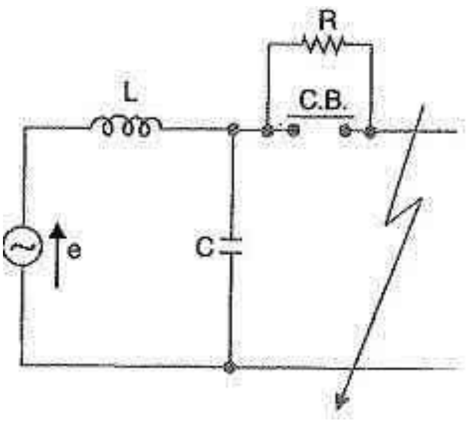
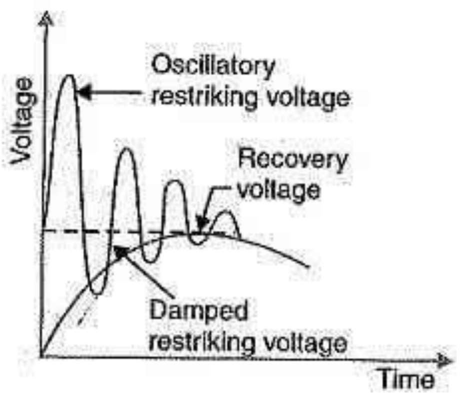
5.1.Resistance switching

The excessive voltage surges during circuit interruption can be preventedby the use of shunt resistance *R* connected across the circuit breaker contacts as shown in below figure





When a fault occurs, the contacts of the circuit breaker are opened and anarc is struck between the contacts. Since the contacts are shunted by resistance *R*, a part of arc currentflows through this resistance. This results in the decrease of arc current and an increase in the rate ofde-ionisation of the arc path. Consequently, the arc resistance is increased. The increased arc resistanceleads to a further increase in current through shunt resistance. This process continues until thearc current becomes so small that it fails to maintain the arc. Now, the arc is extinguished and circuitcurrent is interrupted.The shunt resistor also helps in limiting the oscillatory growth of re-striking voltage. It can beproved mathematically that natural frequency of oscillations of the circuit isgiven by :

$$f_n = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{1}{4R^2C^2}}$$

The effect of shunt resistance *R* is to prevent the oscillatory growth of re-striking voltage and cause it to grow exponentially upto recovery voltage. This is being most effective when the value of*R* is so chosen that the circuit is critically damped. The value of *R* required for critical damping is to sum up, resistors across breaker contacts may be used to perform one or more of thefollowing functions:

(i) To reduce the rate of rise of re-striking voltage and the peak value of re-striking voltage.

(ii) To reduce the voltage surges due to current chopping and capacitive current breaking

(iii) To ensure even sharing of re-striking voltage transient across the various breaks in multibreakcircuit breakers.

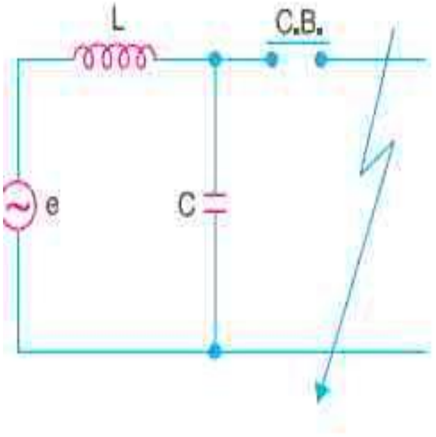
It may be noted that value of resistance required to perform each function is usually different.However, it is often necessary to compromise and make one resistor do more than one of thesefunctions.

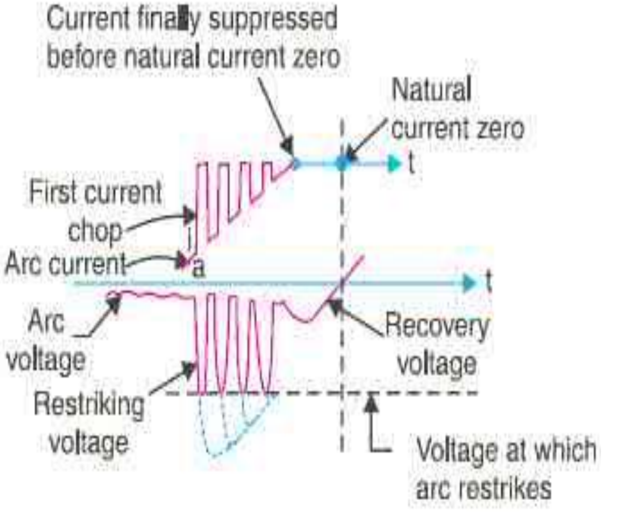
5.2. Current chopping andinterruption of capacitive current

Current chopping

It is the phenomenon of current interruption before the natural currentzero is reached.

