Regulated Power Supply

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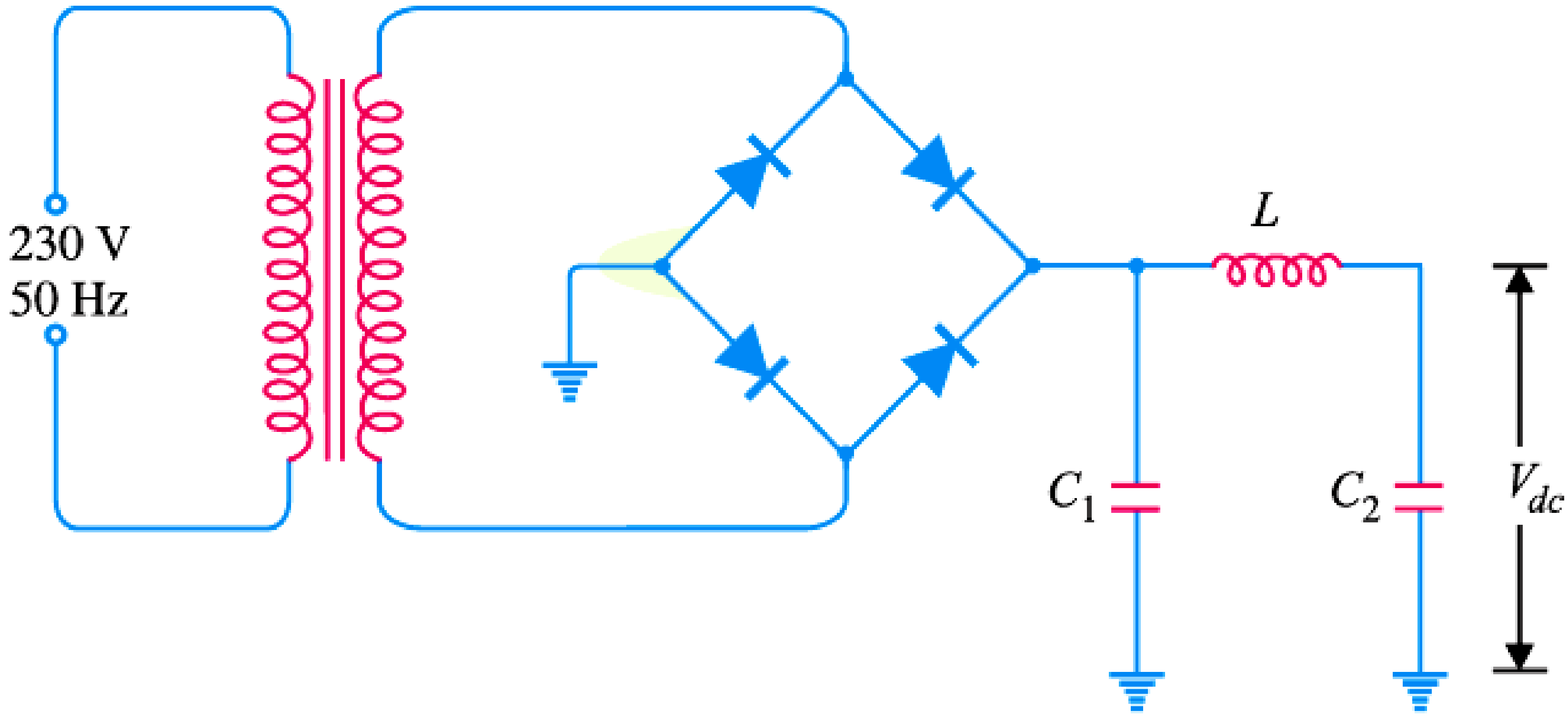
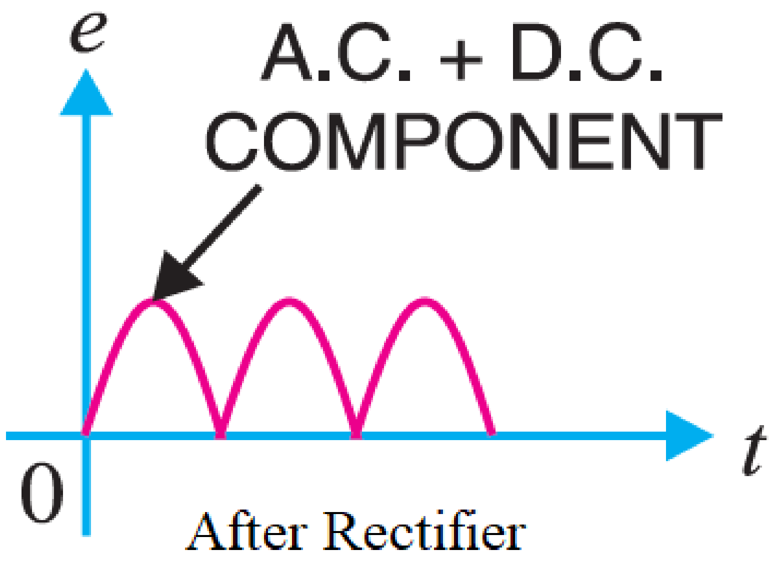
Introduction

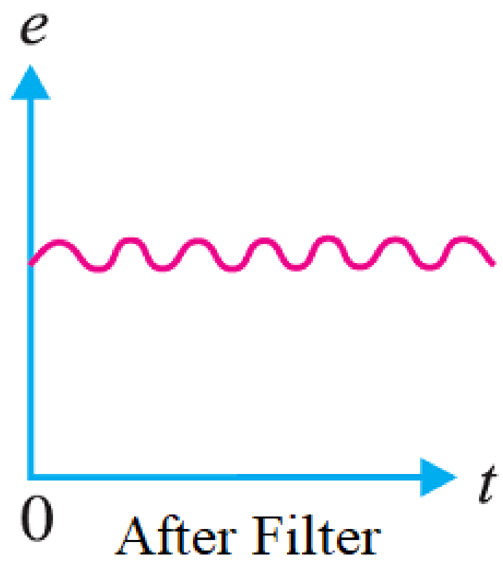
- **In general, electronic circuits using transistors or Integrated circuit (IC) require a source of d.c. power. For example, in amplifiers, oscillator etc. the d.c. voltage is needed for its working.**
- **Batteries (Cells) are rarely used for this purpose as they are costly and require frequent replacement.**
- **In practice, d.c. power for electronic circuits is most conveniently obtained from commercial a.c. lines by using rectifier-filter system, called a d.c. power supply.**

