

CHAPTER-7

HIGH VOLTAGE CIRCUIT BREAKER

7.1 Introduction

Circuit breaker is a mechanical switching device capable of making, carrying and breaking current under normal circuit condition as well as under specified abnormal circuit condition such as short circuit etc. Circuit breakers are generally classified according to interrupting medium used to cool and elongate electrical arc permitting interruption. Selection of outdoor circuit breakers for switchyards 12 kV and above (highest system voltage) as regards types, rating, performance requirements and tests for AC high voltage circuit breakers that are installed in hydro power stations outdoor switchyards after the step up transformer on outgoing transmission line feeders are discussed. Special requirement for rating of AC high voltage generator circuit breakers between the generator and transformer terminals are also discussed.

7.1.1 Standards

Relevant National and important international standard in this connection are as follows:

1. IS: 13118/ IEC56 - Specification for high-voltage alternating current circuit breakers
2. IEC: 62271 - High voltage alternating current circuit breakers
3. IEEE: 37010 - IEEE Application Guide for AC high voltage circuit breakers
4. IEEE 37013 - AC high voltage generator circuit breaker rated on symmetrical current basis

Note: IEC 56 was withdrawn in 2001 and replaced by IEC 62271-100

7.2 Type of HV Circuit Breakers

Following types of circuit breakers formerly used in high voltage outdoor substations are no longer in use and are being phased out.

- i) **Bulk oil circuit breakers** (Dead Tank Design) – In these circuit breakers oil content is used for arc extinction and also for insulating live parts from the tank which is dead and generally earthed (grounded).
- ii) **Minimum oil breakers** (Live Tank Design) – In these circuit breakers oil is primarily used for arc extinction and not necessarily for insulating live parts from earth (ground). The tank of these circuit breakers is insulated from earth ground. The circuit breakers are phase separated. These circuit breakers were widely used up to 72 kV level and are being phased out from existing installation.
- iii) **Air blast circuit breaker** – circuit breaking in these circuit breakers occurs in a blast of air under pressure. These circuit breakers were widely used up to 765 kV system. These circuit breakers are also being phased out.

Following types of circuit breakers (for max. voltage class) are in use now-a-days in hydro plants step up substations.

- i) SF-6 – Sulphur Hexa Flouride Breakers 36 kV to 765 kV class
- ii) Vacuum circuit breakers up to 36 kV class
- iii) Air circuit breaker up to 12 kV

7.2.1 Sulphar Hexafluoride as an Arc Quenching Agent

Pure sulphar hexafluoride gas is inert and thermally stable. It possesses very good arc quenching as well as insulating properties which make it ideally suitable for use in a circuit breaker. Sulphar hexafluoride remains in a gaseous state up to a temperature of 9⁰C at 15 kg/cm² pressure. Its density is about five times

of air and the free heat convection is 1.6 times as much as that of air. Apart from being a gas, it is non-inflammable, non-poisonous and odourless. When arcing takes place through the gas, some by-products are produced due to breakdown of the gas. These by-products are a hazard to the health of the maintenance personnel therefore should be properly taken care of.

At a pressure of three atmospheres the dielectric strength of sulphur hexafluoride is about 2.4 times that of air and compares very well with that of oil. Even when gas is exposed to electric arcs for fairly long periods, it has been found that decomposition effects are small and the dielectric strength is not materially affected. On the other hand the metallic fluorides at the temperatures of the arc are good insulators and the arc is therefore, not at all harmful to the breaker.

Gas circuit breakers generally employ SF₆ (sulphur hexafluoride) as an interrupting medium and sometimes as an insulating medium. In “single puffer” mechanisms, the interrupter is designed to compress the gas during the opening stroke and use the compressed gas as a transfer mechanism to cool the arc and to elongate the arc through a grid (arc chutes), allowing extinguisher of the arc when the current passes through zero. In other designs, the arc heats the SF₆ gas and the resulting pressure is used for elongating and interrupting the arc. Some older low-pressure SF₆ breakers employed a pump to provide the high pressure SF₆ gas for arc interruption.

Gas circuit breakers typically operate at pressures between six and seven atmospheres. The dielectric strength of SF₆ gas reduces significantly at lower pressures, normally as a result of lower ambient temperatures. Monitoring of the density of the SF₆ gas is critical and some designs will block operation of the circuit breaker in the event of low gas density.

Circuit breakers are available as live-tank or dead-tank designs. Dead –tank designs put the interrupter in a grounded metal enclosure. Interrupter maintenance is at ground level and seismic withstand is improved versus the live-tank designs. Bushings are used for line and load connections which permit installation of bushing current transformers for relaying. The dead-tank breaker does require additional insulating gas to provide the insulation between the interrupter and the grounded tank enclosure.

Live-tank circuit breakers consist of an interrupter that is mounted on insulators and is at line potential. This approach allows a modular design as interrupters can be connected in series to operate at higher voltage levels. Operation of the contacts is usually through an insulated operating rod or rotation of a porcelain insulator assembly by an operator at ground level. This design minimizes the quantity of gas used for interrupting the arc as no additional quantity is required for insulation of a dead-tank enclosure. The design also readily adapts to the addition of pre-insertion resistors or grading capacitors when they are required. Seismic capability requires special consideration due to the high center of gravity of the interrupting chamber assembly.

Interrupting times are usually quoted in cycles and are defined as the maximum possible delay between energizing the trip circuit at rated control voltage and the interruption of the main contacts in all poles. This applies to all currents from 25 to 100% of the rated short circuit current.

Breaker ratings need to be checked for some specific application. Applications requiring reclosing operation should be reviewed to be sure that the duty cycle of the circuit breaker is not being exceeded. Some applications for out –of- phase switching or back-to-back switching of capacitor banks also require review and may require specific duty circuit breakers to insure proper operation of the circuit breaker during fault interruption.

7.2.2 Vacuum Circuit Breaker

Vacuum circuit breakers use an interrupter that is a small cylinder enclosing the moving contacts under a high vacuum. When the contacts part, at the first current zero, dielectric strength across the contacts builds up at a very much higher rate than that obtained with conventional circuit breakers. High vacuum gap recovers most of its dielectric strength within 10 micro seconds. The arc products are immediately forced to and deposited on a metallic shield surrounding the contacts. Without anything to sustain the arc, it is quickly extinguished. It is almost maintenance free switchgear.

Vacuum circuit breakers are widely employed for metal-clad switchgear up to 36 kV class. The small size of the breaker allows significant savings in space and material compared to earlier designs employing air magnetic technology. When used in out door circuit breaker designs, the vacuum cylinder is housed in a metal cabinet or oil filled tank for dead tank construction.

7.3 Advantages and Disadvantages

Advantages: Advantages of SF6 breakers over the conventional breakers is given below:

- i) Due to outstanding arc quenching property of SF6, the arcing time is very small. This reduces contact erosion.
- ii) Using SF6 gas at low pressure and low velocity; the current chopping can be minimized.
- iii) During arcing of SF6 breaker, no carbon dioxide is formed and hence no reduction of dielectric strength.
- iv) SF6 breaker is silent in operation and moisture ingression into the gas cycle is almost nil.
- v) SF6 breaker performance is not affected due to variation in atmospheric conditions.
- vi) SF6 breaker is compact in size and electrical clearances are drastically reduced.

Disadvantages: The only disadvantage of using SF6 to some extent is suffocation. In case of leakage in the breaker tank, this gas, being heavier than air settles in the surroundings and may lead to suffocation of the operating personnel. However, it is non-poisonous.

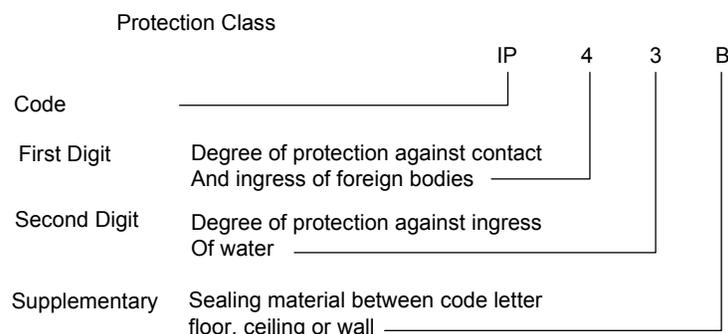
7.3.1 Evaluation of SF6 and Vacuum Switching Technologies

SI. No. 1	Criteria 2	SF 6 circuit breaker 3	Vacuum circuit breaker 4
I. SWITCHING DUTIES			
1.	Summated breaking current capacity	To 50 times rated short circuit breaking current To 10,000 times continuous rated current.	To 100 times rated short circuit breaking current To 20,000 times continuous rated current.
2.	i. Motor, Reactors small inductive current.	Very well suited. Over voltage generally under 2.5 p.u. Normally no action necessary to limit over voltages.	Well suited. Under certain circumstances steps may be necessary to limit over voltages because of possibility of virtual current chopping. Use of surge arresters recommended
	ii. Capacitors	Well suited. Restrike free. In special cases reactors may be necessary to limit in rush current - Low over voltage.	Suited. Generally Restrike free. In special cases reactors may be necessary to limit in rush current. Reignition and restrikes possible in certain cases due to statistical scatter of breakdown voltage in vaccum.
	iii. Over head and cable feeders.	Very well suited-Restrike free.	Very well suited Restrike free.
	iv. Switching of arc furnaces.	Only suitable in applicable with comparatively low number of operations per day.	Suitable also for applications with very high number of operations (over 100 c-o-per day.
3.	Suitability of single and multi shot auto reclose cycles.	Very well suited	Very well suited.

