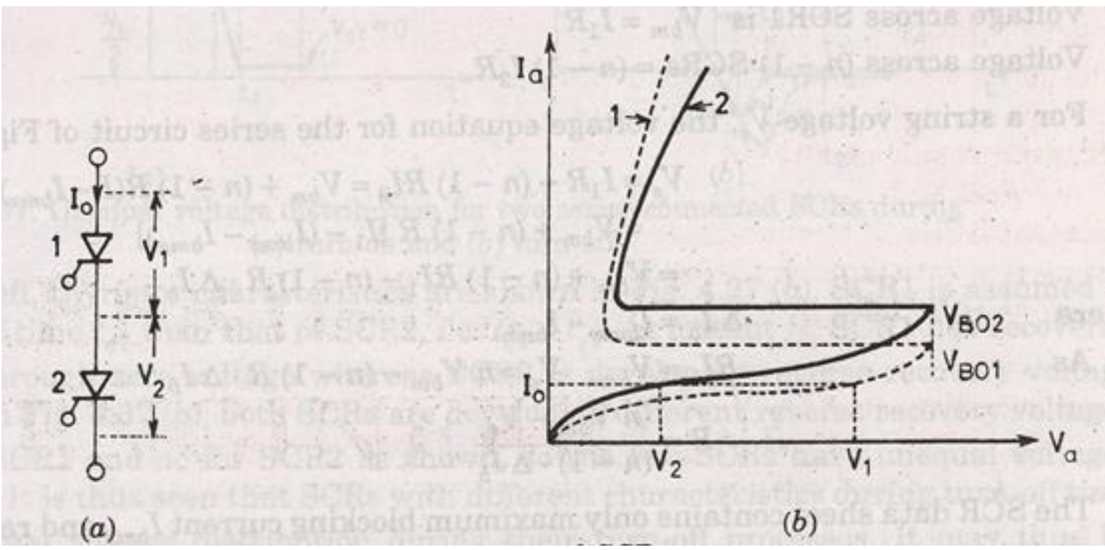
Series and parallel operation of SCR

SCR are connected in series for h.v demand and in parallel for fulfilling high current demand. Sting efficiency can be defined as measure of the degree of utilization on SCRs in a string.

String efficiency < 1. Derating factor (DRF) = 1 – string efficiency.

If DRF more then no. of SCRs will more, so string is more reliable. Let the rated blocking voltage of the string of a series connected SCR is $2V_1$ as shown in the figure below, But in the string two SCRs are supplied a maximum voltage of V_1+V_2.



$$\eta = \frac{V_1+V_2}{2V_1}$$

Significance of string efficiency.

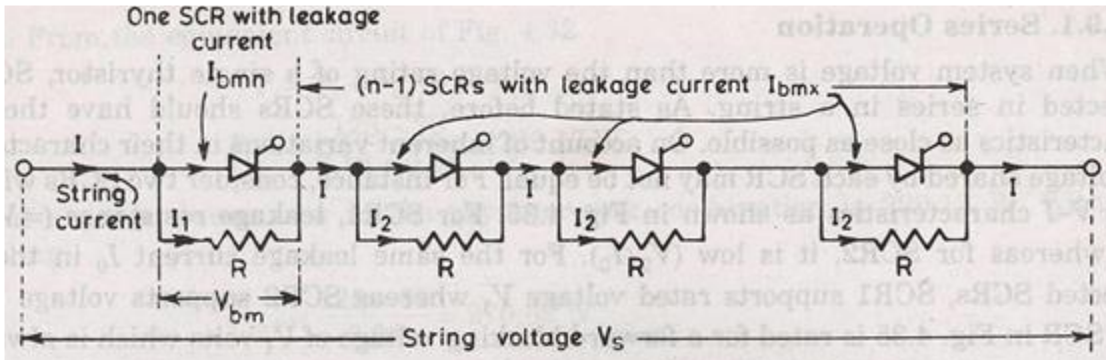
Two SCRs are have same forward blocking voltage ,When system voltage is more then the voltage rating of a single SCR. SCRs are connected in series in a string.
There is a inherent variation in characteristics. So voltage shared by each SCR may not be equal. Suppose, SCR1 leakage resistance > SCR2 leakage resistance. For same leakage current I_0 in the series connected SCRs. For same leakage current SCR1 supports a voltage V_1 , SCR2 supports a voltage V_2,

So string η for two SCRs = $\frac{V_1+V_2}{2V_2} = \frac{1}{2}\left(1+\frac{V_2}{V_1}\right) < 1$.

