

## converter faults and protection:-

As in AC system, the faults in a DC system are caused by

- i) the malfunctioning of the equipment and controllers.
- ii) the failure of insulation caused by external sources such as lightning, pollution, etc.

The faults have to be detected and the system has to be protected by switching and control action such that the disruption in the power transmission is minimized.

Apart from disrupting the normal operation, the various faults that can occur also cause the stressing of the equipment due to overcurrents and overvoltages. In a converter station, the valves are most critical equipment which need to be protected against damage caused by the rise in the junction temperature of thyristors, which is caused by excessive losses in the device and sensitivity to overvoltages.

### Converter faults:-

There are three basic types of faults that can occur in converters are given by

1. Faults due to malfunctions of valves and controllers.

i) Arc backs (or backfire) on Mercury arc valves.

ii) Arc through (fire through)

iii) misfire

iv) Quenching (or) current extinction.

2. Commutation failure in inverters.
3. Short circuits in a converter station.

(i) Arc back is the failure of the valve to block in the reverse direction and results in the temporary destruction of the rectifying property of the valve due to conduction in the reverse direction. This is a major fault in mercury arc valves and is of random nature. This is a non self clearing fault and results in severe stresses on transformer windings as the incidence of arc back is common.

Fortunately, thyristors don't suffer from arc back which has led to the exclusion of mercury arc valves from modern converter stations hence this fault will not be considered in further discussion.

Some of the converter faults such as commutation failure, arc through and mixfire are self clearing if the causes that led to these faults are of transient nature. However, they can still cause a major disturbance unless the system including the controllers is properly designed.

ii) Arc through:- This is a fault likely to occur mainly at the converter station where the valve voltages are positive most of the time (when they are not conducting) - A malfunction in the gate pulse generator (G)

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Surge arresters:— In the initial stages of applications of DC technology DC surge arresters were not available the valves were protected by the spark gaps connected across them later with the development of active spark gaps, it was possible to extinguish the arrester circuit without exceeding the protective level and DC arresters were made of non-linear resistors in series with the active spark gaps.

With the development of metal oxide resistors with high non-linearity, the need for a series gap has disappeared and the present DC arresters are gap less arresters. The metal oxide elements were first applied in AC arresters in 1976. Comprising primarily of zinc oxide, but containing a number of other metal oxides such as  $\text{Bi}_2\text{O}_3$  (Bismuth oxide);  $\text{Sb}_2\text{O}_3$  (Antimony oxide),  $\text{MnO}_2$  (manganese dioxide),  $\text{Cr}_2\text{O}_3$  (chromium oxide) these materials has extremely non linear voltage-current characteristics. A typical disc that conducts less than milliamperes of current at normal operating voltage can carry currents of thousands of amperes at twice the normal voltage. This property makes it possible to eliminate series connected spark gaps and reduce the voltage margins due to the constancy of protective levels.

The properties of the material are such that it is possible to design arresters to control dynamic overvoltages in addition to switching surges. This results in economic insulators coordination. Proper design of the arrester based on the

The evaluation of the energy losses is essential. The ultimate limit on the energy dissipation capability of a disc is imposed by the cracking of the disc under thermal shock. A single column reactor is capable of absorbing around 7 kJ per kV at the maximum continuous operating voltage (MCov).

In many DC applications the energy capability of a single column of discs is inadequate and multiple columns are used.

### Smoothing Reactor :-

The smoothing reactor is connected before the DC filters and in series with the converter. Apart from smoothing the direct current it also serves as a buffer b/w the converter and the DC line. The sizing of the reactor depends on various requirements excluding the reduction of ripple in the current.

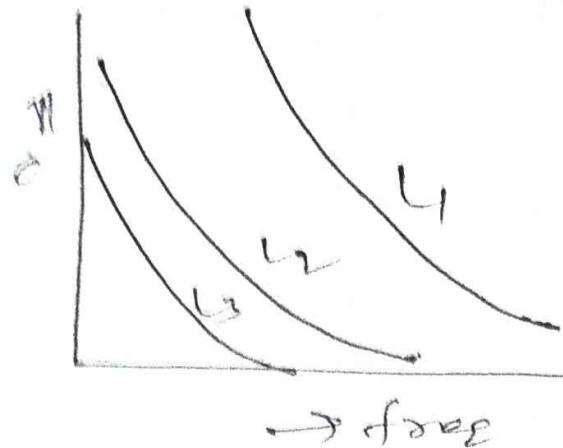
The smoothing reactors have many functions as given by.