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II. MAINTAINABILITY			
1.	Number of operations between servicing, referred to operating mechanism.	500 to 20,000 C-O Operations	10,000 to 20,000 C-O operation
2.	Service life of interrupters	5000 to 20,000 C-O operations (Between over hauls)	20,000 to 30,000 C-O operations or (manufacturers guidelines)
3.	Service interval	Lubrication of operating mechanism after 5 to 10 years (if limiting number of operations not reached)	Lubrication of operating mechanism after 10 years (if limiting number of operations not reached).
4.	Expenditure on overhaul of interrupters.	Overhaul involves complete dismantling of interrupter. Labour costs high, material costs low.	Tester used to check vacuum level. If necessary replace interrupter. Low labour costs. High material costs.
5.	Supervision of Circuit breaker condition.	Supervision of SF6 gas pressure possible (Pressure guage with contacts for remote signalling.)	Checking the insulation and quench media not easily possible- But generally supervision of vacuum level not necessary (sealed for life)
6.	Refilling of arc quenching media	Possible	Not possible
III. RELIABILITY			
1.	Failure rate	Lowest (7-13 per 1000 CB-Yrs)	Lowest (7-13 per 1000 CB-Yrs)
2.	Mechanical life	Good	Excellent
3.	Fire Hazard	Zero	Zero
4.	Interrupting capacity in case of leakage.	Switching of rated current still possible.	Not possible
IV. COST			
1.	Cost of production	Slightly higher than VCB	-
2.	Maintenance cost	Lowest negligible cost for minimum 10 years.	Lowest negligible cost for minimum 10 years.

7.3.2 Protection Classes for Switchgear Installation

The protection classes are identified by a compound symbol made up of the two code letters 'IP', which always remain the same two digits denoting the degree of protection and, if required, the supplementary code letter B. The supplementary code letter must be stated if in the case of switchgear and distribution equipment the protection class is attained only through taking certain measures when the apparatus is installed. The term 'Production class*' denotes the complete compound symbol (code letters, code digits and the supplementary code letter if applicable)



If in addition to the code letters IP only one code digit for the degree of protection is used, the missing digits *a* to be replaced by a dash.

eg. IP - 4 (Protection class: Splash proof)

Degree of protection against Contact and foreign bodies:

Degree of protection against water

First Digit	Description	Second Digit	Description
0	No Protection	0	No Protection
1	Protection against large foreign bodies	1	Protection against vertically falling water droplet
2	Protection against medium sized foreign bodies	2	Protection against obliquely falling water droplet
3	Protection against small foreign bodies	3	Protection against sprayed water (spray proof)
4	Protection against granular foreign bodies	4	Protection against splashing (splash proof)
5	Protection against dust deposit	5	Protection against water jet (Hot proof)
6	Protection against ingress of dust	6	Protection against inundation
		7	Protection against immersion in water
		8	Protection against in define immersion in water

7.4 Rated Characteristics

The main characteristics of a power circuit breaker including its operating devices and auxiliary equipment specified for circuit breakers in step up station in hydro electric project are as follows:-

- Rated voltage
- Rated insulation level
- Rated frequency
- Rated normal current
- Rated short-time withstand current
- Rated short-circuit breaking current
- Rated short-circuit making current
- Rated operating sequence (duty cycle)
- Rated transient recovery voltage (TRV) for terminal fault
- Total breaking time (maximum)
- Rated characteristics for short-line faults, for three pole circuit breakers designed for direct connection to overhead transmission lines and rated at 52 kV and above and at more than 12.5 kA rated short breaking current

In addition, the following characteristics are necessity for specific application.

- Rated line charging breaking current
- Rated inductive breaking current
- Rated capacitor breaking current
- Rated out of phase breaking current

7.4.1 Rated Voltage

Voltage rating of the power circuit breaker is in terms of three phase line to line voltage of the system. The rated voltage of the circuit breaker is of standard rating chosen so as to be at least equal to the highest voltage of the system at the point where the circuit breaker is to be installed. The operating voltage and the

power frequency recovery voltage should not exceed the rated maximum values because this maximum is upper limit for continuous operation.

Operation at altitude above 1000 meters is given special considerations and certification from manufacturer is obtained because of possible influence of altitude on interrupting capacity.

In case of generator circuit breakers the rated maximum voltage should be equal to the maximum operating voltage of the generator, which is usually equal to 1.05 times rated voltage.

The rated voltage is expressed in kV (rms) and refers to phase to phase voltage.

Nominal system voltage kV rms	Rated voltage of circuit breaker kV rms
11	12
33	36
66	72.5
132	145
220	245

7.4.2 Rated Insulation Level

Insulation level of Standard power circuit breakers for voltages in common use in India is selected from standard insulation levels given in IS: 2165 Part II listed in table 6.1 for voltages up to 36 kV, table 6.2 for voltages up to 300 kV and table 6.19.1 for standard voltages 300 kV and above. The selection is based on insulation co-ordination (ref. chapter 6 Para 6.7 & 6.19).

For rated voltage 300 kV and above, the standard value of rated switching impulse withstand voltage across the open circuit breakers should not be exceeded. For circuit breakers intended for synchronizing operation simultaneously with line energisation switching surge standard circuit breaker having higher rated voltage are used. A correction factor is made for the effect of altitude above 1000 m on impulse strength for generator circuit breaker as given in table 7.1 (as per IEEE: 37013).

Table 7.1

Altitude (m)	Insulation level	Rated continuous current
1000	1.00	1.00
1500	0.95	Refer to manufacturer
3000	0.80	Refer to manufacturer

The surge protection of the system is coordinated with the impulse strength of the breaker, both across the open contacts and to ground. Attention is also given to increase in surge voltage because of reflections which occur at breakers when their contacts are open, especially where cables are involved.

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Surge arrestors are generally installed on the bus or on transformers and not on each circuit breaker, the surge voltage at the breaker can exceed that at the arrestors. The amount of the excess depends upon the steepness of the wave front and the distance from the circuit breaker to the surge arrestors. When the circuit breaker is in the open position, either intentionally left open or during operation, an incoming surge voltage may be doubled by reflection at the open contacts. Selection of too low an insulation level for circuit breakers, if not individually protected by arrestors, may result in line-to-ground, or open gap insulation failure of the circuit breaker. Use of individual line entrance surge arrestors may be required if the lightning trip-out rate of the line exceeds 1 per year (refer IEEE std. 37.010-1999).

7.4.3 Rated Frequency

Standard power circuit breakers are rated at 50 cycles. Other frequencies at some old installations are being phased out.

7.4.4 Rated Normal Current

Rated normal current of a circuit breaker is the rms value of the current which the circuit breaker shall be able to carry continuously at rated frequency with the rise in temperature of its different parts not exceeding specified values. Values of rated normal currents is selected from standard value of normal currents as per IS: 13118 which are 400A; 630A; 800A; 1250A; 1600A; 2000A; 2500A; 3500A; 4000A; 5000A; 6300A (if required higher values can be selected). These ratings are based on operation of the circuit breaker or switchgear assembly where the ambient temperature (measured outside the enclosure) does not exceed 40°C and the altitude does not exceed 1000 m. Standard equipment may be operated at higher altitude by reducing the continuous current rating in accordance with the table 7.1 (based on American Practice).

The rated continuous current is based on the maximum permissible total temperature limitations of the various parts of the circuit breaker when it is carrying rated current at an ambient temperature of 40°C.

When the ambient temperature is greater than 40°C, the current is reduced to less than rated continuous current to keep temperatures within allowable limits.

7.4.5 Rated short-time withstand current

Rated short-time withstand current is equal to the rated short circuit breaking current. The rated peak withstand current is equal to rated short circuit making current. Rated duration of short circuit is as per IS 13118.

7.4.6 Rated Short Circuit Breaking Current

The rated short circuit breaking current is the highest short circuit current which the circuit breaker will be capable of breaking in a circuit having power frequency recovery voltage corresponding to rated voltage and transient recovery voltage equal to the rated value of the circuit breaker as specified in IS. For three pole circuit breakers the AC component relates to three phase short circuit including short line fault.

Rated short circuit breaking current is characterized by two values.

- i) rms value of AC component and is termed rated short circuit current
- ii) Percentage DC component

rms value of AC component of the rated short-circuit breaking current is selected from standard values given in IS 13118. Percentage DC component is dependant upon the time from initiation of short circuit current and standard values are given in IS 13118.

The standard values breaking current being 6.3 kA, 8 kA, 10 kA, 12.5 kA, 16 kA, 20 kA, 25 kA, 31.5 kA, 40 kA, 50 kA, 63 kA, 80 kA, 100 kA. The earlier practice was to express the rated breaking capacity in MVA.

$$\text{MVA} : \sqrt{3} kV \times kA$$

MVA : breaking capacity of circuit breaker

kV : rated voltage

kA ; rated breaking current

7.4.7 Rated Short Circuit Making Current

The circuit breakers some times, close on to an existing fault. In such cases, the current increases to the maximum values as the peak of first current loop. The circuit breaker must be able to close without hesitation as contacts touch. The circuit breaker must be able to withstand the high mechanical forces during such closure.

