 shows axial blast type of air circuit breaker. Air- blast circuit breakers are applied in low voltage as well as high voltage systems. It's also used for protection of manufactories, capacitors, and generators(Bansal, 2019).

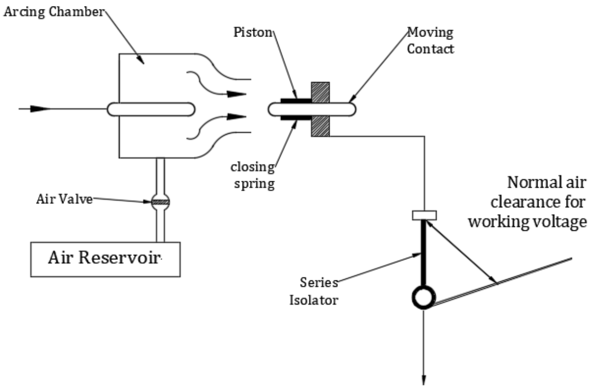

Figure 5: Air-blast circuit breaker (Goh *et al*., 2017)

4) Vacuum Circuit Breaker:

The dielectric strength of vacuum is truly important advanced than other interposing mediums thereby it makes use of the advanced dielectric strength of the vacuum for bow decimation and the rate of dielectric recovery of vacuum is important faster than that of air. The contact separation and movement are truly small, on the order of millimeters rather of centimeters, which makes the part of these breakers and their eventuality of decimation of a bow truly presto. The movable and fixed connections are set up inside an inalterably shut vacuum interrupter as shown in Figure 6. The process and system of the arc quenching is coordinated by a substance face phenomenon during parting of their connections. In other words, the arc is not quenched by the medium of interruption still via the use of substance vapour. The vacuum arc can only be cooled down via the operation of a glamorous field which can move the arc over the contact shells. The capabilities of vacuum circuit breakers for fault-current interruption are similar to SF6 breakers. They are available in the medium range of voltage up to about 35 kV and at 25 kV single phase(50 kV fellow) as double bottle assemblies for electric traction. Vacuum switches as weight- break switches comprising of a series of group of vacuum bottles are accessible up to 245 kV. These breakers are less big, it has high dielectric strength, it requires lower power for control operation, more effective, release of low bow energy, negligible conservation, low- value, truly reliable, compact, and longer life. still, it requires high position technology for the fabricating vacuum interrupters which is precious and also requires supplementary breaker suppressor in resemblant with each phase for interruption of small luring currents. They are generally applied in capacitor switching, shunt reactor switching, motor switching and line dropping(Choonhapran, 2007; Khan, 2008).

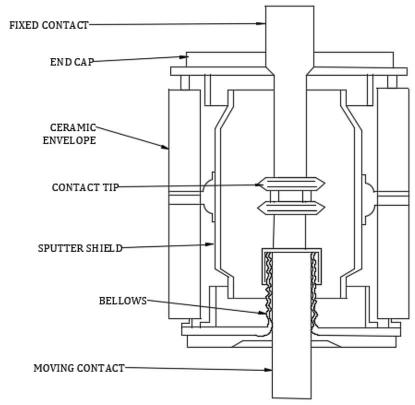

Figure 6: Vacuum circuit breaker (Gupta, 2015)

5) Sulphur Hexafluoride(SF6) Circuit Breaker :

SF6 combers were developed in the 1960s and snappily set off as the favoured choice for wide areas of high and medium voltage operations. They're made up of single pressure type and double pressure type SF6 CBs. The connections of the breaker are opened by the inflow of high- pressure SF6 gas and an electric bow is struck between them as shown in Figure 7. The conducting free electrons in the electric bow are snappily restrained by the means of gas to form relatively motionless negative ions. This loss of conducting electrons in the bow fleetly builds up sufficient and acceptable sequestration strength to quench the bow. The dielectric strength of SF6 at atmospheric pressure is roughly equal to that of air at the pressure of 10 atm. Temperatures in the order of 30000 kelvin(K) are anticipated to be encountered in bends in SF6 and these are, well beyond the detachment temperature of the gas(about 2000 K); nonetheless, nearly all the corruption products are electronegative so that the dielectric strength of the gas recovers snappily after the bow has been