- They reduce the incidence of commutation failure in converters caused by dips in the AC voltage at the converter bus.
- They prevent consequent commutation failures in inverters by reducing the rate of rise of direct current in the bridge when the direct voltage of another series-connected bridge collapses.

- They smooth the ripple in the direct current in order to prevent the current becoming discontinuous at light loads.
- They decrease harmonic voltages & currents in the DC line.
  - They limit the short circuit current in the rectifier due to a short circuit on the DC line.
  - They limit the current in the valves during the converter bypass pair operation, due to the discharge of shunt capacitance of the DC line.

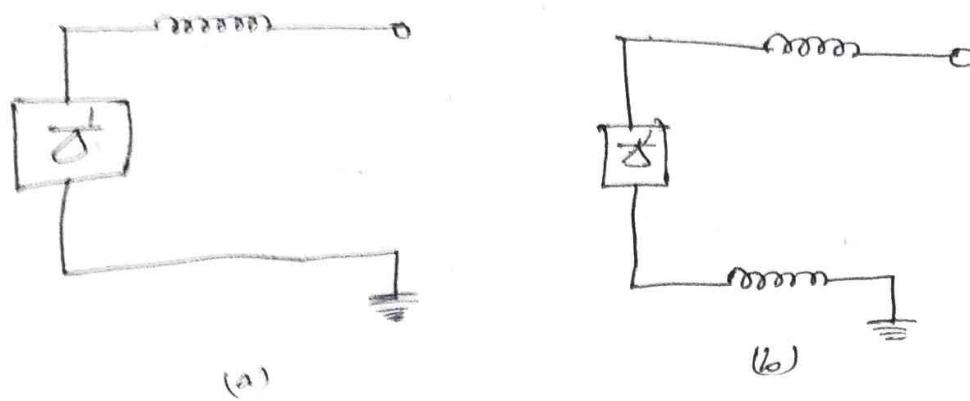
It is to be noted that in back to back HVDC systems, the last three functions are not relevant. For systems with DC transmission lines the inductors of values from  $0.27H$  to  $1.5H$ . have been used. For back to back HVDC systems, the value ranges from  $12mH$  to  $200mH$ .

The sizing of the reactor is done not only from the considerations mentioned above, but also from the point of view of minimizing the effect of low order harmonic resonances in the AC/DC system. It is necessary to avoid series resonance of the DC system at fundamental frequency and also at the second harmonic. The effect of the inductor value on the resonant frequency as a function of the DC filter's capacitance is shown below. The frequency is reduced by increasing the inductance.



$C$  = filter capacitor.  
 $L$  = smoothing reactor  
 Isolating

The location of the smoothing reactor can be either at the high voltage terminal (or) at the ground terminal as shown.



In the latter case it is also necessary to have a small reactor of the order of 5 to 10 mH on the line side to protect the converter station from the consequences of lightning strokes to the line. The advantage of having the reactor at the ground side is that it allows the converter ground faults to be cleared by converter control.

There is a little information available on the choice of the optimum size of the DC smoothing reactor. One criterion used is the 'Si factor'.

$$S_i = V_{dn}/(L I_{dn})$$

- here  $V_{dn}$  &  $I_{dn}$  are the rated direct voltage & direct current; 'L' is the DC circuit inductance in mH which includes the transformer leakage inductance. The  $S_i$  factor is  $\propto$  b/w the no. of back EMVDC links varies from 0.24 to 1.3 ms<sup>-1</sup> Higher the factor, lower is the rate of rise of the fault current.
- Alternate criterion for the sizing of the reactor is the ripple in the direct current.