As per IS: 13118 rated short circuit making current should be at least 2.5 times the rms value of the A. C. component of its rated short circuit breaking current.

7.4.8 Transient Recovery Voltage and Restriking Voltage and First Pole to clear Factor

The instantaneous value of the recovery voltage at the Instant of arc extinction is called the active recovery voltage.

7.4.8.1 Rated Transient Recovery Voltage (TRV) for terminal faults

The rated transient recovery voltage (TRV) for terminal faults relating to the rated short-circuit breaking current is the reference voltage. This constitutes the limit of the prospective transient recovery voltage of circuits, which the circuit breaker will be capable of breaking in the event of a short circuit at its terminals.

Wave form of transient recovery voltage varies according to the arrangement of actual circuit.

7.4.8.2 First Pole to Clear Factors

The ratio of transient voltage that appears across the contacts at the instant of arc extinction to service frequency recovery voltage is called the restriking voltage first pole to clear factor.

In three-phase circuits the restriking voltage refers to the voltage across the first pole to clear because this voltage is generally higher than that appears across each of the other two.

Standard value of rated TRV for 3 pole circuit breaker as per IS: 13118 for voltage in common use for the circuit breakers used in the outdoor step up substations is given table 7.2. Three pole circuit breakers higher than 15 kV and less than 100 kV are now classified as S₁ for breakers used in cable system and S₂ used in line system. Standard values of TRV related to short circuit breaking current has been modified as represented by two factors as shown table 7.2 for S₂ class circuit breaker for out of phase faults.

Table 7.2 Standard values of Transient recovery Voltage (TRV)

Rated voltage	First pole to clear factor	Time	TRV Peak value	Rate of rise	Remarks
(kV)		(μ s)	(kV)	(kV/ μ s)	
3.6	1.5	40	6.2	0.15	Values in brackets are the embedded value of S ₂ class breaker for out of phase breaking as per IEC 62271-100 amb-2
7.2	1.5	52	12.3	0.24	
12	1.5	60	20.6	0.34	
36	1.5 (2.5)	108	62 (92)	0.57 (0.81)	
72.5	1.5 (2.5)	166	124 (185)	0.75 (0.99)	
145	1.3	77	215	2.0	
145	1.5	89	249	2.0	
245	1.3	130	364	2.0	
420	1.3	223	324	2.0	
525	1.3	279	780	2.0	
765	1.3	406	1137	2.0	

7.4.8.3 Recovery voltage: The active recovery voltage depends upon the following factors.

- i) the power factor
- ii) the armature reaction
- iii) the circuit conditions

Effect of power factor on recovery voltage:- With low p.f., for example when the ratio of reactance to resistance of the circuit is high, the active recovery voltage will be high; whereas with high p.f. i.e. when the resistance is high as compared to the reactance, the active recovery voltage would be correspondingly lower. This is illustrated in Figure 7.1. In Figure (a) The p.f. is zero and at the instant of arc extinction A the active recovery voltage is at peak value equaling to AB while in Fig (b) the p.f. is 0.5 and the active recovery voltage at the instant of arc extinction is CD which is less than AB.

In general the active recovery voltage equals the maximum value of the system voltage multiplied by $\sin \theta$ where θ is the power factor angle.

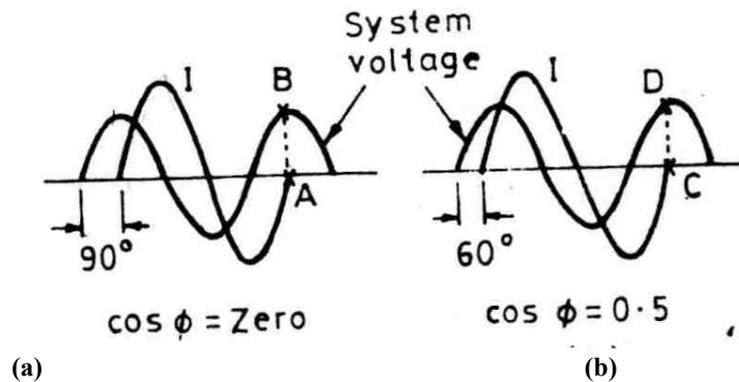


Figure 7.1: Effect of p.f. on recovery voltage

Effect of armature reaction on recovery voltage: The recovery voltage is less than the normal system voltage because of demagnetizing effect of armature reaction. The fault currents flowing in the generator winding are of lagging power factor. They have a demagnetizing armature reaction. Hence they reduce the terminal voltage.

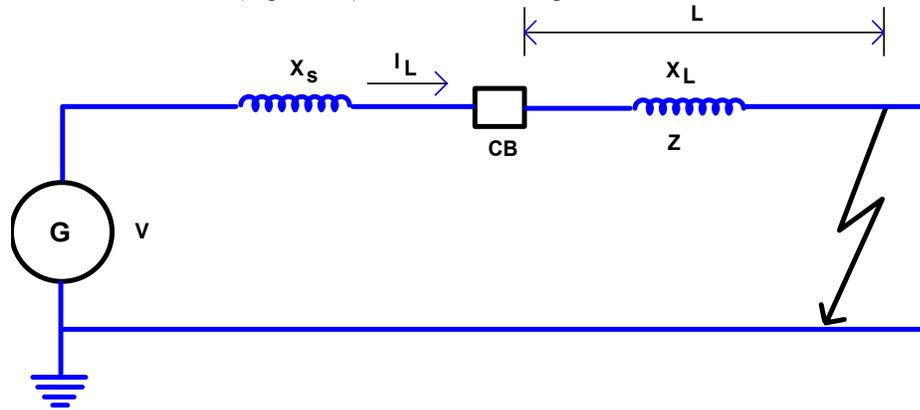
Effect of circuit conditions on recovery voltage: Another factor that influences the recovery voltage is the circuit conditions e.g. three phase faults that are insulated from earth, either at neutral or at fault, produce recovery voltages in the first phase to clear which are normally more severe than those produced by single phase or three phase faults on systems with earthed neutrals. This is explained below.

Consider an unearthed three phase fault, on a three-phase system with the neutral earthed, being cleared by a circuit-breaker. When the breaker opens, it draws out an arc in each phase. Assume that the arc in R phase is the first to be cleared (Figure 7.1 (a)). At the instant of this extinction the Y and B phases are still acting and have the same instantaneous phase voltage $-0.5v$, where v is the phase to neutral value of the system. Now the resistance of the arcs in the Y and B phases at this instant are negligible, which means that the fault itself is momentarily at the potential $-0.5V$. Since the fault is common to all three phases the momentary value of the recovery voltage component in phase R must be $V + 0.5V$ i.e., $1.5V$ (Figure 7.1 (b)). This means that the recovery voltage component in the first phase to clear on a 3-phase unearthed fault is 1.5 times that on an earth fault assuming an earthed neutral.

7.4.10 Rated Characteristics for Short-Line faults

Rated characteristics for short line faults are required for three phase generator circuit breakers designed for direct connection to overhead transmission lines and having a rated voltage of 52 kV and above and a rated short-circuit breaking current exceeding 12.5 kA. These characteristics relate to the breaking of a single phase earth fault in a system with earthed neutral.

The short line fault circuit is taken as composed of a supply circuit on the source side of the circuit breaker and a short line on its load side (Figure 7.2) with the following rated characteristics.



G	= source of power	X_s	= reactance on source side
V	= voltage, phase-to-neutral value: $V/\sqrt{3}$	X_L	= reactance on line side
I_L	= short-line fault current	Z	= surge impedance of the line
CB	= circuit breaker	L	= length of line to fault

Figure 7.2 Short-line fault circuit

7.4.11 Rated Supply Circuit characteristics

Voltage equal to the phase-to-earth voltage $V/\sqrt{3}$ corresponding to the rated voltage V of the circuit breaker short circuit current, in case of terminal fault, equal to the rated short circuit breaking current of the circuit breaker.

Prospective transient recovery voltage, in case of terminal fault is given by the standard values in IS: 13118.

7.4.12 Rated line Characteristics

Standard values of rated surge impedance rated peak factor and time are as per IS: 13118.

7.4.13 Rated out-of-phase breaking current

Rated out-of-phase breaking current is required to be specified for generator breaker and as per IS 13118. This provision will provide following.

- i) The power frequency recovery voltage $2.0/\sqrt{3}$ times the rated voltage for earthed neutral systems and $2.5/\sqrt{3}$ times the rated voltage for other systems.
- ii) The rated out-of-phase breaking current 25% of the rated short-circuits breaking current.
- iii) Transient recovery voltage as per IS: 13118.

7.4.14 Rated Line Charging Breaking Current

Rated Line Charging Breaking Current is required to be specified for feeder circuit breakers. Standard value of line charging capacity of circuit breakers for the commonly used voltages are as follows:

Table 7.3

Rated voltage (kV)	Rated line-charging breaking current (A)
12	2.5
36	40
72.5	40
145	50

245	125
420	400
525	500

This implies for overhead line length (km) equal to 1.2 times the rated voltage of the circuit breaker in kilovolts. In case line length is longer than it may be necessary to specify a higher value of line charging capacity.

7.4.15 Rated time quantities and operating sequence

Automatic reclosing of breakers at step up stations at generating stations can be employed only on isolated feeder or considered on high power lines as single phase reclosing from stability consideration (as in Dehar EHV) because 80% of faults are self clearing type.

Rated values to be assigned to the following time quantities (Figure 7.3) will depend upon rated supply voltage reclosing operations etc.

