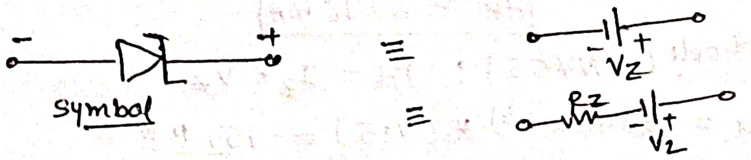
Zener Diode :

(*) A device which work in Reversed biased region as a constant voltage source.

(*) The zener diode having low breakdown voltage because it is heavily doped diode. ~~Devices~~ in which breakdown occurs due to zener process.

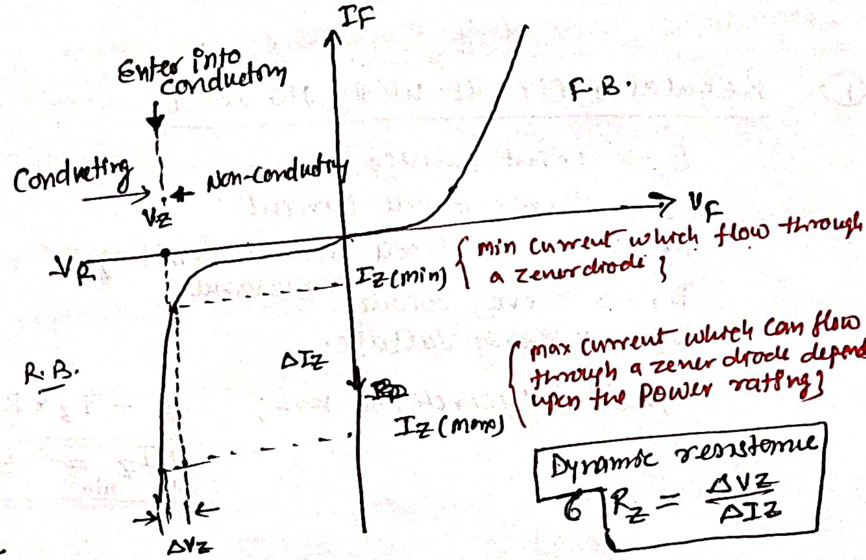
(*) Zener diode having high breakdown voltage, lightly doped diodes in which breakdown occurs due to Avalanche process.



chracteristics

(*) Zener diode is same as normal diode in forward bias.

(*) The region of chracteristics in R.B. where zener current can increase or decrease but voltage remains constant at V_Z is known as breakdown region.



Dynamic resistance

$$\boxed{R_Z = \frac{\Delta V_Z}{\Delta I_Z}}$$

(*) when zener diode is reverse biased below the breakdown voltage, current is practically zero & zener diode is non-conducting & is working as a normal diode.

where :-
$V_Z \rightarrow$ Zener breakdown Voltage
$I_Z \rightarrow$ Zener Current

(*) when reverse voltage equals to breakdown voltage, the current through the zener diode suddenly increases to I_Z^+ this is due to the breakdown phenomena & zener diode enter into conduction

(*) when reverse voltage are greater than breakdown voltage then more & more current will be passing into the zener diode but the voltage drop across the zener diode will be maintain constant.

(*) To control the reverse current in zener diode, ~~~~. in reverse biased a series resistance is connected with zener, is known as current limiting resistor.

(*) The zener diode may be operated at any (Reverse) current level between $I_{Z(min)}$ or I_{ZK} to $I_{Z(max)}$ or I_{ZM}. when the maxm current rating is not given then calculated by -

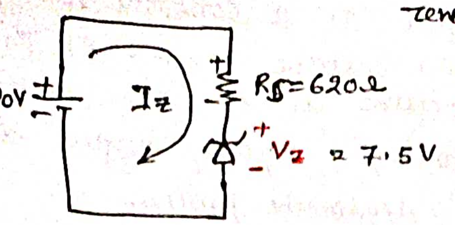
$$\boxed{P_d = V_Z I_{ZM}}$$

or

$$\boxed{I_{ZM} = \frac{P_d}{V_Z}}$$

where
$P_Z \rightarrow$ power rating of zener diode
$V_Z \rightarrow$ Voltage across zenerdiode
$I_{ZM} \rightarrow$ Max zener current.