Ordinary D.C. Power Supply



❖ **An ordinary (unregulated) d.c. power supply contains a rectifier and a filter circuit as shown in Fig.1.**





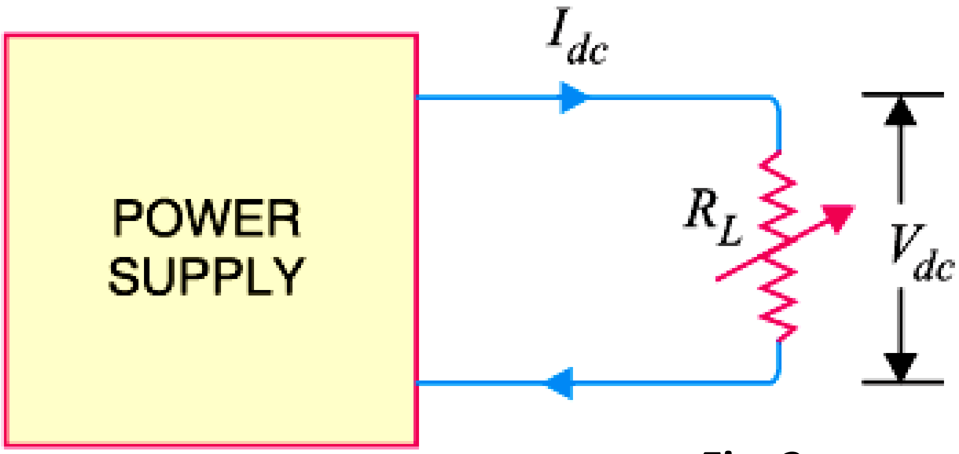
- **The output from the rectifier is pulsating d.c. These pulsations are due to the presence of a.c. component in the rectifier output. Shown in above fig.**
- **The filter circuit removes the a.c. component so that steady d.c. voltage is obtained across the load.**

Limitations:-

- The d.c. voltage from an ordinary power supply remains constant so long as a.c. mains voltage or load is unchanged.
- An ordinary d.c. power supply has the two drawbacks:

1. The d.c. output voltage changes directly with input a.c. voltage. For instance, a 5 % increase in input a.c. voltage results in approximately 5 % increase in d.c. output voltage.

2. The d.c. output voltage changes with load resistance



$$V_{dc} = I_{dc} R_L$$

Fig. 2

For example, if load resistance decreases, the d.c. output voltage decreases or load current increases and similarly If load resistance increases, the d.c. output voltage increases or load current decreases.

- These variations in d.c. output voltage may cause inaccurate/erratic operation in many electronic circuits.
- For example, in an oscillator, the frequency will shift and in transmitters distorted output will result.
- It is desired that d.c. voltage should remain constant irrespective of changes in a.c. mains or load.
- Therefore, ordinary power supply is unsuited for many electronic applications. Under such situations, voltage regulating devices are used with ordinary power supply and is being replaced by regulated power supply.
- The d.c. regulated power supply keeps the d.c. out put voltage at fairly constant value.

Voltage regulation:

- In an unregulated power supply, the output voltage changes whenever input voltage or load resistance changes. It is never constant.
- Therefore the voltage regulation of power supply is a measure of change in the output voltage magnitude whenever input voltage or load resistance changes.
- The voltage regulation is classified into
  (1) line regulation and (2) load regulation
- In line regulation, the output voltage is regulated when input voltage changes and in load regulation, the output voltage is regulated when load resistance changes.

- **The ratio of change in output voltage to change in input voltage is called *line (voltage) regulation***

$$\% \, Voltage \; Regulation = \frac{\Delta V_{out}}{\Delta V_{in}} \times 100$$

- **The amount of voltage changes between no-load to full-load condition is called *load (voltage) regulation*.**

$$\% \, Voltage \; Regulation = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$

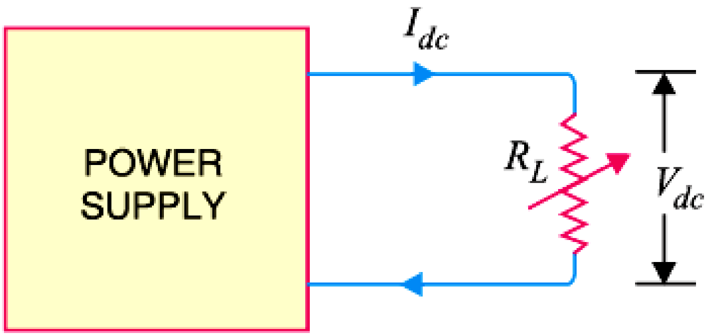
Where, V_{NL} = No-load (open circuit) d.c. output voltage,

V_{FL} = Full-load d.c. output voltage.