- Opening time;
- Break time;
- Closing time;
- Open-close time;
- Reclosing time;
- Close-open time;

Rated operating sequence is defined as follows:-

$o - t - co - t' - co$

Where

o - opening operation

co - closing operation followed immediately by an opening operation
(without internal time delay)

t, t' - time interval between successive operation/ t & t' are in minutes or seconds

Power circuit breakers are rated for interrupting ability on the basis of a standard operating duty.

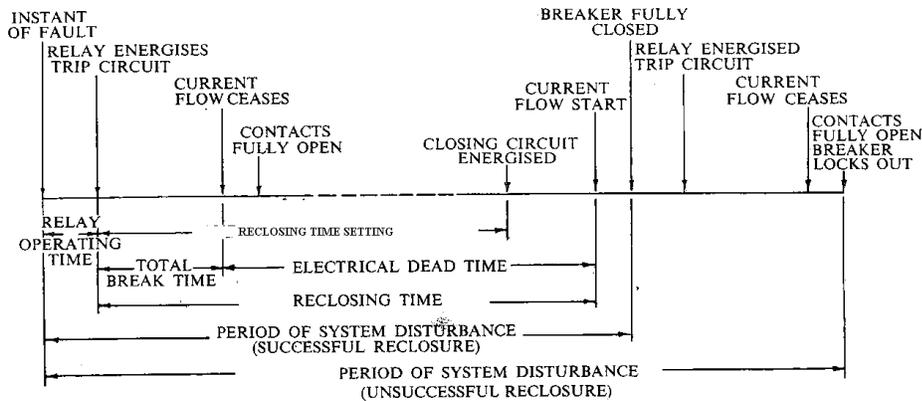


Figure 7.3 Reclosing – Close Open Reclose Time

The rated interrupting time of a circuit breaker is the maximum permissible interval between the energization of the trip circuit at rated control voltage and rated mechanism pressure and the interruption of the current in the main circuit in all poles. It is used to classify breakers of different speed.

For line-to-ground faults, the interrupting time is estimated to exceed the rated interrupting time by 0.1 cycle. For asymmetrical faults, it is estimated that the interrupting time may exceed rated time by an additional 0.2 cycle. Hence, for grounded asymmetrical faults, the last phase to clear is estimated to be 0.3

cycle slower than the rated interrupting time. Additionally, rated interrupting time may be exceeded during extreme cold weather or when the breaker has been closed for an extended period of time. Also, the breaker may be slower at the lower limits of control voltage and/or mechanism stored energy. These interrupting times are in the range of several milliseconds have system stability implications.

The rated interrupting time may be exceeded for close-open operations. The increase in interrupting time on close-open operation may be important from the standpoint of possible system instability. For low values of current, these considerations are less important.

7.5 Co-ordination of rated values

Co-ordination of rated voltages, short circuit breaking current and rated normal current for guidance as per IS 13118 for rated voltage 36 kV and above as commonly used are as follows. (Table 7.4).

Table 7.4

Rated voltage (kV)	Rated short-circuit breaking current (kA)	Rated normal current (A)							
		400	630	1250	1600	2500	4000		
3.6	10	400	630	1250	1600	2500	4000		
	16								
	25								
	40								
7.2	8	400	630	1250	1600	2500	4000		
	12.5								
	16								
	25								
	60								
12	8	400	630	1250	1600	2500	4000		
	12.5								
	16								
	25								
	40								
	50								
36	8		630	1250	1600	2500	4000		
	12.5								
	16								
	25								
	40								
72.5	12.5			800	1250	2000			
	16								
	20								
	31.5								
145	12.5	800	1250	1600	2000	3150			
	20								
	25								
	31.5								
	40								
	50								
245	20		1250	1600	2000	3150			
	31.5								
	40								
	50								
420	20			1600	2000	3150	4000		
	31.5								
	40								
	50								
765	40				2000	3150			

7.6 Tests

Following type tests are normally specified in accordance with IS 13118 and IEC 56 to determine adequacy of the circuit breaker.

7.6.1 Type Test

- i) Dielectric tests (1.2/50 micro second lightning impulse withstand) and 1 minute power frequency voltage with stand (dry & wet) test
- ii) Radio interface voltage (R.I.V.) tests
- iii) Temperature rise tests
- iv) Measurement of the resistance of the main circuit
- v) Short-time withstand current and peak withstand current tests
- vi) Mechanical and environmental tests
- vii) Miscellaneous provisions for making and breaking tests
- viii) Short circuit making and breaking tests
- ix) Basic short circuit test duties
- x) Critical current tests
- xi) Single phase short making and breaking tests
- xii) Capacitive current switching tests
- xiii) Magnetizing and small inductive current switching tests

7.6.2 Routine tests

- i) Power frequency voltage withstand dry tests on the main circuit
- ii) Voltage withstand tests on control and auxiliary circuits
- iii) Measurement of the resistance of the main circuit
- iv) Mechanical operating tests
- v) Design and visual checks

7.7 Fault Calculation

In order to determine interrupting duty of circuit breakers it is necessary to determine fault current at each circuit breaker location. Determination of maximum short circuit current is the most important requirement of circuit breaker application. Rigorous determination of short circuit current as a function of time involves complex calculations. Growth in interconnecting power system as systems expand will increase short circuit duty. Accordingly some approximation and degree of judgment is used.

Different published methods of determining short circuit currents are available. Reference may be made to the following for details and selection.

IEEE application guide for AC high voltage circuit breakers rated on a symmetrical current basis IEEE std. C37010-1999.

First step in carrying out short circuit studies is to determine system impedances with reference to the point of fault and current distribution for different kind of faults. For present day large interconnected system this becomes time consuming laborious study.

AC or DC network analyzer for calculation of fault current was previously frequently used for short circuit studies. In the analyzer all the essential elements of the power system were represented in a miniature replica and fault currents determined from calculation readings. In this method constant voltage behind sub transient/synchronous reactance were used as required. Accordingly real time studies to determine DC component of fault current in addition to AC component to determine the critical current value existing at the time of primary arcing contact parting can not be calculated. Further network analyzer is a fixed place study. Now-a-day computer studies are carried out for such application.

7.7.1 Staged Short Circuit Tests

Staged fault short circuit tests adequately controlled on actual systems have been carried out mostly on new equipments and systems to determine circuit breaker capability. These are accurate, costly and not always possible as selection of circuit breaker precedes power system installation.

7.7.2 Circuit Breaker Rating for Short Circuit Duty

Steps involved in fixing circuit breaker short circuit rating are as follows:

1. Determine normal current duty of the circuit breaker and select higher available rated current from standard values as per IEC/IS 13118 clause 4.4.
2. Short Circuit studies are carried for following types of faults which are considered worst according to IEEE std. C37010-1999.
 - a. Three phase ungrounded faults
 - b. Phase to ground fault

More severe of the short circuit faults is taken for selecting the short circuit rating.

3. Determine short circuit currents for the required accuracy by a suitable method. For line to ground faults, the required symmetrical interrupting capability is 15% higher.
4. Circuit breaker having the rms value of the ac component of the short circuit higher than short circuit duty as calculated from table X A of IS 13118 be selected.
5. A circuit breaker having adequate symmetrical interrupting capability will normally have adequate capability to meet normal asymmetrical requirement. Maximum symmetrical interrupting capacity of new circuit breaker is as follows:

$$\text{Rated short current} \times \left(\frac{\text{Rated maximum voltage}}{\text{operating voltage}} \right)$$

For higher X/R ratio or other special conditions refer the detail methods given in IEEE std. C37010-1999.

7.7.3 Simplified Methods for calculation short circuit current

Simplified methods calculating fault current to fix short circuit rating of circuit breakers have been recommended by standardizing agencies over years as given below.

Simplified conservative methods of calculation were recommended by protective devices committee of AIEEE for general use of the industry. It was recommended that rigorous methods be used when specifically required. The method is based upon determination of an initial value of rms symmetrical current (ac component) to which following multiplying factor are applied for application purposes (table 7.5).

Table 7.5

		General	Generator current breakers/short circuit more than 500,000 kVA
A.	8 cycle breaker	1.0	1.1
	5 cycle breaker	1.1	1.2
	3 cycle breakers	1.2	1.3
	2 cycle breakers	1.4	1.5
B.	Mechanical stresses and mandatory duty	1.6	

Accordingly the steps involved for determining short circuit rating of circuit breakers are as follows as per the AIEE simplified method:

1. Determine highest value of rms symmetrical current for any type of fault equal E/X_1 phase fault or $3E/2X_1+X_0$ for ground fault whichever is greater.
2. Multiply this current by appropriate factors from table 7.5.
3. The resulting interrupting and momentary current should be used to select the available normal rated circuit breaker.

7.7.4 E/X Simplified method as per IEEE std. C37010-1999

The AIEEE simplified method was further referred in IEEE std. 37010-1999. This simplified method is now recommended for specifying short circuit duty of circuit breakers unless complex more accurate studies are warranted.

In these studies generating station and transmission lines interconnected with the system are represented in detail and the system is represented by equivalent system.

For small hydro say 5 MW unit size connected to regional grids, the grid size are assumed to be infinite size and calculation carried out accordingly.

Calculations based on simplified method of calculating short circuit current for the application of method recommended by IEEE std. 37-01-1999 is given as an example (Anneure-1) and compared with calculation made according to earlier AIEE committee report.