### Corona effects on DC line:-

The corona is defined as a luminous discharge due to ionization of air surrounding a conductor caused by a voltage gradient exceeding a certain value. The ionization takes place on a zone which is a very thin circumferential layer (not more than 2 cm). Surrounding the conductor surface. Within this zone, the high field strength causes high velocity particles to collide with the air molecules. Electrons are removed from the atoms of the air molecules and are accelerated towards the positive conductor (or) away from the -ve conductor. These high velocity electrons collide with other air molecules releasing additional electrons in an avalanche process. The ions carrying the same charge as the adjacent conductor are repelled from the ionization zone at initial velocities of about 1.4 cm/sec for +ve ions & 1.6 cm/sec for -ve ions for every V/cm of the field strength.

The ions moving into the interelectrode region (b/w pole to pole / b/w pole to the ground) recombine with oppositely charged ions or neutrals / molecules. To maintain the net charge in this region, a corona current flows from the conductor by the movement of electrons in the ionization zone and by ions beyond this zone.

The Ion Velocity at the ground level are in the range of 3 m/sec for typical voltage gradients. The ion movement in perfectly still air conditions is restricted to the electric field direction. With wind movement the ions are randomly dispersed downwind from the DC line. The losses are also increased.

The effects of the Corona are

- Corona loss
- Radio & television interference
- Audible noise
- Space charge field.

While the first three effects occur on AC lines also the last one is peculiar to DC lines. It involves the effects of movement of ions which results in the increase in the voltage gradient at the ground level. The electrostatic field is defined as the field resulting from the charges on OI near the conductor surface. The total electric field results from the superposition of the electrostatic & space charge fields.

## Radio Interference :- (RI)

The most predominant corona effect that may determine the conductor design is the radio interference. This is measured at a frequency of 1 MHz and for a receiver band width of 9 KHz, at a horizontal distance of 30 meters from the outermost conductor.

The RI is mainly due to the positive conductor. This is because of the fact that the corona discharges from the negative conductor are in the form of Trichel pulses which are uniformly distributed over the conductor surface. Positive corona discharges are of three types - hermanstein glow, plume discharge and streamers. Plumes and streamers are randomly distributed and the more persistent discharges are usually associated with high stress points due to surface imperfections. These are mainly responsible for the RI.

The expression for RI is obtained as

$$RI = 25 + 10 \log n + 20 \log r + 1.5 (g - g_0)$$

This is due to the positive conductor. The RI due to the negative conductor is about 20 dB lower and is not of consequence.

Interestingly, DC-RI levels are decreased by rain & wet snow which completely wet the conductors. This phenomenon is opposite to that in AC conductors.

DC-RI levels are increased by wind, with maximum increase during the wind flow from negative to positive conductor.

The bipolar lateral RI profile is symmetric about the positive and attenuates inversely as the square of the distance from the conductor initially (upto 50 meters) & inversely as the distance thereafter.

The television interference (TVI) with DC lines is mainly due to the ion currents & is of little consequence at distances greater than 25 meters from the right of way.

### Audible Noise (AN) :-

The corona discharges from the conductors produce compression and rarefactions that are propagated through the medium as acoustical energy. the portion of the acoustical energy spectrum that lies within the sonic ranges is perceived as audible noise (AN). The sound level is expressed in decibels and is defined as.

$$dB = 20 \log (P/P_R)$$

here 'P' is the measured sound-pressure level and  $P_R$  is the reference pressure level. the standard level i.e.  $P_R$  is 20 N Pascal which is the average threshold of audio perception at 1 kHz. Test line studies indicate that  $\pm 600$  kV DC lines would produce an audible noise of 45 to 55 dB measured at 30 meters from the Row Contoline. This is not considered to be serious. In general the annoyance produced by the audible noise varies linearly with the conductor surface voltage gradient.

## DC breakers:-

The dc breakers is nothing but to interrupt the circuit and also protect the devices. the development of kVdc circuit breakers has been under way in recent years & recently a 500 kV breaker with current interrupting capability upto 4000A. the several types of DC breakers have been developed by different manufacturers. the basic concepts are the same in all the cases.