- **In an ideal or perfectly regulated power supply, the percentage voltage regulation is zero.**

- **The aim of a voltage regulator circuit is to reduce these variations to zero or, at least, to the minimum possible value.**
- **Therefore, the lesser the difference between full-load and no-load voltages and better is the power supply.**
- **Thus in a well designed power supply, the full-load voltage is only slightly less than no-load voltage i.e. voltage regulation approaches zero.**
- **Power supplies used in practice have a voltage regulation of 1 % i.e. full-load voltage is within 1 % of the no-load voltage.**

❖ **Fig. 3, shows the change of d.c. output voltage with load current or load resistance. This is known as voltage regulation curve.**



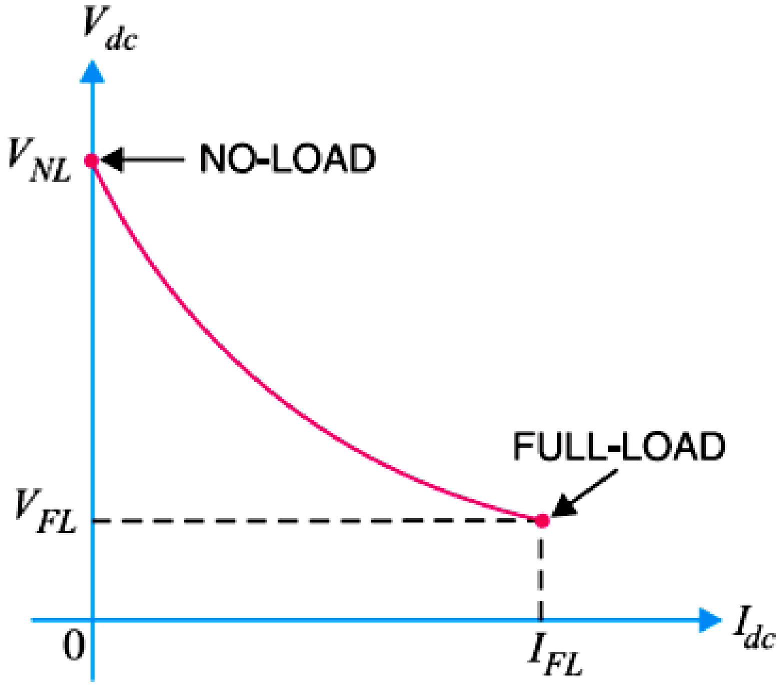


Fig.-3

Example -1

A d.c. voltage supply provides 60 V, when the output is unloaded. When connected to a load, the output drops to 56 V. Calculate the value of voltage regulation.

Solution

$$\% \, Voltage \, Regulation = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$

$$= \frac{60-56}{56} \times 100 = 7.1 \,\%$$

Example -2

If a power supply had a no-load voltage of 9 V and a full-load voltage of 8 V find the percentage voltage regulation.

Solution

$$\% \, Voltage \, Regulation = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100 = \frac{9-8}{8} \times 100 = 12.5 \,\%$$

Regulated Power Supply:

- A power supply which maintains the output voltage constant irrespective of a.c. mains fluctuations or load variations is known as regulated power supply.

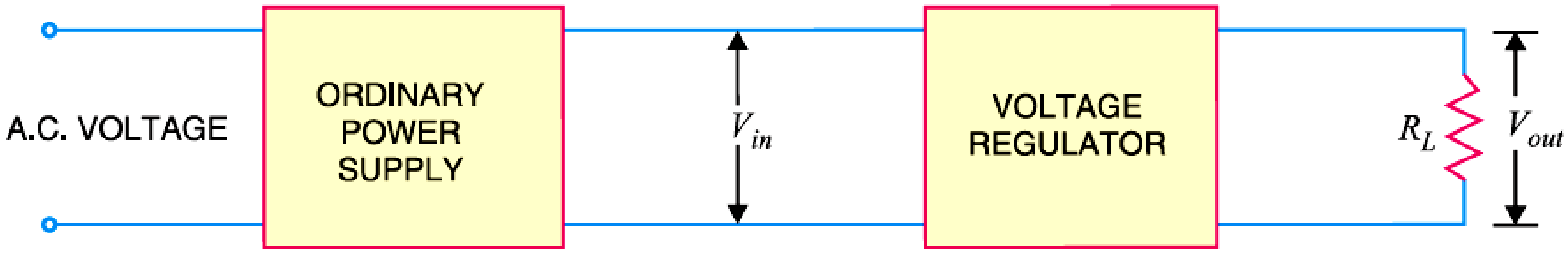


Fig. 4

- Fig. 4 shows the block diagram of a regulated power supply. It consists of an ordinary power supply and voltage regulating device.

- The output of ordinary power supply is fed to the voltage regulator which produces the final output.

- The output voltage remains constant whether the load resistance (load current) changes or there are fluctuations in the input a.c. voltage.
- Fig. 5 shows the complete circuit of a regulated power supply using Zener diode as a voltage regulating device.