Steps involved in applying the method are as follows:

1. Calculate E/X_1 for 3 phase faults where X_1 = positive sequence

Positive sequence X_1 is assumed equal to negative sequence X_2 and obtained from design data or test.

2. Calculate ground fault current $3E/2 X_1 + X_0$

X_0 = zero sequence reactance obtained from design data or test value
 E = phase to neutral voltage

3. If phase fault current does not exceed 80% of 100% symmetrical circuit breaker interrupting capacity or 70% ground fault current then the circuit breaker selection is adequate.

More exact procedure of calculation with adjustment for AC and DC decrements should be used if the criteria is not fulfilled. In this method multiplying factors to initial value of symmetrical short circuit current are given in the form of curves for 2 cycle to 8 cycle.

7.7.5 Simplified Method

Breakers to include effect of ac and dc components for the following types of faults.

- i) Three phase fault
- ii) Line-to-ground fault
- iii) Three phase to ground fault

7.8 Specification

Typical specification for a large hydro (72.5 – 245 kV) is given at Annexure- 2.

Characteristics specified for 72.5 kV Mukerian Stage II (2 x 10 MW) in Punjab, 36 kV Sikasar HE Project (Chattisgarh 2 x 3.5 MW) and 2 x 500 kW Dehra Canal Fall Project 12 kV circuit breakers are given in table 7.6.

Table 7.6

S. No.	Description	Mukerain Stage –II HEP (2 x 10 MW)	Sikasar HEP (2 x 3.5 MW)	Dehra HEP (2 x 500 kW)
	Type and circuit breaker	SF ₆	SF ₆	Vacuum
i.	Number of poles	3	3	3
ii.	Class	Outdoor	Outdoor	Indoor
iii.	Rated frequency	50 c/s	50 c/s	50 c/s
iv.	Rated voltage of breaker	72.5 kV	36 kV	12 kV
v.	Rated insulation level : a). 1.2/ 50 micro sec. Lightning impulse withstand voltage for complete C.B. i. to earth (with C.B. closed) ii. across terminals of open circuit breaker b). one minute dry and wet power frequency withstand voltage i. to earth (breaker closed) ii. across terminals of open circuit breaker	325 kVp 325 kVp 140 kV rms 140 kV rms	170 kVp 28 kV	75 kVp 28 kV
vi.	Rated normal current at site conditions	1600 A	630 A	630 A
vii.	Rated line charging breaking current	Not less than 10A. corresponding switching over voltage values on line side & supply side to be intimated by the tenderer	100 A	
viii.	Rated short circuit breaking current a) rms value of AC component (rated short circuit current) b) percentage D.C. component	31.5 KA at 72.5 KV As per IEC-56 (Latest edition)	12.5 kA at 36 kV (750 MVA) as per IS: 13118	25 kA (350 MVA)
ix.	First pole to clear factor	1.5		
x.	Rated transient recovery voltage for terminal faults a) corresponding to rated short circuit breaking current (Symmetrical & Asymmetrical) b) Corresponding to currents below the rated & short circuit current	As per IEC –56 (latest edition) -do-	-	50% of rated capacity
xi.	Breaking capacity under short line fault conditions with rated supply side and line side characteristics	-do-		
xii.	Rated short circuit making current	78.75 KA peak at 72.5 kV	2.5 times the rms value of Ac component	62.5 kA
xiii.	Rated operating sequence	Break dead Time-Make-Break (Minimum dead time should not be more than 15 cycles at 50 c/s inclusive of the time for auto reading relay. Unit of adjustment of dead time shall be 15 to 35 cycles.		0 – 3 min. – CO – 3 min. - CO

xiv.	Total break time for any current up to rated breaking current	Not more than 60 ms		100 ms
xv.	Min. short time current rating and its duration	31.5 kA for 3 sec.		25 kA
xvi	Minimum total creepage distance phase to earth	1700 mm		
xvii.	Difference in the instant of closing/opening of contacts of all the 3 pole a) Opening b) Closing	Not more than 3.33 ms. Not more than 5 ms.		
xviii	Small inductive current interrupting capacity	Any value up to 10A with out switching over voltage exceeding 2.0 p.u.	-	-
xix.	Whether breaker suitable for single pole operation or gang operation of three poles	Gang operation of three poles through mechanical linkages	Gang operation	Gang operation
xx.	Number of trip coils	Two Nos. per breaker		

Example: - Circuit Breaker Rating for hydro electric power system shown in Figure 7.4 is proposed to be determined.

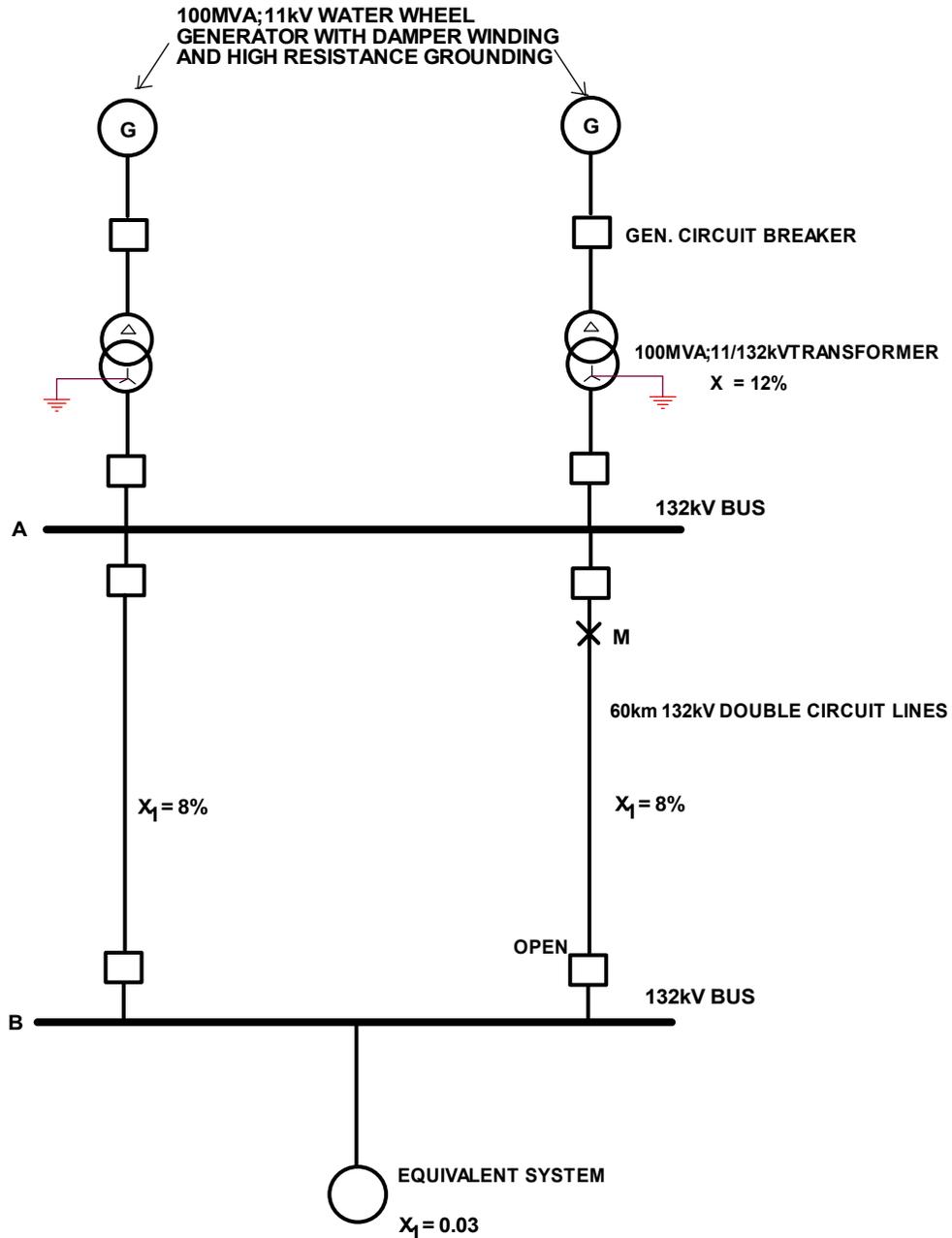


Figure 7.4 Circuit Breaker Rating for hydro electric power system

(Typical)

Data

- i) Sub transient reactance of generator on own base - 24%
- ii) 100 MVA transformer impedance - 12%
- iii) 132 KVA transmission lines impedance - 8%
- iv) Power house is interconnected with grid at bus B.

- v) Equivalent system $X_1 = 0.03$ of $X_0 = 0.04$
1. Consider the fault at M which is fed by the grid system and the hydro- generators which is considered worst.
 2. Three phase fault calculations:- In the system shown in figure 7.5 per unit reactances are indicated.