Calculate the diode current and power dissipation for given ckt. the zener voltage for zener 1N755 is 7.5V



Accor^n to KVL

$20 - I_Z * 620 - 7.5 = 0$

$I_Z = \frac{20 - 7.5}{620}$

$\boxed{I_Z = 20.16\ mA}$

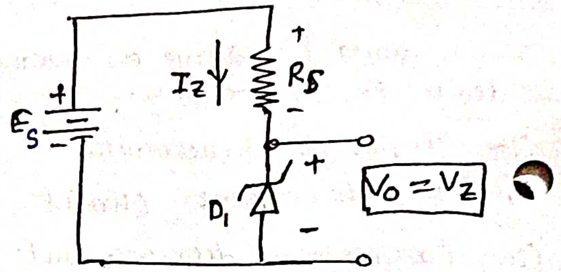
Power dissipation Across diode (1N755) ; $P_d = I_Z * V_Z$

$P_d = (20.16 \times 10^{-3}) * (7.5) = 151\ mW$

Zener Diode As Voltage Regulator

① Regulator circuit with No load

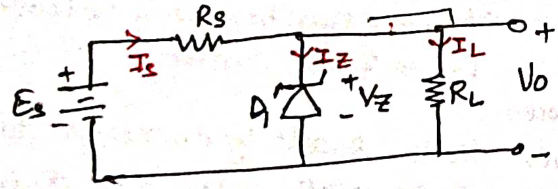
- $E_S \rightarrow$ Input voltage
- $I_Z \rightarrow$ Zener diode current
- $R_S \rightarrow$ zener diode current limiting resistance
- $D_1 \rightarrow$ zener diode
- $V_Z \rightarrow$ Zener voltage.



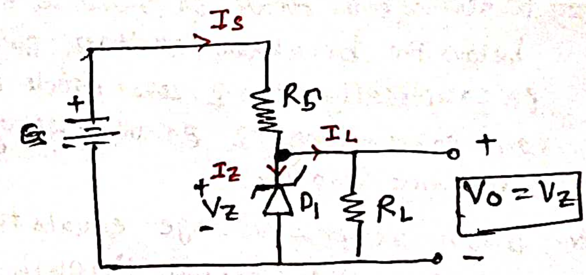
Then According to KVL; $E_S - I_Z * R_S - V_Z = 0$

$$\boxed{I_{Z_{min}} = \frac{E_S - V_Z}{R_S}}$$

② Loaded Regulator



or



- $E_S \rightarrow$ Unregulated Supply voltage
- $R_S \rightarrow$ Series current limiting resistance
- $V_Z \rightarrow$ Zener Voltage
- $R_L \rightarrow$ Load resistance
- $I_Z \rightarrow$ Zener diode current
- $I_L \rightarrow$ Load resistance

$\boxed{I_S = I_Z + I_L}$ $\boxed{V_O = V_Z \neq \left(\frac{R_L}{R_L + R_S}\right) E_S}$

After conduction

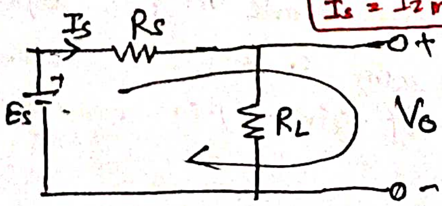
$E_S - I_S R_S - V_Z = 0$

$\boxed{I_S = \frac{E_S - V_Z}{R_S}}$ or $\boxed{I_Z + I_L = \frac{E_S - V_Z}{R_S}}$

NOTE: For a given I_S; $\boxed{\text{if } I_L \uparrow \text{ then } I_Z \downarrow}$ ie

$I_S = I_{Z\,min} + I_{L\,max}$
$I_S = I_{Z\,max} + I_{L\,min}$

If zener diode is disconnected then V_O;



$E_S - I_S(R_S + R_L) = 0$

or $I_S = \frac{E_S}{R_S + R_L}$

and $\boxed{V_O = I_S * R_L = \left(\frac{R_L}{R_S + R_L}\right) E_S}$

NOTE: V_O depends upon the value of R_S, R_L and E_S. So if these parameters are ↑ or ↓ then V_O is also ↑ or ↓ respectively, i.e. V_O is unregulated type.