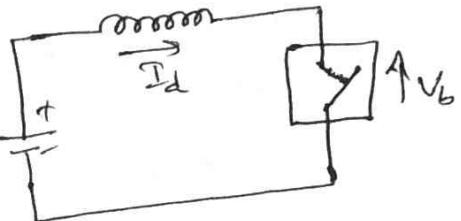
### Basic concepts of DC circuit Interruption:-

The major problem in the current interruption in DC circuits is that there is no natural current zero as in the case of AC circuits. the currents can be brought to zero only by applying a counter voltage higher than the system voltage. the second problem is the dissipation of large energy stored in the inductance of the circuit.

consider the simple representation of DC circuit is shown.

the breaker has a counter voltage  $V_b$ .

It can be shown that the energy absorbed by  $V_d$  is



the breaker is

$$W_b = \frac{1}{2} L I_d^2 (V_b/V_b - V_d)$$

the time required to bring the current to zero is given by

$$T_i = L I_d / (V_b - V_d)$$

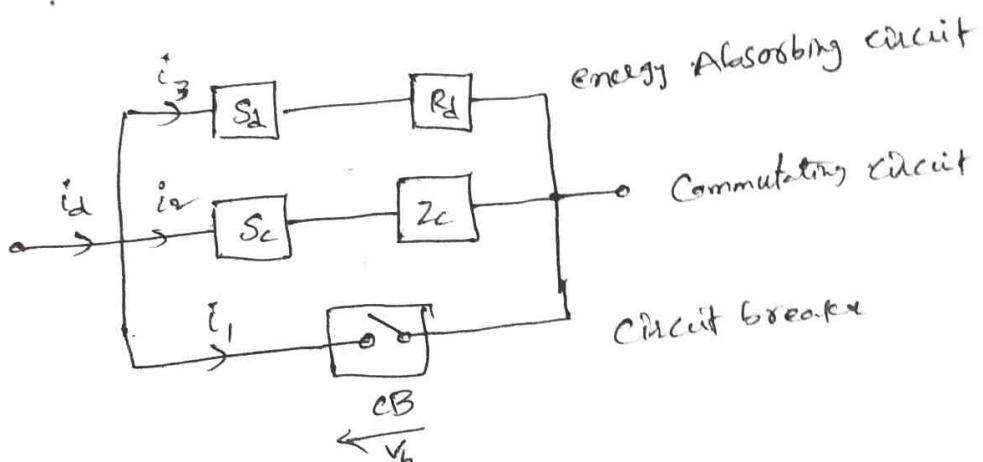
here  $I_d$  is the current in the breaker prior to interruption.

It is obvious that reduction of  $I_d$  has a significant effect on breaker costs as  $V_b$  is decreased which results in the reduced requirements of the energy capability of a breaker.

The current  $I_d$  is brought down to the rated value by the normal action of current control in converter. Although this requires certain amount of time (say 30 to 50 msec) the time required for interruption reduces the alternate strategy is to interrupt the off peak current first but this will increase the interruption time  $T_i$  apart from increasing the cost of the breaker.

The counter voltage produced by the arc that is struck when the breaker contacts separate, is not sufficient in HVDC breakers. This requires an auxiliary circuit in which a capacitor is inserted to develop the required counter voltage. The capacitor is unable to dissipate the energy and the current in the capacitor has to be commutated to non-linear resistors which then dissipate the energy without undue increase in the voltage across them.

the general arrangement of HVDC circuit breaker.



The test results also show that positive polarity conductor is the primary source of AN. Rain causes a very slight reduction of AN. Audible noise is produced in converter stations by current transformers, and smoothing reactors due to the phenomenon of magnetostriction. Although higher AN is to be expected in converter t/f. Due to the presence of harmonics, this is counterbalanced by the operation at lower flux densities in the converter. Audible noise has not been a serious problem in converter stations.

### Space charge (Ion flow) Field :-

As mentioned earlier, the ions produced by corona on overhead DC lines drift through space under the action of electric field and wind. The possible environmental effects due to electric fields and space charges, particularly at the ground level are matters of concern and have to be considered in transmission planning. In AC lines, the problem of ion flows is not present as all the ions created during the one-half cycle are recaptured during the second half-cycle by the polarity reversal on the conductors. The net effect is the increase in the diameter of the ionization zone as the surface gradient increases above the critical level. Very few ions escape the ionization zone.

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