Apparent power is 100 MVA base and nominal voltage 132 kV is used as base at all levels.

$$X_1 = \frac{\left(\frac{0.24}{2} + \frac{0.12}{2}\right) \times (0.08 + 0.03)}{\left(\frac{0.24}{2} + \frac{0.12}{2}\right) + (0.08 + 0.03)} = \frac{0.18 \times 0.11}{0.18 + 0.11} = 0.068$$

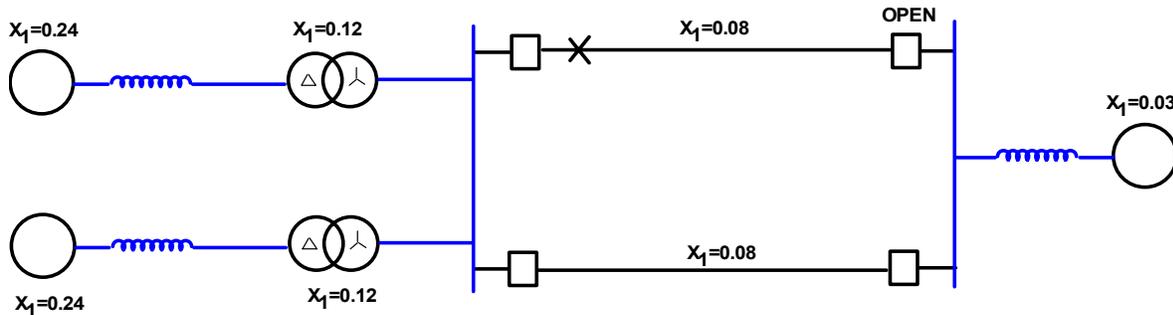


Figure 7.5

Base voltage 132 kV
Base current 437A

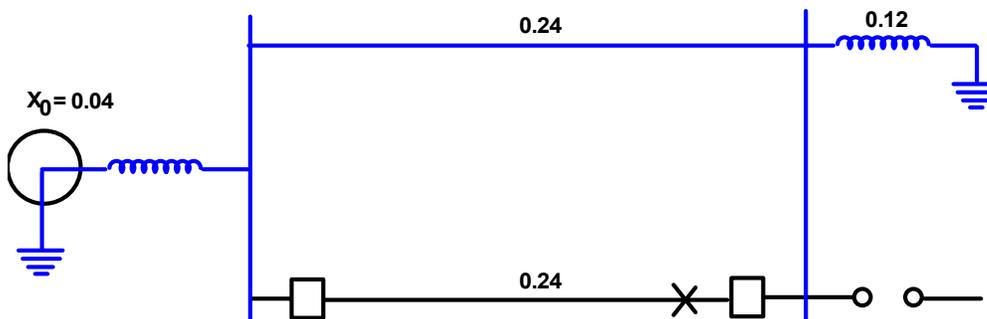
The value of operating voltage corresponding to the highest operating voltage at faults is 145 kV or 1.098/unit

$$\text{Three Phase Fault Current (Isc)} = \frac{1.098}{0.068} \times 437 = 7056\text{A}$$

3. Single line to ground fault current

Zero sequence impedance would be that of transformers above as 12 % on 100 MVA. Impedance X of diagram is shown in figure.

$$X_0 = \frac{(0.04 + 0.24) \times 0.12}{(0.04 + 0.24) + 0.12} = \frac{0.28 \times 0.12}{0.28 + 0.12} = 0.084$$



Since X_0 is greater than X_1 , single line to ground fault need not be considered.

4. Selection of Breaker rating as per IEEE std. 37010-1999.

Load current = $437 \times 2 = 874\text{A}$

Rated normal continuous current = 1250A

As per table Xc of IS 13118

Rated short circuit breaking current = 20,000A at 145 kV

Three phase short circuit current is 7056A is less than 80% of symmetrical interrupting capability (16,000A) and large growth margin exists; the 132 kV breakers at step up sub station are rated 1250A; with rated short circuit breaking current of 20,000A.

Rating as per earlier AIEEE Committee method

Maximum initial symmetrical current	=	7050A
Rating for 5 cycle breakers & factor	=	1.1
And mandatory duty factor	=	1.6
Short circuit rating	=	$7050 \times 1.1 \times 1.6$
	=	12419A
And for 3 cycle breakers	=	134547.5
According 20,000 A; 1250 A breakers as O. K.		

TECHNICAL SPECIFICATION FOR SF6 GAS FILLED CIRCUIT BREAKERS

1.1 Codes and Standards

All standards, specifications and codes of practice referred to herein shall be the latest editions including all applicable official amendments & revisions as on date of opening of bid. The following standards and codes shall be applicable:

IS: 13118	Specification for high voltage alternating current circuit breaker
IS: 4379	Identification of contents of industrial gas cylinder
IS: 2629	Recommended practice for hot dip galvanizing of iron and steel
IS: 14674	High voltage alternating current circuit breakers – Guide for seismic Qualifications of HV AC circuit breaker
IS: 14658	HV AC circuit breakers – Guide for short circuit and switching test procedure for metal enclosed and Dead Tak circuit breaker
IS: 9135	Guide for testing of circuit breaker with respect to out of phase switches
IS: 13516	Method of synthetic testing of HV AC circuit breakers
IEC: 56	High voltage alternating current circuit breakers
IEC: 37010	Application guide for AC high voltage circuit breakers

1.2 Climatic Conditions

The equipment to be supplied under this specification will be installed outdoor at an altitude below 1000 metres and shall be suitable for satisfactory operation under the following tropical humid conditions:-

i)	Maximum temperature of air under hot sun.	---- ⁰ C
ii)	Max. temperature of air in shade	---- ⁰ C
iii)	Min. temperature of air in shade	---- ⁰ C
iv)	Max. relative humidity at 35 ⁰ C	-----%
v)	Average number of dust storm days per annum	-----
vi)	Average annual rain fall	----- cms
vii)	Average rainy days per annum	-----
viii)	Number of months during which tropical monsoon conditions prevail	-----
ix)	Maximum wind pressure	--kg/metre sq.
x).	Seismic level	
	- Horizontal acceleration	---- g
	- Vertical acceleration	---- g

1.3 Type & Rating

The --- kV SF 6/vacuum circuit breakers shall be triple pole, outdoor type, suitable for rapid three phase re-strike free and suitable for outdoor installation/ operation under the climatic conditions specified above, without any protection from sun & rain. These circuit breakers are required for the control of transmission lines, transformers and bus coupler. Each circuit breaker shall comprise of three identical poles linked together mechanically to ensure simultaneous gang operation of 3 poles. The circuit breaker shall be of established design & of robust construction so as to require minimum of maintenance to provide long trouble free service & shall have the following ratings :-

S. No.	Description	Rating of circuit breakers
i.	Number of poles	3
ii.	Class	Outdoor
iii.	Rated frequency	50 c/s
iv.	Rated voltage of breaker	----- kV
v.	Rated insulation level :	

	a). 1.2/ 50 micro sec. Lightning impulse withstand voltage for complete C.B. iii. to earth (with C.B. closed) iv. across terminals of open circuit breaker a. one minute dry and wet power frequency withstand voltage iii. to earth (breaker closed) iv. across terminals of open circuit breaker	---- kVp ---- kVp ---- kV rms ---- kV rms
vi.	Rated normal current at site conditions	----- A
vii.	Rated line charging breaking current	Not less than ----. corresponding switching over voltage values on line side & supply side to be intimated by the tenderer.
viii.	Rated short circuit breaking current c) rms value of AC component (rated short circuit current) d) percentage D.C. component	----- KV As per IEC-56 (Latest edition)
ix.	First pole to clear factor	1.5
x.	Rated transient recovery voltage for terminal faults c) corresponding to rated short circuit breaking current (Symmetrical & Asymmetrical) d) Corresponding to currents below the rated & short circuit current	As per IEC -56 (latest edition) -do-
xi.	Breaking capacity under short line fault conditions with rated supply side and line side characteristics	-do-
xii.	Rated short circuit making current	----- KA peak at ----KV
xiii.	Rated operating sequence	Break dead Time-Make-Break (Minimum dead time should not be more than 15 cycles at 50 c/s inclusive of the time for auto reading relay. Unit of adjustment of dead time shall be 15 to 35 cycles.
xiv.	Total break time for any current up to rated breaking current	Not more than 60 ms
xv.	Min. short time current rating and its duration	----- kA for 3 sec.
xvi.	Minimum total creepage distance phase to earth	-----mm
xvii.	Difference in the instant of closing/opening of contacts of all the 3 pole c) Opening d) Closing	Not more than ---- ms. Not more than ---- ms.
xviii.	Small inductive current interrupting capacity	Any value up to 10A without switching over voltage exceeding 2.0 p.u.
xix.	Whether breaker suitable for single pole operation or gang operation of three poles	Gang operation of three poles through mechanical linkages
xx.	Number of trip coils	Two Nos. per breaker

The rate of rise of re-striking voltage applicable to the ratings offered shall be clearly stated in tender. Actual rupturing capacity of circuit breakers offered shall also be indicated in the tender.

1.4 Type of Breakers

The circuit breakers to be offered shall be SF-6 gas filled type suitable for outdoor installation under the specified climatic conditions.

The breakers shall be furnished as complete units with all the auxiliary equipment and all internal wiring installed and terminated in the apparatus box/switch cubicle for ready installation at site on receipt at destination. All apparatus connections and cabling shall be designed and arranged so as to minimize the risk of fire and any damage that may be caused in the event of fire.

The circuit breakers shall ensure rapid and smooth interruption of current under all conditions completely suppressing undesirable phenomena even under the most severe and persistent short circuit conditions or when interrupting small currents including leading or lagging reactive currents.

1.5 SF6 Circuit Breakers

SF6 circuit breakers shall consist of three identical single pole units each using SF6 gas at single pressure and puffer type interrupting arrangement. Circuit breaker shall have a common operating device for three poles. SF6 gas conforming to IEC 376 shall be used in the interrupting units at such a pressure that the breaker does not require any complex auxiliary circuit for pressure & temperature control, special heating system and special compressors etc. Suitable gas filling and pressure monitoring arrangements (preferably independent pole wise) shall be provided.