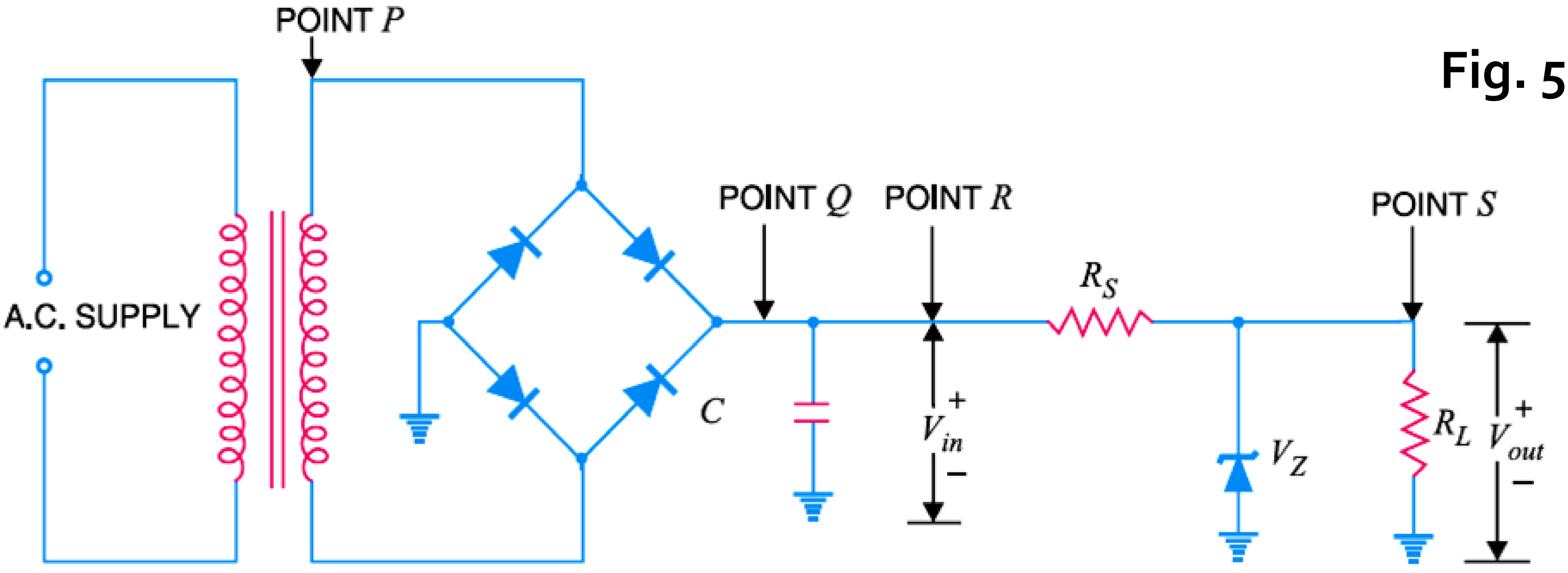


Fig. 5

- **As you can see, the regulated power supply is a combination of three circuits viz.,**
  - **(i) Bridge rectifier**
  - **(ii) Capacitor filter**
  - **(iii) Zener voltage regulator.**
- **The bridge rectifier converts the transformer's secondary a.c. voltage (at point P) into pulsating voltage (at point Q).**
- **The pulsating d.c. voltage is applied to the capacitor filter. This filter reduces the pulsations in the rectifier d.c. output voltage (at point R).**

- Finally, the Zener voltage regulator performs two functions. Firstly, it reduces the variations in the filtered output voltage.
- Secondly, it keeps the output voltage (V_{out}) nearly constant whether the load current changes or there is change in input a.c. voltage.
- Fig. 6 shows the waveforms at various stages of regulated power supply.

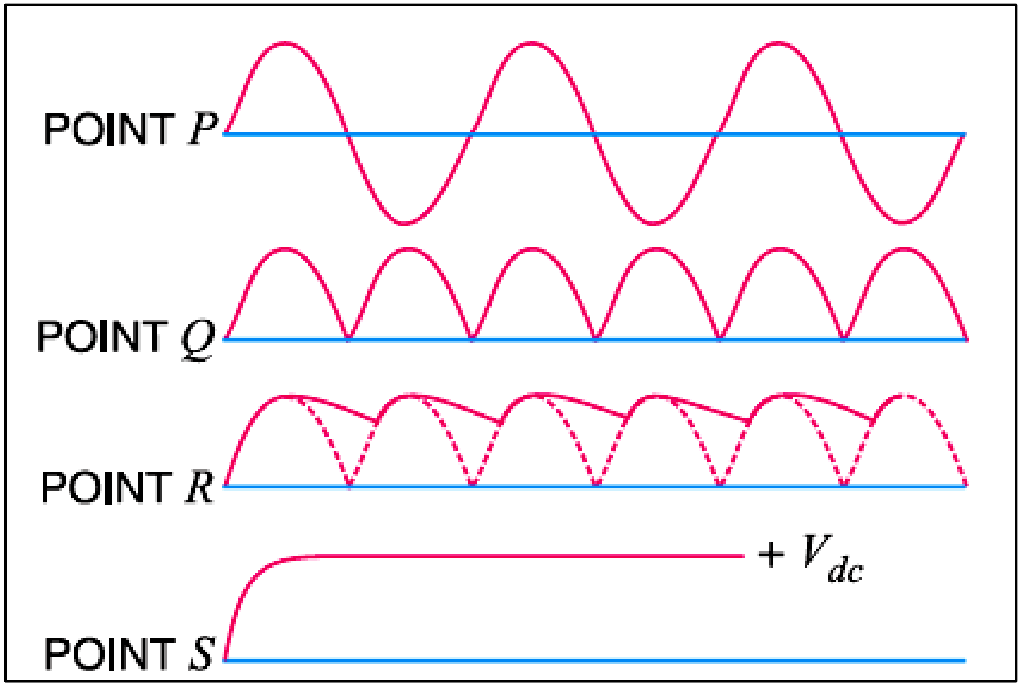


Fig. 6

- **Note that bridge rectifier and capacitor filter constitute an ordinary power supply. However, when voltage regulating device is added to this ordinary power supply, it turns into a regulated power supply.**

Requirement (Need) of Regulated Power Supply:

- **In an ordinary power supply, the voltage regulation is poor i.e. d.c. output voltage changes appreciably with load current. Moreover, output voltage also changes due to variations in the input a.c. voltage. This is due to the following reasons :**

1) **In practice, there are considerable variations in a.c. line voltage caused by outside factors beyond our control. This changes the d.c. output voltage. Most of the electronic circuits will refuse to work satisfactorily on such output voltage fluctuations. This necessitates to use regulated d.c. power supply.**

2) **The internal resistance of ordinary power supply is relatively large (> 30 Ω). Therefore, output voltage is markedly affected by the amount of load current drawn from the supply. These variations in d.c. voltage may cause erratic operation of electronic circuits.**

❖ **Therefore, regulated d.c. power supply is the only solution in such situations.**

Types of Voltage Regulators:

❖ There are basic two types of voltage regulators,

1. Series voltage regulator
2. Shunt voltage regulator.

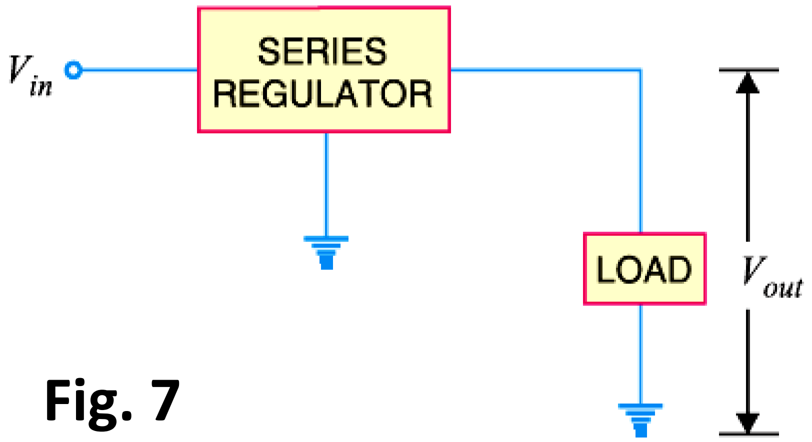


Fig. 7

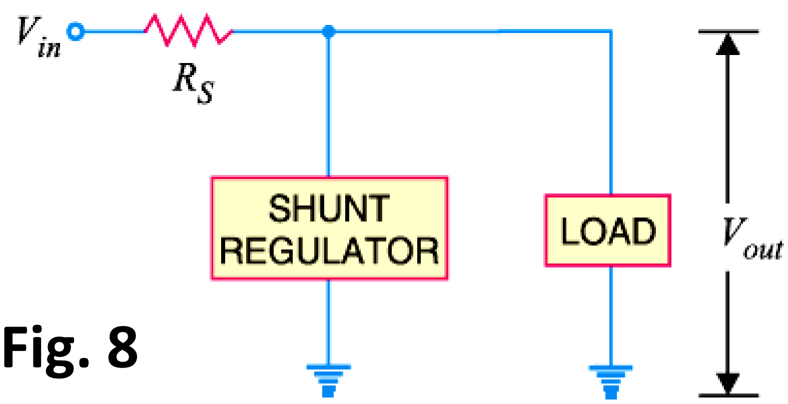


Fig. 8

❖ The series regulator is placed in series with the load as shown in Fig. 7. On the other hand, the shunt regulator is placed in parallel with the load as shown in Fig. 8.

- Each type of regulator provides an output voltage that remains constant even if the input voltage varies or the load current changes.

1. For low voltages.

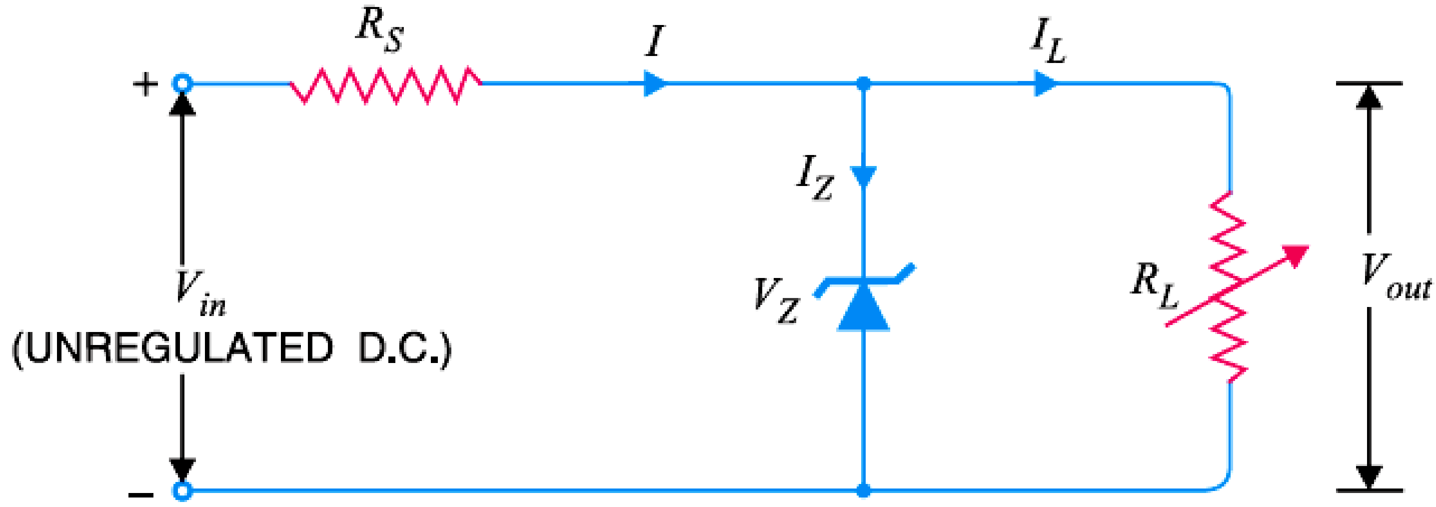
- For low d.c. output voltages (up to 50V), either Zener diode alone or Zener in conjunction with transistor is used. Such supplies are called transistorized power supplies.
- A transistor power supply can give only low stabilized voltages because the safe value of V_{CE} is about 50 V and if it is increased above this value, it will be destroyed due to excessive heat.

2. For high voltages.

- **For voltages greater than 50 V, glow tubes are used in conjunction with vacuum tube amplifiers. Such supplies are generally called tube power supplies and are extensively used for the proper operation of vacuum valves.**

Zener Diode as a Voltage Regulator:

- When the zener diode is operated in breakdown region, the voltage across it (or load), is maintains constant.



- The circuit of zener diode as a voltage regulator shown in Fig. The series resistance R_S is used to limit the input current.

Operation:-

- The zener will maintain constant voltage across the load, when, change in load resistance or input voltage.

1. As the load current increases due to decreasing R_L, the zener current decreases so that current I through resistance R_S is constant.

   As output voltage $V_{out} = V_{in} - IR_S$ therefore, output voltage remains constant (unchanged).

   The reverse would be true should the load current decrease.

2. The circuit will also correct for the changes in input voltages. If the input voltage V_{in} increase then increasing in I, thereby more current will flow through the zener and the voltage drop across R_S will increase but out put voltage would remain constant.

The reverse would be true should the input voltage decrease.