Pr A Circuit will acts as regulator if current through R_s is atleast $I_{Zmin} + I_L$.

ie $\boxed{I_S \geq I_{Zmin} + I_L}$

and supply valtage should be sufficient to provide minimum valtage drop across R_s & valtage V_Z across the zener diode. $\boxed{E_S \geq I_S R_S + V_Z}$

$$\boxed{E_S \geq (I_{Z\,min} + I_L) R_S + V_Z}$$

Analysis of zener diode circuit

① E_S and R_L both are fixed :

Step-I Determine the state of zener diode by removing the diode from the ckt and calculate the voltage across resulting open circuit.

Step-II Substitute the appropriate equivalent ckt and solve for the desired unknowns.

if $V > V_Z$ → Zener diode (ON) → replace the zener diode by V_Z valtage source

if $V < V_Z$ → Zener diode off → replace the zener diode as open circuit.

Step-III When zener diode will be ON, then $\boxed{V_L = V_Z}$

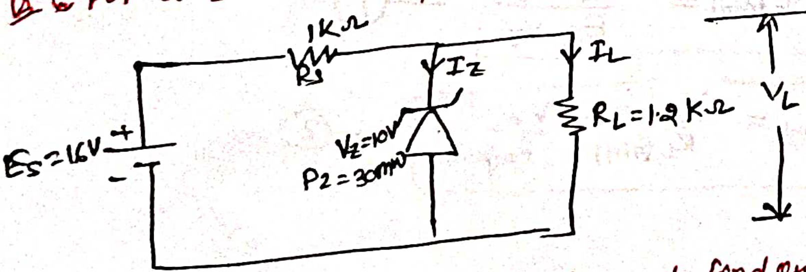
Step-IV $I_S = I_Z + I_L$ or $\boxed{I_Z = I_S - I_L}$

where $I_S = \dfrac{E_S - V_L}{R_S}$, $I_L = \dfrac{V_L}{R_L}$, $\boxed{R_{L(max)} = \dfrac{V_Z}{I_{L(min)}}}$

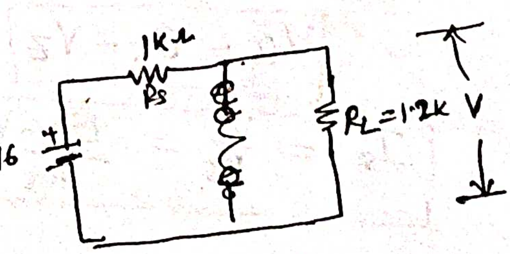
Step-V $\boxed{P_Z = V_Z I_Z}$

$\boxed{I_{Z\,max}(I_{ZM}) = I_S - I_{L(min)}}$ $\boxed{I_{L(min)} = I_S - I_{ZM}}$

Q For a zener diode, shown below; ① find out V_L, V_R, I_Z, P_Z ② Repeat (1) with $R_L = 3\,k\Omega$

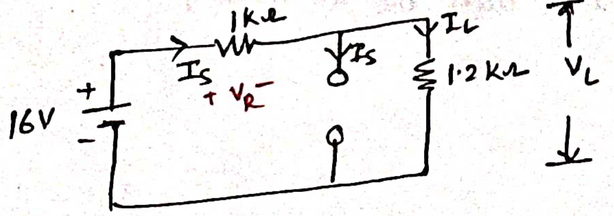


Step-I Remove the zener diode and findout valtage



$$V = \left(\frac{1.2}{1+1.2}\right) * 16 = 8.73\,V$$

since $V < V_Z$ ie $8.73\,V < 10\,V$ → zener diode off



Then $V_L = I_L * 1.2\,k\Omega = V = 8.73$

Then $I_L = \dfrac{V_L}{1.2\,k\Omega} = \dfrac{8.73}{1.2 \times 10^3} = 7.27\,mA$

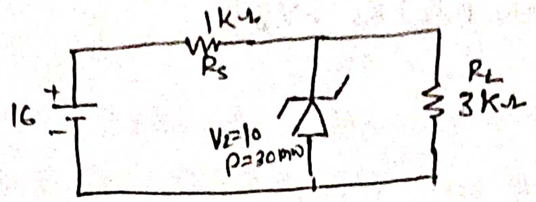
But $E_S - V_R - V_L = 0$

or $V_R = E_S - V_L = 16 - 8.73 = 7.27V$

$I_Z = 0A$

$P_Z = V_Z . I_Z = 10 \times 0 = 0$ watt

(B) if $R_L = 3 k\Omega$



Step-I Remove zener diode

then $V = \left(\frac{R_L}{R_S+R_L}\right) * 16$

$V = \left(\frac{3}{1+3}\right) * 16 = 12 V$

Since $V > V_Z$ i.e $12V > 10V$ then zener diode will be on.