Insulation to earth of the circuit breaker shall be independent of SF6 pressure. Suitable measures shall be adopted in the individual interrupting units to achieve requisite degree of dryness for SF6 gas and to absorb its decomposition products. SF6 gas filling should not develop dangerous over pressures inside the interrupting units within the temperature rise limits to be encountered in service. SF6 gas filling in the interrupting units should work in the closed circuit without causing any exhaust to the open air after performing opening or closing operations. Time period in terms of number of operations on fault, number of years of normal service after which SF6 gas filling needs replacement shall be stated in the tender.

There should be no leakage of SF6 gas from the joints and sealing points. The gaskets used between the support insulators of the breakers should be such that these should not fail.

Facilities shall be provided to reduce the gas pressure within the circuit breaker to a value not exceeding 8 milibar within 4 hours or less. Each circuit breaker shall be capable of withstanding this degree of vacuum without distortion or failure of any part.

SF6 gas for first filling of each circuit breaker plus 20% extra (to be supplied in non-returnable gas cylinders) shall be included in the scope of supply and complete specification of the SF6 gas proposed to be utilized shall be stated in the tender. Prices of SF6 gas with cylinder filling device, and trolley indicating the net weight of the gas in it must also be quoted separately.

The high pressure cylinders in which the SF6 gas shall be supplied and stored at site shall comply with the requirements of following standards and regulations:-

- i. IS- 4379: Identification of the contents of industrial Gas cylinders.
- ii. IS-7311: Seamless High carbon steel cylinders for permanent and high pressure liquifiable gases.
- iii. Indian Boiler Regulations

Equipment for filling, evacuation and detecting leakage of SF6 gas recommended by the bidder for proper maintenance of circuit breaker shall be offered. Prices for the same shall also be taken into consideration for bid evaluation. In case purging of breaker before filling with SF6 gas is desirable then the required equipment shall also be furnished as a part of the maintenance equipment. The plant shall be complete with necessary pipes, couplings, flexible tubes and valves for coupling to the circuit breakers.

The offer should be of latest design but of proven performance. Further the design of circuit breakers should be such that it does not become obsolete so that the normal spares are easily available even after 10-15 years of its service.

1.6 Circuit Breaker Operation

Each circuit breaker shall be remote controlled from the control room but provision shall be made for local electrical/spring control operation also. For remote and local electrical operation, 48/110/220 volts D.C. Supply shall be available and the power operating coils viz. Closing and Tripping coils shall be so designed that they operate the circuit breaker satisfactorily within a control voltage varying between 70% to 110% of the normal voltage for trip coils and 80% - 110% of the normal voltage for closing coils.

Each circuit breaker shall be offered along with unit spring charging equipment comprising of A.C motor unit, spring, accessories, limit switches etc. Along with auto recharging of the spring after each tripping manual arrangement for charging the spring shall be provided.

Each circuit breaker shall be equipped with its own spring charging system. Suitable provisions shall be made for lockout, alarm/ indicating etc. under low SF6 gas pressure conditions.

Two independent trip coils shall be provided for each breaker from reliability view point. It is intended to have continuous type of pre-closing and post –closing trip circuit supervision through auxiliary relays and suitable resistors to be connected in series with each trip coil for the purpose. All the trip coils shall therefore be designed keeping in view the above requirement.

It shall be possible to lock out the circuit breaker operating apparatus box/ switch cubicle in the open as well as closed position of the breaker.

The operating mechanism shall be trip free as per IEC-56 and shall have antihunting feature.

A mechanical position indicator for ON/ OFF condition of the circuit breaker shall also be provided on each breaker /switch cubicle/ apparatus box in addition to electrical or pneumatic type of indications.

Mechanical indicator provided to show open and close position and operation counter shall be located in a position not more than 1.5 m. from the ground where it will be visible to a man standing on the ground level with mechanism housing closed.

1.7 Apparatus Box

All the control equipment immediately connected with the operation of the circuit breaker shall be installed in an outdoor type, weather, vermin and splash proof strong cubicles having suitable number of hinged doors so as to afford easy access for all equipment's mounted inside. Apparatus box shall be fabricated from heavy gauge M.S. Sheet of at least 3mm thickness. Positive locking arrangement with lock (s) shall be provided on the front door to check unauthorized operation. The cubicles shall be either hot dip galvanized or of other approved design and construction so as to be suitable for use under tropical conditions at site. The cabinet shall contain the following equipment in addition to any other equipment required for satisfactory operation of the circuit breakers:

1. Control selector switch for local /remote electrical operation with a neutral position.
2. Control switch for local electrical operation.
3. Control Manual switch for local operation in the absence of DC supply.
4. Separate pressure switches with alarm contacts for signaling high / low pressure of SF6 gas pressure. Switches shall also be provided for start and stop of the motors on complete spring releasing or charging.
5. Suitable pressure gauge (s) (Density Monitors) for showing SF6 gas pressure of each limb and pressure switches for giving low gas pressure alarm and blocking of closing/ tripping. The contacts should be provided and wired up to terminal block for getting annunciation in the control room.
6. Circuit breaker mechanical ON/OFF position indicator and spring charged indication.
7. Anti hunting device (Electrically operated).
8. Trip coils and Closing coils

9. Indicating lamps for various operations
10. A heating element complete with a rotary switch
11. Safety valves.
12. Switches and fuses for controlling AC & DC supplies
13. A power plug with switch
14. A light point with door switch
15. Complete wiring for the cabinet should be fire resistant and having stranded copper conductor of cross-sectional area 2.5 mm² or more according to current requirements.
16. A terminal board with suitable number of numbered terminals including 20% spare terminals
17. Cable glands for various power and control cables
18. Emergency trip device
19. Operation counter
20. Rating and diagram plate in accordance with IEC incorporating the year of manufacture and purchaser's order reference.
21. Earthing terminals and lugs for the earthing of marshalling/ apparatus box
22. Any other item to complete the job

All fixtures, nuts, bolts etc. for mounting the apparatus box either on the circuit breaker supporting structure or on a nearby plinth shall be supplied by the tenderer. Apparatus box shall be equipped with requisite number of cable glands for receiving PVC insulated power and control cables necessary for the control and operation of circuit breakers.

1.8 AUXILIARY SWITCHES

Each circuit breaker shall be provided with necessary number of auxiliary switches both of the normally open and normally closed type for satisfactory operation of the breaker and for operating ON/OFF indication lamps locally and semaphore indicators on the control panel. In addition 10 nos. normally open and 10 nos. normally closed contacts shall also be provided with each circuit breaker as spare for various interlocking, schemes and remote position indications. It shall be possible to change any number of normally closed contacts into normally open contacts and vice versa. The total number of auxiliary switches thus provided and the rating of each contact shall be clearly stated. There shall be a provision to add more auxiliary switches at a later stage. The leads from auxiliary switch contacts shall be brought to a terminal board installed inside the auxiliary switch housing and suitable cable glands shall be provided for terminating PVC insulated control cables.

The tenderer shall clearly state in the tender whether the NO/NC contacts are of normal design or of make before break and vice versa type.

1.9 MOUNTINGS

The circuit breakers shall be self supporting type. However, if necessary for the purpose of minimum ground clearance the circuit breakers shall be mounted on raised steel structures which shall be included in the scope of supply. The successful tenderer shall supply the following information and data for design of foundations after the award of the contract.

1. Dead weight per pole for complete circuit breaker
2. Static bending moments about the feet of each pole and for complete circuit breaker.
3. Static shear force at the foot of each pole and for complete circuit breaker
4. Maximum height of the steel supporting structure
5. Maximum diameter of the pole
6. Maximum horizontal force acting at upper terminal of each pole due to impact of closing/opening of the circuit breaker
7. Max. impact loading in terms of equivalent static load both compression and upward due to opening/closing of the breakers. It shall be clearly stated whether these forces shall act simultaneously or at different timing.
8. No. of steel supporting columns provided for mounting the equipment.

The above data shall represent static reactions for the worst windage or operation conditions. Circuit breakers whether of self supporting type or on raised steel structure shall ensure minimum sectional clearance of ----- mm.

Necessary connecting materials such as clamps, bolts, nuts, washers etc. and fixing bolts for mounting the equipment on the supporting structures wherever required shall also be supplied by the tenderer.

1.10 Design Features

1.10.1 Contact System

The design of contact system of the circuit breakers shall be such as will provide easy access to the contact system while undertaking maintenance and replacement jobs.

Auxiliary arcing contacts may be provided to protect the main contacts from damage during circuit breaker operation.

It shall be clearly stated whether the main contacts are silver plated or not and the thickness of silver plating shall be stated if the same has been provided, Material of main & arcing contacts shall also be stated in the tender.

It may clearly be stated whether the contact travel is sufficient to withstand the rated voltage of the breaker in the event of leakage of SF6 gas from the poles.

In the event of leakage of extinguishing medium to a value which cannot withstand dielectric stresses specified in the open condition, it may be clearly stated whether the contacts will remain in the open condition or self close.

Main contacts shall have an ample area and contact pressure for carrying the rated current and short time rated current without excessive temperature rise which may cause pitting or welding. Material and cross section area of the main contacts shall clearly be stated in the tender.

