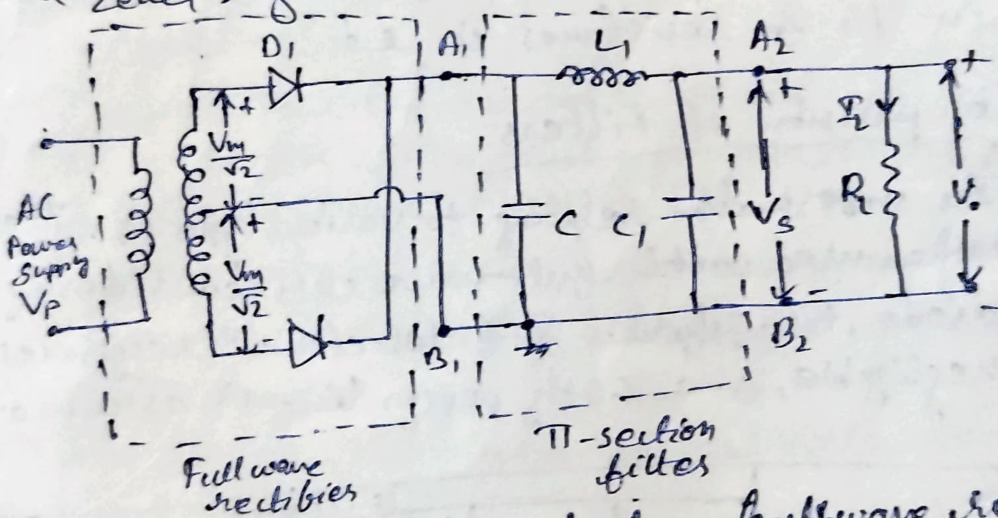
# Voltage Regulation Using Zener Diode

→ Zener diodes are specially designed p-n junction diodes with adequate power dissipation capabilities to operate in the breakdown region which are employed as voltage reference or const. voltage devices in the electronic devices or ckts.

→ A zener diode maintains nearly a const. voltage across its terminals in the breakdown region irrespective of current flowing through the diode.

→ This property of zener diodes is used to minimize the voltage fluctuations of a dc power supply obtained by the rectifier-filter combination.

→ So zener diode is sometime called a voltage regulator diode & the diode circuit in which the zener diodes are used as voltage regulator is called a zener voltage regulator or simply a zener regulator.




→ Consider the ckt that consists of a fullwave rectifier followed by a π-section filter whose o/p is applied to a load resistance $R_L$

→ for $R_L = \infty$ (i.e. under open load condition), no current flows through the load (i.e. $I_L = 0$) & the dc voltage of the filter o/p is $V_s = V_m$

→ For any finite value of $R_L$, a dc current must flow through $R_L$ & hence $I_L \neq 0$.

→ Under these condition, discharging will take place through the load resistance & o/p voltage across the load become $V_o = V_m - \frac{I_L}{4fC}$

where f is the power line freq.

$V_m$ is the peak of transformer secondary w.r.t ~~the~~ center tap

C is the capacitor

→ Suppose that $R_L$ represents the i/p impedance of an instrument which works satisfactorily if a const. dc voltage $V_L$ is applied across it which results in a const. dc ~~voltage~~ current $I_L$ (i.e. $I_L = \frac{V_L}{R_L}$)

→ If we maintain $V_L = V_0 = V_m - \frac{I_L}{4fC}$ as const. for the desired value of $I_L$ by fixing the values of $V_m$, C, & f, the instrument must work satisfactorily.

→ We can easily choose the desired value of C which remains const. for all the time.

→ Since f is the power line freq., it is a const. parameter for all the time.

→ $V_m$ may not be const. to the desired value for all the time since it depends on the i/p voltage $V_p$ of the power line to the transformer primary winding.

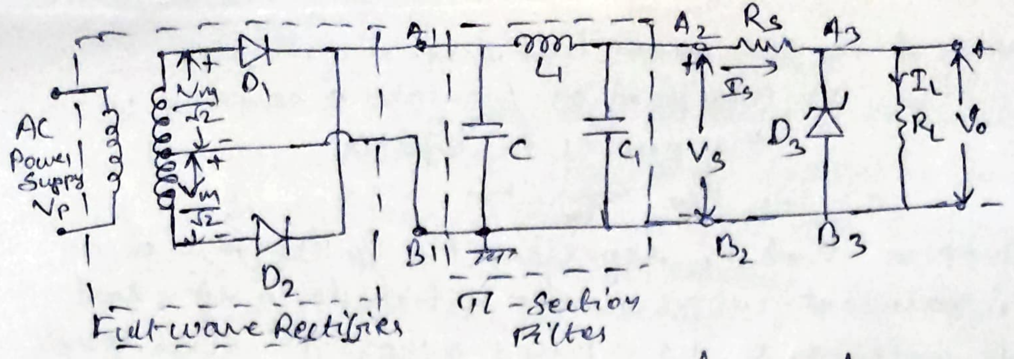
→ Consider a transformer with $N_1$ & $N_2$ as the no: of turns in the primary & secondary windings respectively.