Then $\boxed{V_L = V_Z = 10V}$

$V_R = E_S - V_L = 16 - 10 = 6V$

$I_L = \frac{V_L}{R_L} = \frac{10}{3} = 3.33 mA$

$I_S = \frac{V_R}{R_S} = \frac{6}{1k\Omega} = 6 mA$

$I_Z = I_S - I_L = 6 mA - 3.33 mA = 2.67 mA$

$P_Z = V_Z * I_Z = 2.67 mA * 10 = 26.7 mW$

(2) Fixed E_S and Variable R_L

To findout min load resistance (R_L) that will turn on the zener diode i.e

$\boxed{V_L = V_Z}$

or $V_L = V_Z = \left(\frac{R_L}{R_S+R_L}\right) * E_S$ or $R_S \cdot V_Z + V_Z R_L = R_L * E_S$

or $R_L(E_S - V_Z) = R_S \cdot V_Z$

or $\boxed{R_{L(min)} = \frac{R_S \cdot V_Z}{E_S - V_Z}}$ — (1)

$I_L = \frac{V_L}{R_L} = \frac{V_Z}{R_L}$ or $\boxed{I_{L(max)} = \frac{V_L}{R_{L(min)}} = \frac{V_Z}{R_{L(min)}}}$ — (2)

$\boxed{V_R = E_S - V_Z}$

$\boxed{I_S = \frac{V_R}{R_S} = \frac{E_S - V_Z}{R_S}}$ — (3)

$\boxed{I_Z = I_S - I_L}$

if I_R is fixed then for $I_{Z(max)}$, I_L will be minimum

Then $\boxed{I_{ZM} = I_S - I_{L min}}$

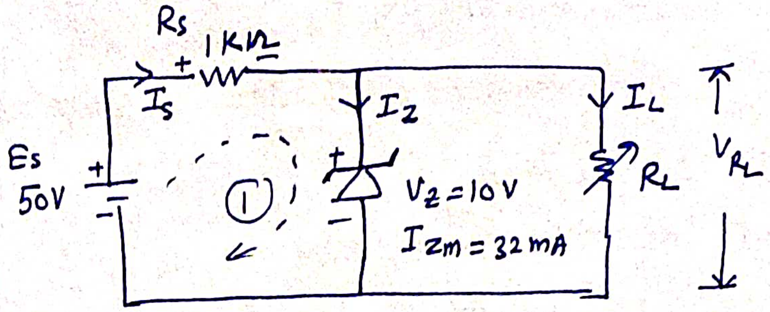
$\boxed{I_{L min} = I_S - I_{ZM}}$

$\boxed{R_{L max} = \frac{V_Z}{I_{L min}}}$

Case-II $E_s \rightarrow$ fixed , $R_L \rightarrow$ variable

① Findout the Range of R_L & I_L that will result in V_{RL} to be maintained at 10 V.

② Determine the max^m wattage rating of Diode.



Sol^n Step-I Find out $R_{L\,min}$ that turn on the zener.

when zener is ON then Voltage Across load (R_L) = V_Z

$$V_{RL} = V_Z = \left(\frac{R_L}{R_L+R_S}\right) * E_S = \left(\frac{R_L}{R_L + 1\,K\Omega}\right) 50$$

or $(R_L + 1\,K\Omega)\,V_Z = 50\,R_L$ or $R_L V_Z + 1\,K\Omega * V_Z = 50\,R_L$

But $V_Z = 10$ Then ⇒ $10\,R_L + 10^3 \times 10 = 50\,R_L$

$$40\,R_L = 10000$$

$$\boxed{R_{L\,Min} = \frac{10000}{40} = 250\,\Omega}$$

Then $\boxed{I_{L\,max} = \frac{V_{RL} \text{ or } V_Z}{R_{L\,min}} = \frac{10}{250} = 40\text{ mA}}$