Main contacts shall be the first to open and last to close so that contact burning and wear are the least.

1.10.2 Temperature Rise

The maximum temperature and temperature rise (to be stated in the GTPs) attained by various parts of the circuit breaker when in service at site under continuous full load conditions and exposed continuously to the air and direct rays of the sun shall not exceed the permissible limits specified in IEC-56 (latest edition) or relevant ISS.

1.10.3 Recovery Voltage And Power Factor

Each circuit breaker shall be capable of interrupting without opening resistors rated power with recovery voltage corresponding to the rated maximum line to line service voltage at rated frequency and at a power factor not exceeding 0.15 . The breakers shall also be capable of interrupting faults currents of magnitude 2 to 10% of rated breaking current without causing any re-strike or non permissible over voltage in the system .critical current which gives the longest arc duration at lock out pressure of extinguishing medium and arc duration shall be indicated in the tender

1.10.4 Faulty Synchronising

Each circuit breaker shall be capable of satisfactory operation even under conditions of phase opposition which may arise due to faulty synchronism as per IEC-56 requirements. The maximum current which the circuit breaker can satisfactorily interrupt at twice the maximum phase to ground applied voltage under phase opposition conditions shall be stated in the tender.

1.10.5 Transformer Charging Current Breaking Capacity

The circuit breakers shall be capable of interrupting small inductive currents such as those occurring while switching off unloaded transformer banks and reactor/ capacitor loaded transformers without giving rise to undue over voltage and without re-strikes. The minimum transformer charging current which can be interrupted by the breaker and corresponding over voltage value under such conditions shall be stated in the tender

1.10.6 Restriking Voltage

The circuit breakers offered shall be re-striking free. The rated transient recovery voltage for terminal faults shall be as already specified. Measures adopted for ensuring proper operation at high rate of rise of re-striking voltage and for limiting actual voltage across the circuit voltages breaker shall be described. The details of any device incorporated to limit or control the rate of rise of re-striking voltages across the circuit breaker contacts shall also be stated. The circuit breaker shall be capable of with –standing higher peak voltage and RR of TRV expected during clearance of short circuit immediately after the power transformers in the vicinity of centre of generation and at the end of long lines.

1.10.7 Overhead Line Charging Current Interrupting Capacity

Each circuit breaker shall be designed so as to interrupt without restriking the assigned line changing current as per IEC publication No. 56 (latest edition) , if any , corresponding assigned maximum over voltages both on the line and supply side of the circuit breaker shall be clearly stated.

1.10.8 Breaking Capacity For Kilometeric Faults

The interrupting capacity of the circuit breaker for kilometeric faults under supply side and line side characteristics specified in clause 8.6 shall be as per IEC –56. The details of test conducted from providing the capabilities of the breakers under kilometeric fault conditions shall also be stated in the tender.

1.10.9 Insulating Supports

The porcelain used for bushing/support insulators shall be homogenous, free from cavities and other flaws. The bushings shall be securely cemented with the pole base such that its failure to base due to shear is minimum. The insulators shall be designed to have ample insulation. Mechanical strength and rigidity for satisfactory operation under the conditions indicated in this specification. All insulators / bushings of identical ratings shall be interchangeable. The puncture strength of insulators/bushings shall be greater than the flash –over value. The insulators/bushings shall be entirely free from ratio disturbance when operating at voltage 10% above rated voltage and shall also be free from external and internal corona. Total phase to earth creepage distance and that between top and bottom terminals shall not be less than the values specified under clause –8.6

1.10.10 Noise Level

The circuit breakers shall be reasonably quiet in operation. Noise level at the base of the breaker should be less than 140db. Breakers shall be provided with sound muffles to reduce the noise level, if required. Bidders shall indicate the noise level of breaker at distance of 50, 100 and 150 m from itself.

1.10.11 Interlocks

Necessary interlocks shall be provided to prevent manual/auto closing or opening of the breaker under low gas pressure. Devices for initiating the necessary alarms and indications shall also be provided

1.10.12 Control Connections and Wiring

All connections and wiring shall be suitable for tropical atmosphere. Apparatus box connections shall be insulated and shall be neatly and securely fixed to the panel. All box wiring shall be of self extinguishing type and shall run in porcelain or non rusting metal cleats of the limited compression type.

The cable/wiring used shall be of fire resistant type. Where conduits are used, the runs shall be laid with suitable falls, and the lowest parts of the run shall be external to the boxes. All conduit-runs shall be adequately drained and ventilated, conduits shall not be run at or below ground level.

Where 415 Volts connections are taken through junction boxes or marshalling boxes they shall be adequately screened and 415 Volts –Danger” notice must be affixed to the outside of the junction boxes or marshalling boxes .

All box wiring shall be with stranded copper conductor having size 2.5 mm² or more as per current requirement and in accordance with relevant ISS.

All wires on apparatus box and all multi-core cables shall have ferrules which shall bear the same number on both ends.

Ferrules shall be of white insulating material and shall be provided with glossy finish. These shall be clearly and durably marked in black and shall not be affected by dampness or oil.

Ferrule numbering shall be in accordance with relevant ISS. The same ferrule number shall not be used in wires in different circuits on the same apparatus box.

Stranded wires shall be terminated with tinned (not soldered) insulated crimped lugs of copper or other suitable claw washers, separate washers being used for each wire. The size of the washers shall be suitable for the size of wire terminated. Wiring shall in general be accommodated on the sides of the box and the wires for each circuit shall be separately grouped.

Wires shall not be joined or tied between terminal points. Wherever practicable all circuits in which the voltage exceeds 125 volts shall be kept physically separate from the remaining wiring. The function of each circuit shall be marked on the associated terminals boards.

Where apparatus is mounted on the box all metal cases shall be separately earthed by means of copper wire or strip having adequate cross-section.

Multicore cable tails shall be so bound that each wire may be traced without difficulty to its cable.

All terminal boards shall be suitably mounted to give easy access to terminations and to enable ferrule numbers to be read without difficulty.

Terminal board rows shall be adequately spaced and not less than 100mm apart to permit convenient access to wire terminations. Terminal boards shall be so placed with respect to the cable clutch (at a minimum distance of 200 mm) as to permit satisfactory arrangement of multi-core cable tails.

Insulating covers of self-extinguishing material, preferably transparent, shall be provided on terminal boards on which connections for circuit with a voltage greater than 125 volts are terminated.

Cables shall be provided on the front portions of the terminal board. No live metal shall be exposed at the back of the terminal boards. All fuses shall be of the cartridge type

Fuses and links shall be labelled (circuit wise). MCBs shall be provided wherever necessary and feasible.

1.10.13 Terminal Connectors

Circuit breakers shall be provided with appropriate number of solderless clamp type Aluminium / Bimetallic connectors which shall be universal type suitable for horizontal as well as vertical take off with single conductor as per actual requirement to be intimated to the successful tenderer. Short circuit rating and time as well as continuous current rating of the terminal connectors shall be the same as that of the circuit breaker offered.

1.10.14 Grounding

Two grounding terminals shall also be provided on each equipment / apparatus for proper grounding connection with the station ground mat.

1.10.15 Metal Parts

All ferrous parts of equipment shall be heavily hot dip galvanised . Bolts, nuts, screws, pins, washers etc. used in these equipment shall also be galvanised. The galvanising should conform to IS –2629 – latest edition.

All current carrying parts shall be of non ferrous metal or alloys and shall be designed to limit sharp points, edges and sharp faces.

1.11 Tests

Type tests

The circuit breaker along with its operating mechanism shall conform to the requirement of type tests as per latest edition of, IEC –publication No. 56 /IEC –694 /IS –13118.

Complete set of type test reports with necessary oscillograms, drawings pertaining to the offered circuit breakers shall be submitted with the tender. Tenders not accompanied by Type Test Reports as specified in IEC –56, shall not be considered.

Routine tests

The routine tests as per latest edition of IEC publication No. 56-/ IEC –694 or IS –13118 covering up to the data amendments shall be carried out in the presence of purchaser’s representative, if so desired by the purchaser. In addition to above speed curve for each breaker shall be obtained with the help of a suitable operation analyser to determine breaker contacts movement during opening, closing, under normal as well as limiting operating conditions (control voltage and SF6 gas pressure etc). The curves shall show speed of contacts at various stages of operation, travel of contacts , opening time, closing time shortest time between separation and meeting of contacts at break/ make operation etc. Operation analyser to perform these test shall be included in the list of tools and equipment for initial erection and subsequent maintenance.

Routine test certificates of associated equipment such as motors support insulators, hollow insulators ,gas cylinders and SF6 gas etc as per relevant IS/IEC shall also be supplied for reference and record of the purchaser.

Field Tests of Breakers

Each circuit breaker shall be liable to undergo field testing before its initial operation. During the field testing, each circuit breaker must satisfactorily perform and satisfy the requirements of the specification. Special tests, if any, arranged by the purchaser at site to prove any of the requirement of the breaker shall be carried out in the presence of supplier’s Engineers who shall fully associate with the testing. Details of the pre-commissioning tests to be carried out on the breakers at site shall be enclosed with the tender for reference of the purchaser.

Special tools and tackles required, if any, for the pre-commissioning tests shall also be clearly indicated in the tender.

All test reports for routine tests shall be submitted and got approved from the purchaser before dispatch of the equipment.

1.12 Interchangeability

Corresponding parts of similar items should be interchangeable in every respect.