So, $V_1 > V_2$,

The above operation is when SCRs are not turned ON. But in steady state of operation , A uniform voltage distribution in the state can be achieved by connect a suitable resistance across each SCRs , so that parallel combination have same resistance.
But this is a cumbersome work. During steady state operation we connect same value of shunt resistance across each SCRs. This shunt resistance is called ***state equalizing circuit.***

Suppose,



Static-voltage equalization for series-connected string.

Let SCR1 has lower leakage current $Ibmn$, It will block a voltage comparatively larger than other SCRs.

Voltage across SCR1 is $Vbm = I1R$. Voltage across (n-1)SCR is (n-1) $I2$R, so the voltage equation for the series circuit is Vs = $I1R$+ $(n-1)I2R$ = Vbm+ (n-1)R ($I-$ $Ibmx$)

As $I1= I-$ $Ibmn$

$I2= I-Ibmx$

So, Vs = Vbm+ (n-1)R [$I1-(Ibmx-$ $Ibmn)$]

If $\Delta Ib=Ibmx-Ibmn$

Then Vs = Vbm+(n-1)R ($I1-\Delta Ib$)

Vs = Vbm+ (n-1)R $I1$-(n-1)R ΔIb

R$I1$= Vbm

So, Vs = Vbm+ (n-1) Vbm -(n-1)R ΔIb

= n Vbm- (n-1)R ΔIb

$\Rightarrow$R = $nVbm-VS$(n−1)ΔIb

SCR data sheet usually contain only maximum blocking current , $Ibmx$

so we assume $Ibmn$=0

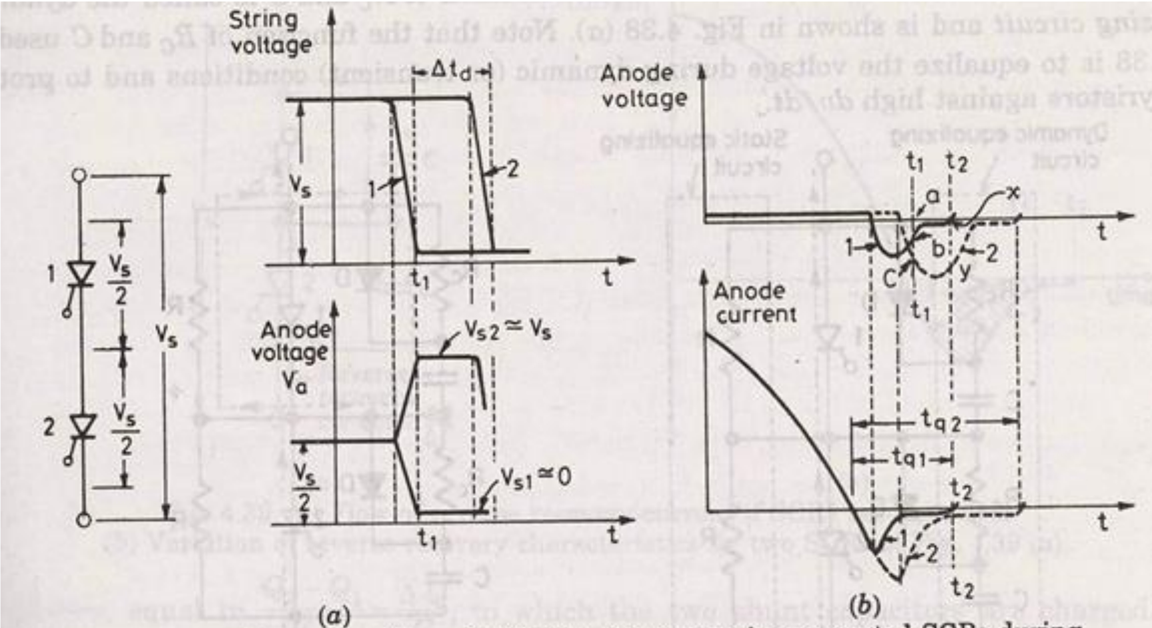
So $\Delta Ib=Ibmx$

So the value of R calculated is low than actually required.

SCRs having unequal dynamic characteristics*:*

It may occur that SCRS may have unequal dynamic characteristics so the voltage distribution across the SCR may be unequal during the transient condition. SCR 1 and SCR 2 have different dynamic characteristics. Turn ON time of SCR 2 is more than SCR 1 by time Δtd .