Step-II

But $I_S = I_Z + I_L = I_{Z\,max} + I_{L\,min}$

so $I_{L\,min} = (I_S - I_{Z\,max}) = (I_S - 32\text{ mA})$ — ①

Findout I_S Write KVL in loop ① $50 - 1K\Omega * I_S - 10 = 0$

$$I_S = \frac{50-10}{1\,K\Omega} = \frac{40}{10^3} = 40\text{ mA}$$

Then $\boxed{I_{L\,min} = 40\text{ mA} - 32\text{ mA} = 8\text{ mA}}$

For $R_{L\,max}$ $V_{RL} = I_L * R_L = V_Z = 10$

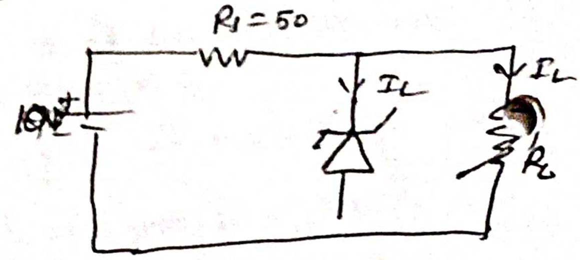
$R_L = \frac{10}{I_L}$ or $R_{L\,max} = \frac{10}{I_{L\,min}} = \frac{10}{8\text{ mA}}$

$$\boxed{R_{L\,max} = 1.25\,K\Omega}$$

so Range of R_L ⇒ 250 Ω to 1.25 KΩ
Reg of I_L ⇒ 8 mA to 40 mA } Ans.

Part ⓑ Max Wattage rating $= I_{Z\,max} * V_Z = 32\text{ mA} \times 10 = 320$ mWatt

Q. In ckt zener breakdown voltage 6 V and $I_{Z\,knee}$ current 5 mA. Calculate the min load resistance & min power rating of the diode such that the o/p voltage remains constant at 6 V.



Ans Given. $V_Z = 6V$, $I_{Z\,knee} = 5mA$

$$I_S = \frac{E_S - V_Z}{R_S} = \frac{10-6}{50} = 80\,mA.$$

When R_L is minimum then I_L is maximum.

$$I_{L(max)} = I_S - I_{Z(min)} = 80\,mA - 5\,mA = 75\,mA$$

Then $R_L = \frac{V_L}{I_L} = \frac{V_o}{I_L} \Rightarrow R_{L\,min} = \frac{V_Z}{I_{L\,max}} =$

$$\underline{R_{L(min)}} = \frac{6}{75} = 80\Omega$$

$$\underline{P_{Z\,(min)}} = V_Z \times I_{Z(min)} = 6 \times 5 = \cancel{480\,watt}\ 30\,watt$$

If R_L is disconnected, load current become zero and zener current become maximum then

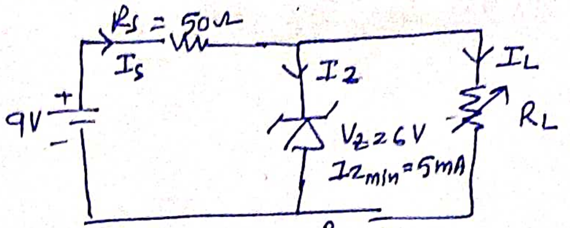
$$I_S = I_{Z\,max} + I_{L\,min} \Rightarrow I_{Z\,max} = I_S - I_{L(min)}$$
$$= 80 - 0 = 80\,mA$$

$$\boxed{P_{Z(max)} = V_Z \times I_{Z(max)} = 480\,mW}$$

↑ V_i

For a ckt zener diode has breakdown voltage 6V and I_Z (min) = 5mA and a max^m allowed power dissipation of 300 mW. Calculate the Range of load current such that the o/p voltage remains regulated at 6V.

Find out I_L → Range



$P_{Z\,max} = 300mW$

Sol^n when Zener is ON

$$I_S = \frac{E_S - V_Z}{R_S} = \frac{9-6}{50} = 60mA$$

But $\underbrace{I_S = I_Z + I_L = I_{Z\,min} + I_{L\,max}}$ $= \underbrace{I_{Z\,max} + I_{L\,min}}$

$$60mA = 5mA + I_{L\,max}$$

$$\boxed{I_{L\,max} = 55mA}$$

$$I_{L\,min} = I_S - I_{Z\,max}$$

But $P_{Z\,max} = 300mW = I_{Z\,max} * V_Z$

$$I_{Z\,max} = \frac{300mW}{V_Z} = \frac{300mW}{6}$$

$$I_{Z\,max} = 50mA$$

$$I_{L\,min} = 60mA - 50mA$$

$$\boxed{I_{L\,min} = 10\ mA}$$

The Range of I_L

$\boxed{10mA \text{ to } 55\ mA}$

(3) Fixed R_L, variable 'E_s' The voltage 'E_s' must be large to turn on the zener diode. The minimum turn on voltage ($E_{s(min)}$) is determined by –

$$V_L = V_Z = \left(\frac{R_L}{R_S+R_L}\right) * E_S \Rightarrow V_Z R_S + V_Z R_L = R_L E_S$$

$$\boxed{E_{S(min)} = \frac{V_Z(R_S+R_L)}{R_L}} \text{ — (1)}$$

The max. value of E_s is limited by max. zener current I_{ZM}.