→ Let $V_p$ be the rms voltage of the ac power line which is applied to transformer primary, then the total rms voltage of transformer secondary is $\left(\frac{N_2}{N_1}\right) V_p$ which is equal to $\frac{2V_m}{\sqrt{2}}$ where $2V_m$ is the peak value of the total transformer secondary voltage.

→ Thus the peak voltage is $V_m = \left(\frac{N_2}{N_1}\right)\frac{V_p}{\sqrt{2}}$

→ Since the power line voltage $V_p$ may fluctuate from its desired value to a no: of uncontrolled reasons, there always exists a possibility of fluctuation in $V_m$

→ Therefore the circuit does not guarantee that the desired instrument will operate satisfactorily for all the time.



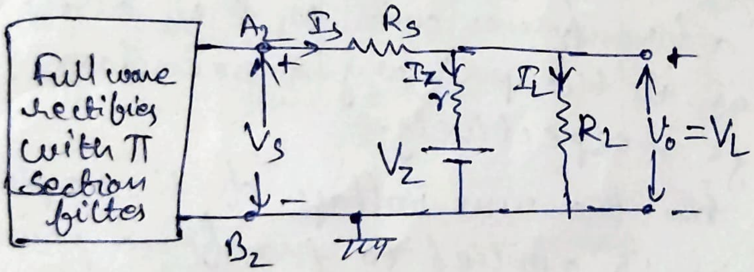

→ The difficulties of the previous ckt can be removed by connecting a Zener diode $D_3$ with breakdown voltage $V_Z$ & a series resistance $R_s$.

→ Suppose that $V_m$ varies b/w $V_{s\,min}$ & $V_{s\,max}$ corresponding to the min. & max. limits of the power line voltage applied to the primary winding of the transformer.

→ So $V_{s\,min} \le V_s \le V_{s\,max}$ is the dc voltage variation in the filter o/p.

→ If the breakdown $V_Z$ is chosen to be equal to the desired voltage $V_L$ across the instrument with load impedance $R_L$ such that $V_{s\,min} > V_Z = V_L$, the filter o/p voltage $V_s$ reverse biases the zener diode for all the time & hence the diode must operate in breakdown region.

→ Under this condition, Zener diode behaves as a battery




→ $r$ is the dynamic resistance of Zener diode

→ Let $I_L$, $I_s$ & $I_Z$ be the currents passing through $R_L$, $R_s$ & Zener diode respectively.

→ The current flowing through load resistance is

$$I_L = \frac{V_L}{R_L} \quad \text{where } V_L = V_Z + r I_Z \quad \text{--- (1)}$$

provided that Zener diode is operated in breakdown region.

→ The current flowing through the series resistance $R_s$ is

$$I_s = \frac{V_s - V_L}{R_s}$$

→ Since $I_s = I_Z + I_L$, the Zener current is given by

$$I_Z = I_s - I_L = \left(\frac{V_s - V_L}{R_s}\right) - \frac{V_L}{R_L} \quad \text{--- (2)}$$

→ From ① & ②
$$I_Z = \frac{\left(\frac{V_S - V_Z}{R_S}\right) - \frac{V_Z}{R_L}}{1 + \left(\frac{r}{R_S} + \frac{r}{R_L}\right)}$$

→ In most of practical ckts, $r << R_S$ & $R_L$ & hence
$$1 + \left(\frac{r}{R_S} + \frac{r}{R_L}\right) \simeq 1$$

→ Thus the Zener current can approx.ly be given by
$$I_Z \simeq \left(\frac{V_S - V_Z}{R_S}\right) - \frac{V_Z}{R_L}$$

→ When the effect of $r$ is neglected, $V_L \simeq V_Z$ which is normally considered in most of the practical cases for designing of Zener diode ckts.

→ If there is any fluctuation in $V_S$ due to fluctuation in the power line voltage, the Zener current $I_Z$ is changed accordingly, whereas the load current $I_L$ & series current $I_S$ are unchanged.

→ Determination of Breakdown Region of Operation of the Zener Diode

↳ $I_L = \frac{V_L}{R_L}$ & $I_Z \simeq \left(\frac{V_S - V_Z}{R_S}\right) - \frac{V_Z}{R_L}$ are valid provided that the Zener diode is operated in the breakdown region.