As string voltage is VS so voltage shared by each SCRs be VS/2. Now both are gated at same time so SCR 1 will turn ON at $t1$ its voltage fall nearly to zero so the voltage shared by SCR 2 will be the string voltage if the break over voltage of SCR 2 is less than VS then SCR 2 will turn ON .



Unequal voltage distribution for two series connected SCRs during (a) turn-on and (b) turn-off.

* In case VS is less than the breakoverer voltage, SCR 2 will turn ON at instant 2. SCR 1 assumed to have less turn off $tq1$ time then SCR 2, so $tq1 < tq2$. At $t2$ SCR 1 has recovered while SCR 2 is developing recovery voltage at $t1$ both are developing different reverse recovery voltage. At $t2$ SCR 1 has recovered while SCR2 is developing reverse recovery voltage.

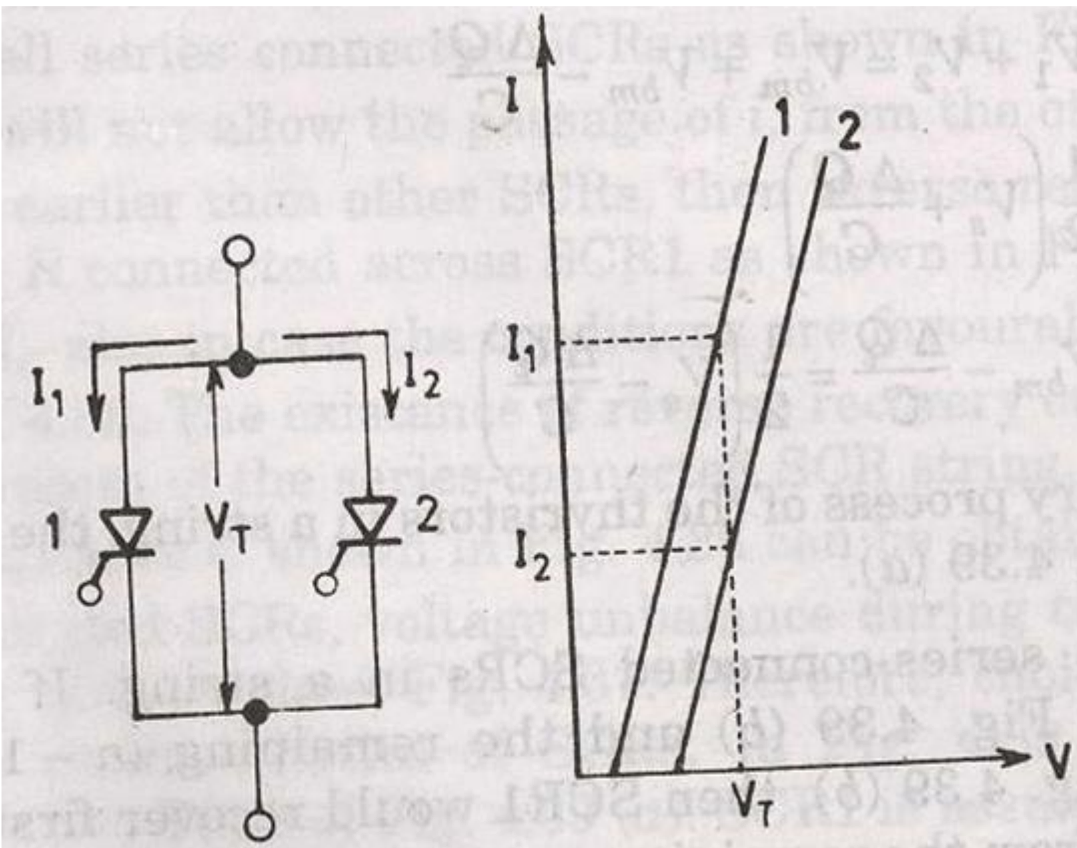
Conclusion:

* Series connected SCR develop different voltages during turn ON and turn OFF process. Till now we connect a simple resistor across the diode for static voltage equalizing circuit.
* During turn ON and turn OFF capacitance of reverse biased junction determine the voltage distribution across SCRs in a series connected string. As reverse biased junction have different capacitance called *self capacitance,* the voltage distribution during turn ON and turn off process would be different.
Under transient condition equal voltage distribution can be achieved by employing shunt capacitance as this shunt capacitance has the effect of that the resultant of shunt and self capacitance tend to be equal. The capacitor is used to limits the dv/dt across the SCR during forward blocking state. When this SCR turned ON capacitor discharges heavy current through the SCR. The discharge current spike is limited by damping resistor Rc . Rc also damps out high frequency oscillation that may arise due to series combination of Rc , C and series inductor . Rc & C are called *dynamic equalizing circuit*
Diode D is used during forward biased condition for more effective charging of the capacitor.
During capacitor discharge Rc comes into action for limiting current spike and rate of change of current *di/dt* .