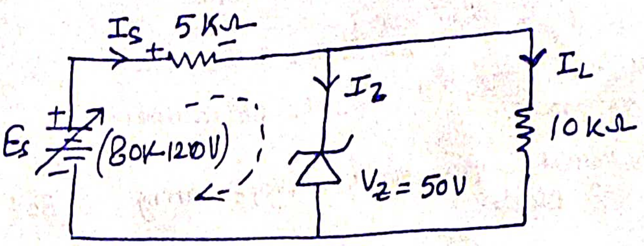
$$I_{ZM} = I_R - I_L \quad \text{or} \quad \boxed{I_{R(max)} = I_{ZM} + I_L}$$

$$\boxed{E_{S(max)} = V_{R(max)} + V_Z}$$

$$\boxed{E_{S(max)} = I_{R(max)} \cdot R_S + V_Z}$$

When $E_S \rightarrow$ variable and $R_L \rightarrow$ fixed

Findout max & Min value of I_Z



\# $I_S = I_Z + I_L$

But R_L is fixed, then value of I_L is also fixed.

so $\boxed{I_S \propto I_Z}$ ie if $I_S \uparrow$ Then $I_Z \uparrow$

if $I_S \downarrow$ Then $I_Z \downarrow$

When zener is ON then $V_{RL} = V_Z = 10K\Omega * I_L$

But $V_Z = 50V$; so $\boxed{I_L = \frac{50}{10K\Omega} = 5\ mA}$

~~For~~ Calculate the value of $I_{Z\,min}$ & $I_{Z\,max}$

$$I_S = I_Z + I_L$$

For $I_{Z\,min}$ $\quad I_{S(min)} = I_{Z\,min} + I_L \Rightarrow I_{Z\,min} = I_{S\,min} - I_L$ —— ①

Find out $I_{S\,min}$ write down KVL in first loop.

$$E_S - I_S * 5K\Omega - 50 = 0$$

$$I_S = \frac{E_S - 50}{5K\Omega} \text{ —— ②}$$

from eqn ② it is clear that $I_S \propto E_S$ ie if $E_{S\,min}$ then $I_{S\,min}$ and $E_{S\,max}$ then $I_{S\,max}$

For $I_{S\,min}$ the value of $E_S = 80V$ {Bcz E_S vary from 80V to 120V}

Then $I_{S\,min} = \frac{80-50}{5K\Omega} = \frac{30}{5K\Omega} = 6\ mA$

and $I_{S\,max} = \frac{120-50}{5K\Omega} = \frac{70}{5K\Omega} = 14\ mA$

from eqn ① $\quad I_{Z\,min} = I_{S\,min} - I_L = 6\,mA - 5\,mA = 1\ mA$ Ans

$I_{Z\,max} = I_{S\,max} - I_L = 14\,mA - 5\,mA = 9\ mA$ Ans

Then range of I_Z = 1 mA to 9 mA Ans

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① $\boxed{I_S = \frac{E_S - V_Z}{R_S}}$ ON

② $I_S = I_Z + I_L$ → $I_S = I_{Z(min)} + I_{L(max)}$; $I_S = I_{Z\,max} + I_{L\,min}$

③ $V_Z = V_{RL} = \left(\frac{R_L}{R_L + R_S}\right) E_S$

④ $P_{Z\,max} = I_{Z\,max} * V_Z$

⑤ For zener Conduction

$\boxed{I_{S\,min} \geq I_{Z\,min} + R_L}$

⑥ $E_{S\,min} \geq \underbrace{(I_{Z\,min} + I_L) R_S}_{I_S R_S} + V_Z$

⑦ When Zener is off

$\boxed{V_0 = V_{RL} = \left(\frac{R_L}{R_L + R_S}\right) E_S}$