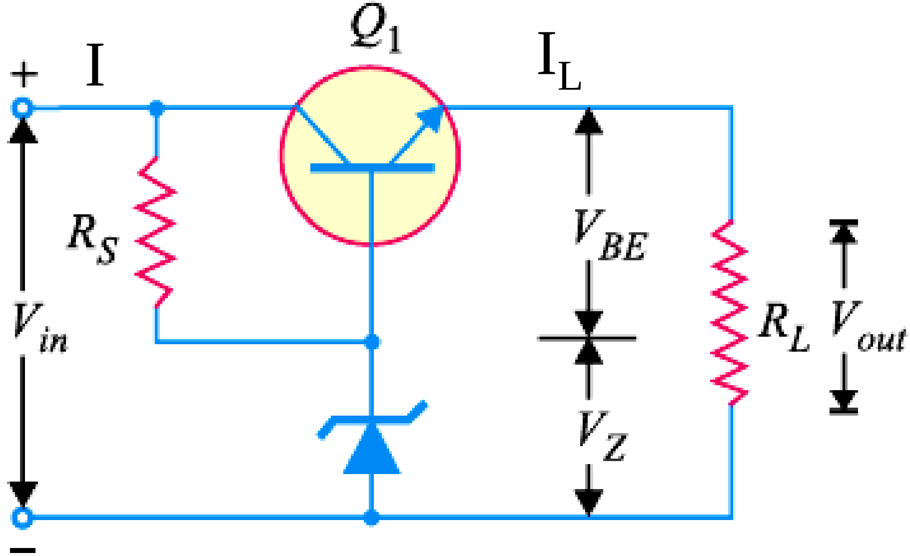
Limitations:

1. **The output voltage remains constant only when the input voltage is sufficiently large so that the voltage across the zener is V_Z i.e the breakdown region. The minimum zener current is generally 10 mA to put the zener diode in the ON state.**
2. **The zener should not be allowed to exceed maximum current, otherwise it will be destroyed due to excessive heat.**
3. **Voltage regulation is maintained only between these limits, the minimum current and the maximum permissible current through the zener diode. Typical values are from 10 mA to 1 A.**

4. **It has low efficiency for heavy load currents. Because, if the load current is large, there will be considerable power loss in the series limiting resistance.**
5. **Such circuit applicable, where variations in load current and input voltage are small.**
6. **There is a minimum value of R_L to ensure that zener diode will remain in the regulating region i.e. breakdown region.**

   If the value of R_L falls below this minimum value, the proper voltage will not be available across the zener to drive it into the breakdown region.

Transistor Series Voltage Regulator:



- Figure shows a simple series voltage regulator using a transistor and zener diode. Transistor Q_1 is the series control element and Zener diode provides the reference voltage (V_Z).
- The circuit is called a series voltage regulator because the load current (I_L) passes through the series transistor Q_1. It is also called ***emitter-follower regulator*** because the voltage at the emitter follows the base voltage.

- **In this set-up, the transistor behaves like a variable resistor whose resistance is determined by the base current. It is called *pass* transistor because total current to be regulated passes through it.**
- **The unregulated d.c. supply is fed to the input terminals and the regulated output voltage (V_{out}) is obtained across the load.**

Operation:

- **The base voltage of transistor Q_1 is held to a relatively constant voltage across the zener diode.**

For example, if *8V* zener (*i.e.,* $V_Z = 8$ *V*) is used, the base voltage of Q_1 will remain approximately *8V*.

- Now, the output voltage is given by,

$$V_{out} = I_L R_L \quad \text{and} \quad V_{out} = V_Z - V_{BE} \qquad (1)$$

- When current demand is increased by decreasing R_L, the V_{out} tends to decrease.
- As seen from the above equation, it will increase V_{BE} because V_Z is fixed. This will increase base current I_B of transistor Q_1, thereby increasing its level of conduction.
- This, is turn, will lead to decrease in the collector emitter resistance of the transistor which will slightly increase the input current ($I_C \cong I_E = I_L$) in order to compensate for decrease in R_L so that $V_{out} = (I_L R_L)$ will remain at a constant value.

- Similarly, if the V_{out} is increased by increasing R_L, as seen from the equation (1), V_{BE} is decreased, causes transistor Q_1 to conduct less, thereby reducing the output voltage. Consequently, the output voltage is maintained at a constant level.
- The resistance (R_S) is used for limiting current passing through the Zener diode.