The R, Rc & C component also provide path to flow reverse recovery current. When one SCR regain its voltage blocking capability. The flow of reverse recovery current is necessary as it facilitates the turning OFF process of series connected SCR string. So C is necessary for both during turn ON and turn OFF process. But the voltage unbalances during turn OFF time is more predominant then turn ON time. So choice of C is based on reverse recovery characteristic of SCR .

Parallel operation*:*

When current required by the load is more than the rated current of single thyristor , SCRs are connected in parallel in a string .



For equal sharing of current, SCRs must have same $V-I$characteristics during forward conduction. VT across them must be same. For same VT , SCR 1 share $I1$and SCR 2 share I2 .
If $I1$ is the rated current
$I2 < I1$
The total current $I1+I2$ and not rated current 2$I1$.Type equation here.

Thus string efficiency,
$I1+I22I1 = 12(1+I2I1)$

Middle conductor will have more inductance as compared to other two nearby conductor. As a result less current flow through the middle conductor. Another method is by magnetic coupling.

Thyristor gate characteristics:-

Vg = +ve gate to cathode voltage.
Ig= +ve gate to cathode current.
As the gate cathode characteristic of a thyrister is a p-n junction, gate characteristic of the device is similar to diode.

Curve 1 the lowest voltage value s that must be applied to turn on the SCR.

Curve 2 highest possible voltage values that can be safely applied to get circuit.

Vgm= Maximum limit for gate voltage .

Igm= Maximum imilt for gate current.

Pgav = Rated gate power dissipation for each SCR.

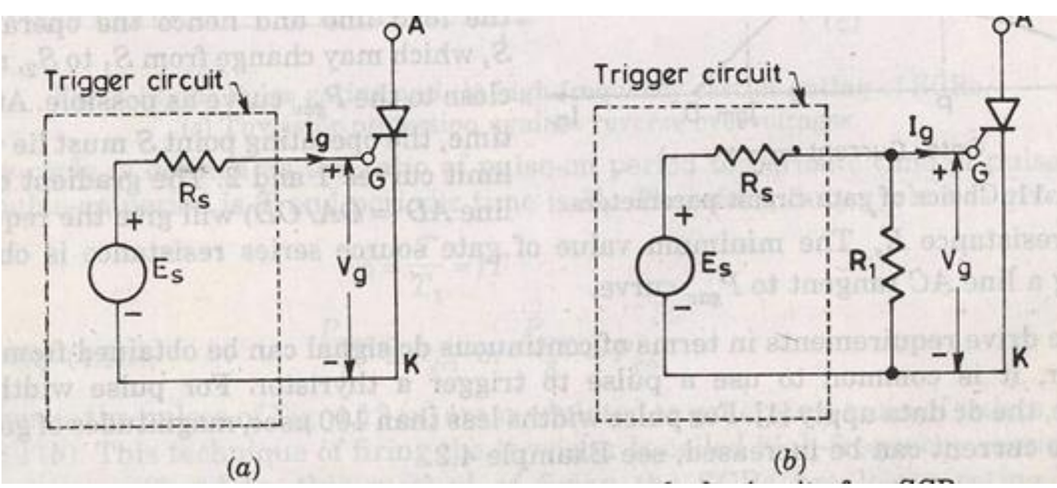
These limits should not be crossed in order to avoid the permanent damage of the device junction $J3$.

OY = Minimum limit of gate voltage to turn ON .

OX = minimum limit of gate current to turn ON.

If Vgm, Igm,Pgav are exceeded the thyristor will damage so the preferred gate drive area of SCR is bcdefghb.

oa = The non triggering gate voltage , If firing circuit generates +ve gate signal prior to the desired instant of triggering the SCR.It should be ensured that this un wanted signal should be less than the non –triggering voltage oa.



$ES = Vg + IgRS$
ES =Gate source voltage

Vg = Gate cathode voltage

Ig = Gate current

RS = Gate source resistance

RS = The internal resistance of the trigger source

$R1$ is connected across the gate cathode terminal, which provides an easy path to the flow of leakage current between SCR terminal. If $Igmn$, Vgmn are the minimum gate current and gate voltage to turn ON the SCR.

$ES = (Igmn + V\text{gmn}/ R1)\ RS + Vgmn$