Current chopping mainly occurs in air-blast circuit breakers because they retain the sameextinguishing power irrespective of the magnitude of the current to be interrupted. When breakinglow currents (*e.g.*, transformer magnetising current) with such breakers, the powerful de-ionisingeffect of air-blast causes the current to fall abruptly to zero well before the natural current zero isreached. This phenomenon is known as current chopping and results in the production of high voltagetransient across the contacts of the circuit breaker





Suppose the arc current is *i*when it ischopped down to zero value as shown by point *a*in Fig As the chop occurs at current *i*,therefore, the energy stored in inductance is *L* *i*2/2. This energy will be transferred to the capacitance*C*, charging the latter to a prospective voltage *e* given by :

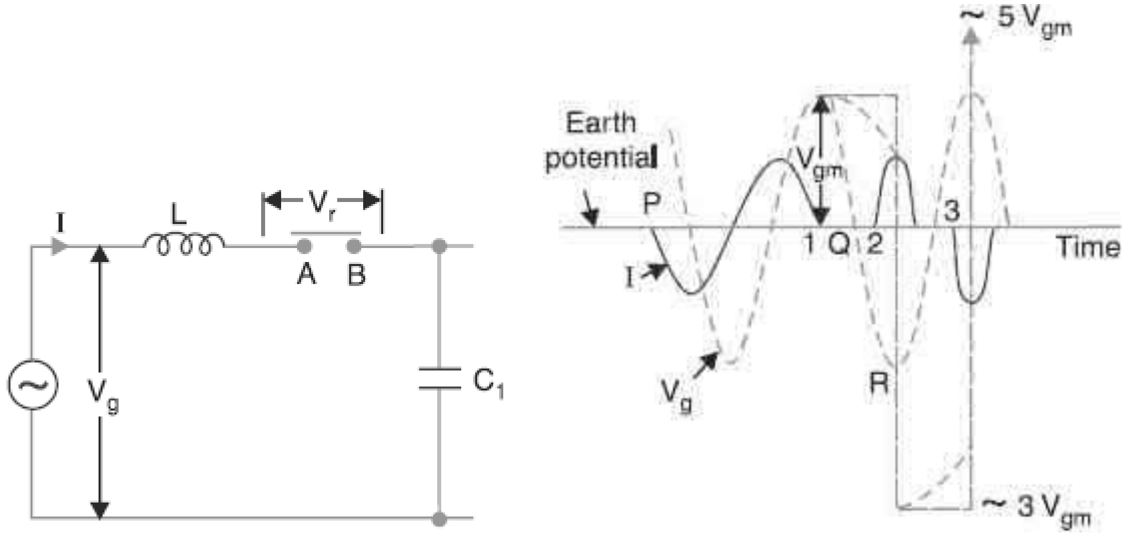
$$\frac{1}{2} L i^2 = \frac{C e^2}{2}$$

$$e = i \sqrt{\frac{L}{C}} \text{ volts}$$

The prospective voltage *e* is very high as compared to the dielectric strength gainedby thegap so that the breaker restrikes. As the de-ionising force is still in action, therefore, chop occursagain but the arc current this time is smaller than the previous case. This inducesa lower prospectivevoltage to re-ignite the arc. In fact, several chops may occur until a low enough current is interruptedwhich produces insufficient induced voltage to re-strike across the breaker gap. Consequently, thefinal interruption of current takes place.Excessive voltage surges due to current chopping are prevented by shunting the contacts of thebreaker with a resistor (*resistance switching*) such that reignition is unlikely to occur.

Interruption of capacitive current

Another cause of excessivevoltage surges in the circuit breakers is the interruptionof capacitive currents. Examples of such instances are openingof an unloaded long transmission line, disconnecting a capacitorbank used for power factor improvement etc.



Such a line, although unloaded in the normal sense, willactually carry a capacitive current *I* on account of appreciableamount of capacitance *C* between the line and the earth.Let us suppose that the line is opened by the circuit breakerat the instant when line capacitive current is zero. At this instant, the generatorvoltage *Vg* will be maximum (*i.e., Vgm*) lagging behind the current by 90º. The opening of the lineleaves a standing charge on it (*i.e.*, end *B* of the line)and the capacitor *C*1 is charged to *Vgm*. However, thegenerator end of the line (*i.e.*, end *A* of the line) continuesits normal sinusoidal variations. The voltage *Vr*across the circuit breaker will be the difference betweenthe voltages on the respective sides. Its initial value iszero (point 1) and increases slowly in the beginning.But half a cyclelater, the potentialof the circuit breaker contact _*A*' becomes maximumnegative which causes the voltage across the breaker (*Vr*)to become 2 *Vgm*. This voltage may be sufficient to restrikethe arc. Thetwo previously separated parts of thecircuit will now be joined by an arc of very low resistance.The line capacitance discharges at once to reducethe voltage across the circuit breaker, thus setting up highfrequency transient. The peak valueof the initial transient will be twice the voltage at that instant i.e., − 4 Vgm. This will cause thetransmission voltage to swing to − 4 Vgmto + Vgm i.e., −3Vgm.The re-strike arc current quickly reaches its first zero as it varies at natural frequency. Thevoltage on the line is now −3Vgm and once again the two halves of the circuit are separated and the lineis isolated at this potential. After about half a cycle further, the aforesaid events are repeated even onmore formidable scale and the line may be left with a potential of 5Vgm above earth potential. Theoretically,this phenomenon may proceed infinitely increasing the voltage by successive increment of2 times Vgm.While the above description relates to the worst possible conditions, it is obvious that if the gapbreakdown strength does not increase rapidly enough, successive re-strikes can build up a dangerousvoltage in the open circuit line. However, due to leakage and corona loss, the maximum voltage onthe line in such cases is limited to 5 Vgm.