Summery of regulator action:-

V_{out} decreases

↓

V_{BE} increases

↓

I_B increases

↓

I_C increases

↓

V_{BE} decreases

↓

V_{out} gets original value

V_{out} increases

↓

V_{BE} decreases

↓

I_B decreases

↓

I_C decreases

↓

V_{BE} increases

↓

V_{out} gets original value

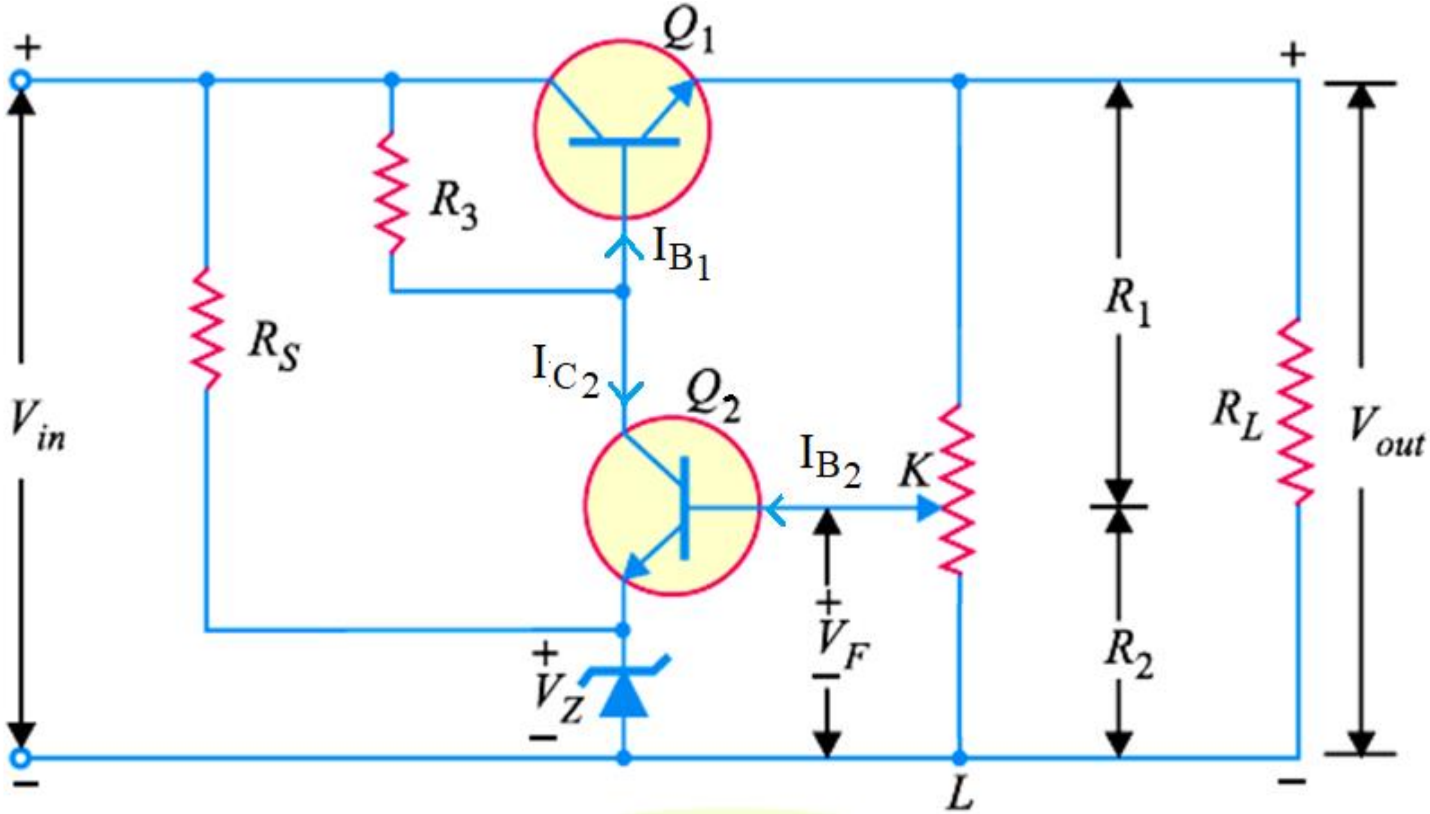
Advantages:

- ❖ The advantage of this circuit is that the changes in zener current are reduced by a factor β. Therefore, the effect of zener impedance is greatly reduced and much more stabilized output is obtained.

Limitations:

1. Although the changes in zener current are much reduced, yet the output is not absolutely constant. It is because both V_{BE} and V_Z decrease with the increase in room temperature.
2. The output voltage cannot be changed easily as no such means is provided.

Series Regulator with Two Transistor:



- The circuit employing a second transistor Q_2 as a sensing element is shown in Fig. It has additional feature of control with the help of voltage divider (potentiometer) $R_1 - R_2$.

- **It also employs principles of negative feedback to hold the output voltage almost constant despite changes in line voltage (V_{in}) and load current.**
- **The transistor Q_1 is called a pass transistor because all the load current passes through it.**
- **The sample and adjust circuit is the voltage divider that consists of R_1 and R_2.**
- **The voltage divider samples the output voltage and delivers a negative feedback voltage to the base of Q_2.**
- **The feedback voltage V_F controls the collector current of Q_2.**

Operation:

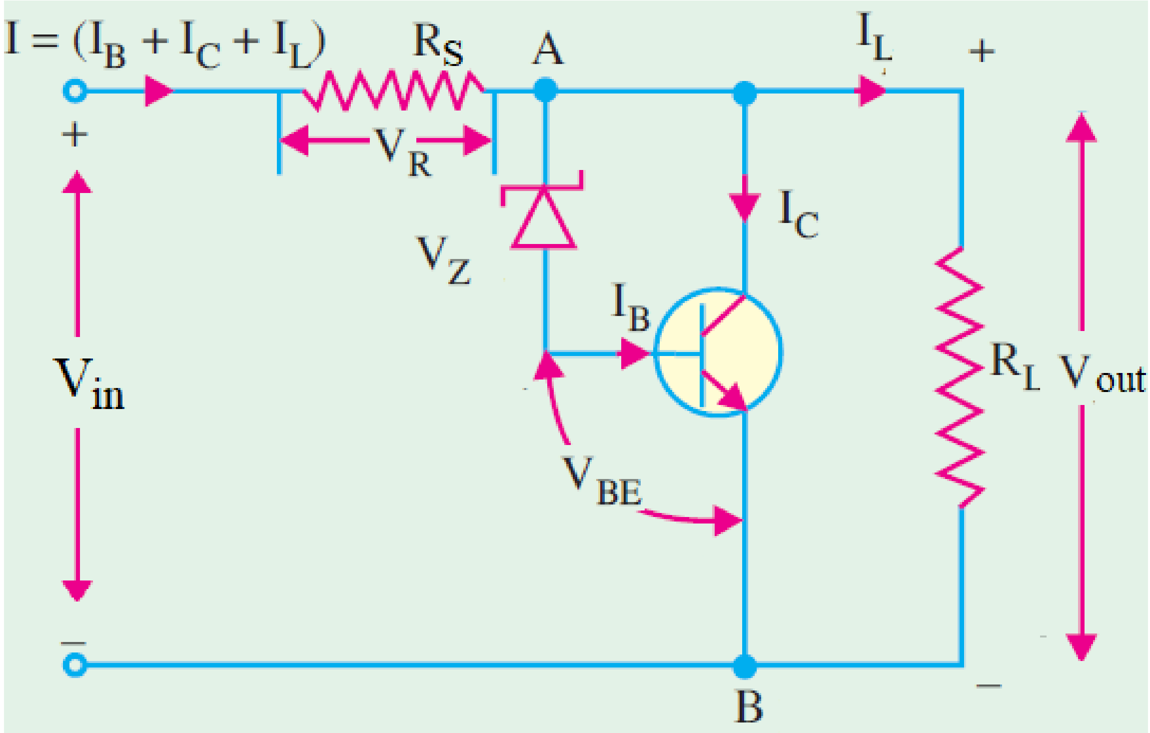
- The unregulated d.c. supply is fed to the voltage regulator. The circuit maintains constant output voltage irrespective of the variations in load or input voltage.
- Suppose the output voltage (V_{out}) increases due to any reason. This causes an increase in voltage (V_F) across K-L (i.e. R_2) as it is a part of the output circuit. This in turn means that more V_F is fed back to the base of transistor Q_2; producing a large collector current (I_{C2}) of Q_2. Most of this collector current I_{C2} flows through R_3 and base of Q_1; causes the base current (I_{B1}) of Q_1 to increase.
- This leads to decrease in V_{CE_1}, thereby offsetting the increases in voltage V_{out} ; which is, therefore, returned to its original value. Thus output voltage remains constant.