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quenched. Pollutants are made available to ensure the corruption products are inoffensive and only a knob of fluorine reacts with metallic corridor of the breaker. The advantages of SF6 CBs includes SF6 gas CBs can control all known switching marvels, they've a high degree of trust ability, it's largely electronegative, SF6 gas CBs bear minimal conservation, bow reignition is minimized due to the chemical parcels of SF6, contact detachment in SF6 gas CBs is least due to dielectric strength handed by the high- pressure SF6, the nearly packed design of SF6 gas CBs significantly minimizes the space demands and costs of erecting installation, and the lower- and medium-current conditions of SF6 gas CBs are veritably economically satisfied by the modular design. While the faults of SF6 CBs are the high- value of the SF6 gas used in the circuit combers, SF6 has to be repaired after every operation and the high pressure of SF6 gas will absorb all the conducting free electrons which leads to extermination of the bow. SF6 circuit combers comprises single- interrupter SF6 CB which is applied up to 220 kV, two- interrupter SF6 CB which is applied up to 400 kV and four- interrupter SF6 CB which is applied up to 715 kV(Weedy etal., 2012; Turan, 2014).

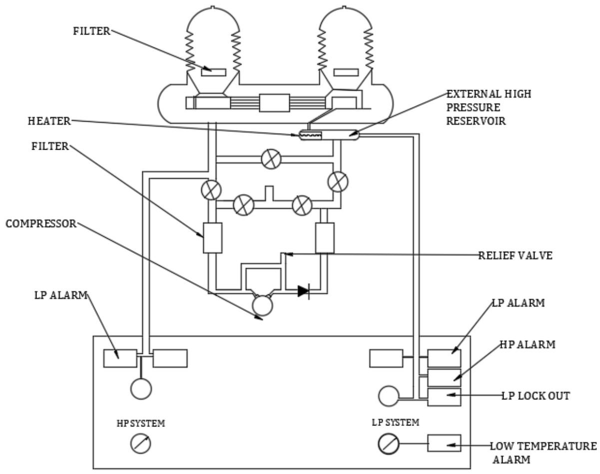

Figure 7: Sulphur hexafluoride circuit breaker (Wadhwa, 2012)

E.Types of DC Circuit Breakers used in DC Power Network

The direct current circuit breaker(DCCB) is the crucial piece of outfit used in high voltage direct current(HVDC) network system for the protection of electrical bias that operate with direct current.(Siemen, 2017; Stanley, 2018). The DCCB comprises solid- state, mechanical and cold-blooded combers. The mongrel dc circuit breaker is the combination of solid- state and mechanical circuit combers(Atmadji and Sloot, 1998; Meyer etal., 2005; Yao etal., 2019; Zheng etal., 2019). The HVDC circuit breaker operates grounded on dicker principle, giving artificial current bottoms. The dc circuit combers haven't generally been used in HVDC network system because of its high cost, complex nature and redundancy(Rao, 2013). The dc waveform of the combers doesn't have natural current zero- crossing point, so the dc bow is more delicate to extinguish than the ac bow(Grieshaber, 2010; IEEE norms Association, 2010). thus, in designing a HVDC circuit breaker, conformation of artificial current

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zero, preventing of restrikes and dispersion of stored energy, are the many issues that have to be answered for maximum optimization and dependable operation and interruption of short circuit current(Shrishti etal., 2019). The creation of artificial current- zero is the major problem endured in extinguishing of bow in dc circuit combers. This can be successfully achieved by

i. Connecting a series resonant L- C circuit across the main contact of a conventional circuit breaker as shown in Figure 8. In this process, the main current is intruded indicating discharge of capacitor C through inductance L and setting up of oscillatory current by the main contact M and supplementary contact S1, hence, artificial current bottoms are produced and the circuit breaker main contact M is opened at a current zero.