→ To ensure the breakdown condition of the diode, we can consider the following two cases:

Case-I: Fixed $V_S$ & Variable $R_L$

→ When the diode is in breakdown region $V_L \simeq V_Z$

→ If the load resistance $R_L$ is less than a certain value $R_{L\,min}$, the voltage $V_L = I_L R_{L\,min}$ across the load resistance may become less than $V_Z$ which implies that diode is not in its operating region.

→ Consider the extreme case when $R_L \to 0$ (i.e. nearly short-ckted) which results $V_L \to 0$ & hence diode has no control over the load voltage.

→ Thus, in order to maintain a const. voltage $V_L$ across the load resistor for different values of $R_L$, we must have to maintain a minimum value $R_{Lmin}$ of load resistance to ensure that Zener diode operates in breakdown region.

→ The Thevenin voltage facing the zener diode, say $V_{TH}$, is the voltage that appears b/w the diode terminals $A_3$ & $B_3$ when diode is removed from the ckt.

→ $I_L = I_S = \dfrac{V_S}{R_L + R_S}$ when diode is open-circuited.

→ Thus voltage $V_{TH}$ b/w $A_3$ & $B_3$ is basically the voltage dropped across $R_L$

$$V_{TH} = I_L R_L = \frac{R_L V_S}{R_L + R_S}$$

→ Diode will be in breakdown region only when $V_{TH} \geq V_Z$, thus we can write the breakdown condition of diode as

$$\frac{R_L V_S}{R_L + R_S} \geq V_Z$$

$$\Rightarrow R_L \geq \frac{R_S V_Z}{V_S - V_Z} = R_{Lmin}$$

where $R_{Lmin} = \dfrac{R_S V_Z}{V_S - V_Z}$

→ For $V_L \approx V_Z$, $I_L = \dfrac{V_L}{R_L}$ implies that the increase in $R_L$ will result in the decrease in load current & viceversa

$$I_L \leq \frac{V_Z}{R_{Lmin}} = \frac{V_S - V_Z}{R_S} = I_{Lmax}$$

where $I_{Lmax}$ represents the max. Zener current corresponding to the min. value of load resistance $R_{Lmin}$.

→ At $I_L = I_{Lmax}$, $I_Z = I_S - I_{Lmax} = 0$ which represent the minimum ~~value of the load resistance $R_{Lmin}$~~ ~~$= \left(\dfrac{V_S - V_Z}{R_S}\right)$~~ [illegible] Zener current. $I_{Zmax}$ gives the min. value of the load current $I_L = I_{Lmin}$ (say) which can be written as $I_{Lmin} = I_S - I_{Zmax}$

→ $I_{L\,min} = \left(\frac{V_S - V_Z}{R_S}\right) - I_{Z\,max}$

→ The min. value of $R_L$ should be such that $I_{L\,min} \leq I_L \leq I_{L\,max}$

→ Since $V_L = V_Z$ is const. in the breakdown region of diode, $I_{L\,min}$ will correspond to the max. possible value of load resistance which is defined as

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

Case-II: Fixed $R_L$ and Variable $V_S$

→ When no load dc voltage obtained by using a suitable rectifier-filter combination is fluctuating due to the fluctuation in the line voltage or some other reasons whereas the load resistance is const.

→ Using the condition $V_{TH} \geq V_Z$

$$\frac{R_L V_S}{R_L + R_S} \geq V_Z$$

$$\Rightarrow V_S \geq \left(\frac{R_S + R_L}{R_L}\right) V_Z = V_{S\,min}$$

where $V_{S\,min} = \left(\frac{R_S + R_L}{R_L}\right) V_Z$ is minimum dc voltage required to turn on Zener diode into the breakdown region.

→ For $V_S \geq V_{S\,min}$, the increase in $V_S$ will result in increase in Zener current $I_Z$ since $I_L$ is const.

→ This implies that the max. listing value $V_{S\,max}$ (say) of $V_S$ for which Zener diode will work satisfactorily can be obtained using the calculation for which Zener current is max., i.e $I_Z = I_{Z\,max}$

→ Since $I_L$ is const., the max. Zener current will result in max. value of $I_S$ flowing through the series resistance $R_S$ which is defined by

$$I_{S\,max} = I_{Z\,max} + I_L$$

For $r \simeq 0$, $V_S = V_{S\,max}$ & $I_S = I_{S\,max}$

$$V_{S\,max} = R_S I_{S\,max} + V_Z$$

→ The load current remains const. at $\frac{V_Z}{R_L}$ for all the values of $V_s$ since $R_L$ is const.