- **Similarly, if output voltage (V_{out}) tries to decrease, the feedback voltage V_F also decreases. This reduces the current I_{C2} and I_{B1}.**
- **This leads to increase in V_{CE_1}, thereby offsetting the decreases in voltage V_{out}; the output voltage remains at the original level.**

Summery of Regulator Action:-

V_{out} increases	V_{out} decreases
⇩	⇩
V_F increases	V_F decreases
⇩	⇩
I_{B2} & I_{C2} increases	I_{B2} & I_{C2} decreases
⇩	⇩
I_{B1} increases	I_{B1} decreases
⇩	⇩
V_{CE1} decreases	V_{CE1} increases
⇩	⇩
V_{out} gets original value	V_{out} gets original value

Transistor Shunt Voltage Regulator:



- Figure shows the circuit of shunt voltage regulator in which the transistor is connected in shunt (or parallel).
- A shunt voltage regulator provides regulation by shunting current away from the load to regulate the output voltage.

❖ If the voltage drop across series resistance is V_R then,

$$V_{in} = V_{out} + V_R \quad Or \quad V_{out} = V_{in} - V_R \qquad (1)$$

❖ From the circuit in path AB,

$$V_{out} = V_Z + V_{BE} \qquad (2)$$

❖ If V_{out} decreases due to decreases of load resistance, then as seen from eqn. (2), V_{BE} also decreases. As a result, I_B decreases, hence, I_C (= βI_B) decreases, thereby decreasing I and hence V_R (= IR_S). Consequently, V_{out} increases as seen from eqn. (1), thereby maintaining the regulated voltage across the load.

❖ In sequential logic,

$$V_{out}\downarrow \rightarrow V_{BE}\downarrow \rightarrow I_B\downarrow \rightarrow I_C\downarrow \rightarrow I\downarrow \rightarrow V_R\downarrow \rightarrow V_{out}\uparrow$$

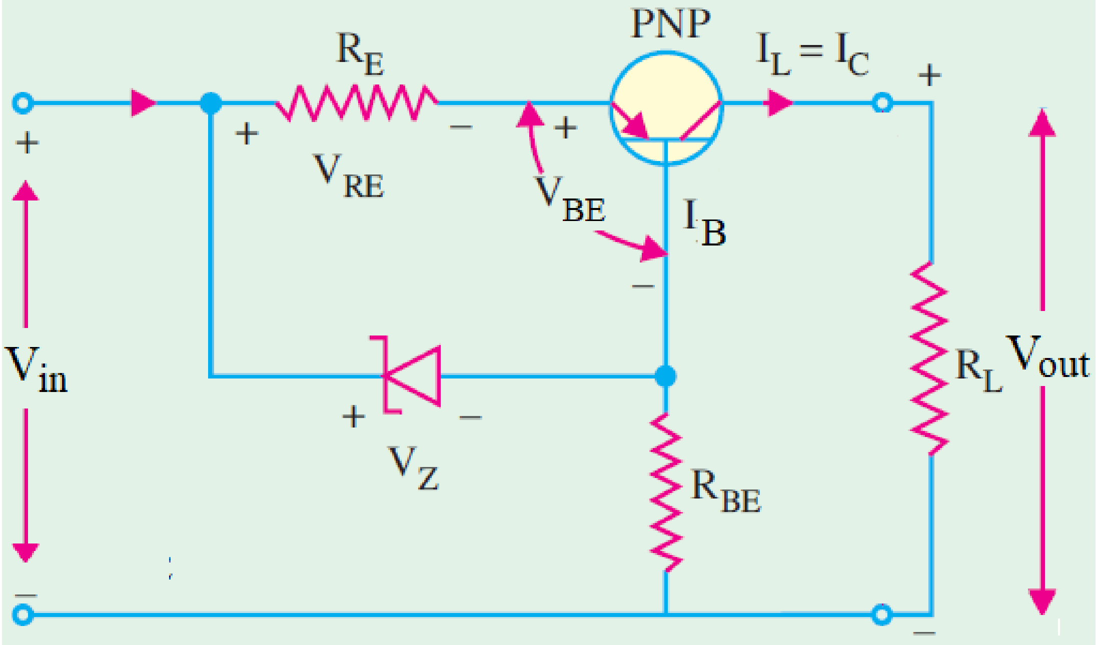
❖ Reverse happens should the load resistance increase.

Drawbacks:-

1. **A large portion of the total current through R_S flows through transistor rather than to the load.**
2. **There is considerable power loss in R_S.**
3. **There are problems of over-voltage protection in this circuit.**

For these reasons, a series voltage regulator is preferred over the shunt voltage regulator.

Current Regulator by Transistor



❖ **The main function of a current regulator is to maintain a fixed current through the load where variations in the output voltage.**

❖ **Such a circuit employing a Zener diode and a *PNP* transistor is shown in Fig.**

- **As per Kirchoff's Voltage Law**

$$- V_{RE} - V_{BE} + V_Z = 0$$

$$\therefore V_{BE} = V_Z - V_{RE}$$

- **Suppose, the current I_L (= I_C) is decreased due to drop in V_{out} . This will decrease I_E ($\cong I_C$). Hence, drop across R_E i.e. V_{RE} will decrease.**
- **As seen above equation, a decrease in V_{RE} will increase V_{BE} because V_Z is fixed, hence, the conductivity of the transistor increases, thereby increasing in I_C , keeping I_L at a original (fixed) level.**
- **A similar logic applies when there is increase in I_L .**