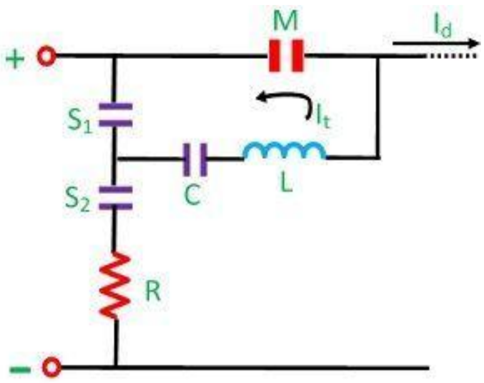

Figure 8: HVDC circuit breaker with series resonant L-C (Norum, 2016)

ii. Diverting the main current Id to the capacitor C which is originally uncharged as shown in Figure 9. In the process of diverting the main current Id to the Capacitor C, the breadth of current to be intruded by the breaker reduces. When the main CB contact M opens, Id is distracted to the capacitor C, thereby reducing the current to be intruded by the main contact M of the circuit breaker.

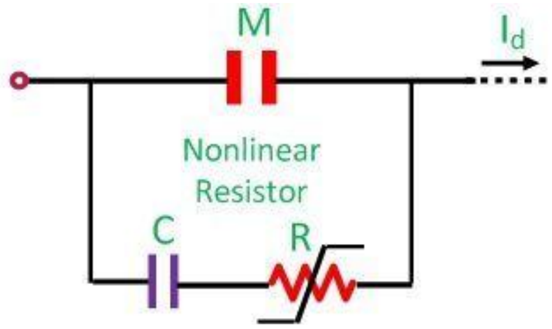

Figure 9: HVDC circuit breaker with non-linear resistance (Zheng *et al*., 2019)

The tone-agitated oscillation mechanical DCCB utilizes the negative resistance trait of a dc bow, to allow the LC oscillation arm and the main current arm to conduct tone-agitated oscillation to give rise to the current zero- crossing points. Hence, the creation of the oscillating current is dependent on the bow parcels and if interruption time is overly lengthy, the short circuit current is hard to intrude. These type of circuit combers are extensively applied in high- voltage dc power transmission, continued power force(UPS), energy ferocious diligence, renewable powers and energy storehouse, road transportation and vessels(Kevin, 2007; IEEE norms Association, 2010; Xiang etal., 2014; Gupta, 2015; Xiang etal., 2017; Secheron, 2020; Yang etal., 2020,).

F. Differences in Alternating Current(AC) and Direct Current(DC) Circuit Breaker Applications

Alternating Current(AC) circuit breakercannot be interchangeably used or applied in Direct current(DC) circuits for some workable base revealed in this review; Alternating current(AC) circuit combers need fresh sequestration than direct current(DC) circuit combers. sequestration material in circuit breaker is of utmost significance in circuit breaker effective operation(Csanyi, 2014; Kong etal., 2016).

In AC circuits, current and voltage cross the zero after every half cycle because of the frequency, magnitude and direction change at time interval. In DC circuits zero cross is unfeasible in view of the fact that neither the current nor voltage has frequency since they're constant, hence DC melts circuit breaker connections briskly(Chan, 2015; Xiang etal., 2017).

Direct current(DC) bow is stronger than Alternating current(AC) bow because of the steady state status of the electrons that produce the bow consequent upon breaking a DC circuit via a circuit breaker. In AC circuit, the applied voltage and current change direction and magnitude thereby relaxing inflow of electrons hence, weaker bow is created(Huo etal., 2017).

III. CONCLUSION

On the review of operations of different orders of circuit combers, it's observed that the most suitable way for classifying circuit combers is on the position of voltage standing which is astronomically grouped under DC or AC circuit combers. It's noted that in the operation of dc circuit combers, artificial current zero is created by connecting a series resonant circuit with inductor and capacitor across the main contact of a CB and by diverting the main current to the capacitor so that the breadth of current to be intruded becomes lower, since there's absence of current zero on dc waveform. The DC circuit combers are substantially seen in domestic and artificial operations that operate with direct current(DC) and contains fresh bow extinguishing measures, while AC circuit combers are substantially used in low voltage, high voltage and redundant high voltage transmission and distribution system for the protection of electrical machines, mills, capacitors, creators, switching of loads in artificial and marketable settings, and in road computerizations. The AC and DC circuit combers cannot be interchangeably applied as they're else used in AC and DC network independently.

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