Setting up a Power Supply using a Zener Diode as Voltage Regulator

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The well regulated power supply is desired to ensure that the circuit components operate properly otherwise the fluctuations may cause malfunctions of the circuit operation or damage to the components. In this experiment, we use a zener diode that maintains a constant voltage to regulate D.C. converted output from a full wave rectifier circuit.

I. THEORY

Zener diodes have a region of almost a constant voltage in its reverse bias characteristics, regardless of the current flowing through the diode. This voltage across the diode (zener Voltage, V_z) remains nearly constant even with large changes in current through the diode caused by variations in the supply voltage or load. This ability to control itself can be used to great effect to regulate or stabilize a voltage source against supply or load variations.

The zener diode maintains a constant output voltage until the diode current falls below the minimum I_z value in the reverse breakdown region, which means the supply voltage, V_S, must be much greater than V_z for a successful breakdown operation. When no load resistance, R_L, is connected to the circuit, no load current ($I_L = 0$), is drawn and all the circuit current passes through the zener diode which dissipates its maximum power. So, a suitable current limiting resistor, (R_S) is always used in series to limit the zener current to less than its maximum rating under this "no-load" condition.

The D.C. output voltage from the half or full-wave rectifiers contains ripples superimposed on the d.c. voltage and that the average output voltage changes with load. A more stable reference voltage can be produced by connecting a simple zener regulator circuit across the output of the rectifier. The breakdown condition of the zener can be confirmed by calculating the **Thevenin voltage**, V_{TH}, facing the diode is given as:

$$V_{TH} = \frac{R_L}{R_S + R_L} V_S \tag{1}$$

This is the voltage that exists when the zener is disconnected from the circuit. Thus, V_{TH} has to be greater than the zener voltage to facilitate breakdown. Now, under this breakdown condition, irrespective of the load resistance value, the current through the current limiting resistor, I_S, is given by

$$I_S = \frac{V_S - V_Z}{R_S} \tag{2}$$

The output voltage across the load resistor, V_L, is ideally equal to the zener voltage and the load current, I_L, can be calculated using Ohm's law:

$$V_L = V_Z \tag{3}$$

$$I_L = \frac{V_L}{R_L} \tag{4}$$

Thus the zener current, I_Z, is

$$I_Z = I_S - I_L \tag{5}$$

A basic power supply has now been constructed. Its quality now depends on its load and line regulation characteristics as defined below.

Load Regulation: It is the capability to maintain a constant voltage (or current) level on the output channel of a power supply despite changes in the supply's load. It indicates how much the load voltage varies when the load current changes. Quantitatively,

$$\text{Load Regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\% \tag{6}$$

where V_{NL} = load voltage with no current ($I_L = 0$) and V_{FL} = load voltage with full load current. The smaller the regulation, the better is the power supply.

Line Regulation: It is the ability of a power supply to maintain a constant output voltage despite changes to the input voltage, with the output current drawn from the power supply remaining constant. It indicates how much the load voltage varies when the input line voltage changes. Quantitatively,

$$\text{Line Regulation} = \frac{V_{HL} - V_{LL}}{V_{LL}} \times 100\% \tag{7}$$

where V_{HL} = load voltage with high input line voltage, and V_{LL} = load voltage with low input line voltage. As with load regulation, the smaller the regulation, the better is the power supply.

Applications

Every power supply uses a voltage regulator to provide the desired output voltage and to prevent any damage to the components. It is used in electrical power transmission and distribution systems as well as in computers and other sensitive electronic devices. They are also used in motor controller circuits, driver circuits etc.

II. EXPERIMENTAL SETUP

Circuit components

1. A variable transformer
2. 4 junction diodes
3. A.C. power supply
4. A zener diode ($V_{\text{breakdown}} = 5.6$ V)
5. Current limiting resistors
6. Load resistors
7. Capacitor (100μ F)
8. Multimeters
9. Connecting wires
10. Breadboard

Circuit Diagram

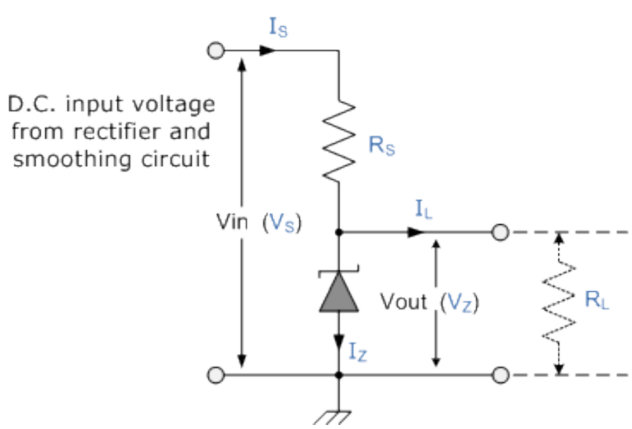

FIG. 1: Circuit diagram for the setup.

III. DATA ANALYSIS

Load Regulation

The plot for the load voltage vs load resistance looks like this.

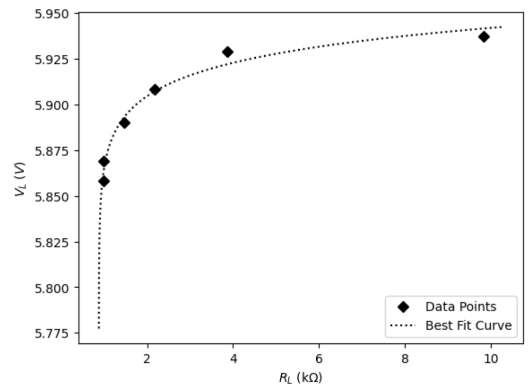

FIG. 2: Output voltage vs load resistance plot for a fixed input current

As you can see, the load voltage increases rapidly with increases in load resistance and then stabilises after certain value of R_L.

At $R_L = \infty$ (no load current), $V_{NL} = 5.938$ V. For this setup, load voltage with full load (maximum load current) is $V_{FL} = 5.858$ V.

Therefore, percentage load regulation (Eq. 6) can be calculated as,

$$\begin{aligned} \text{Load Regulation} &= \frac{5.938 - 5.858}{5.858} \times 100\% \\ &= 1.366\% \end{aligned}$$

Additionally, we can plot V_L vs I_L.

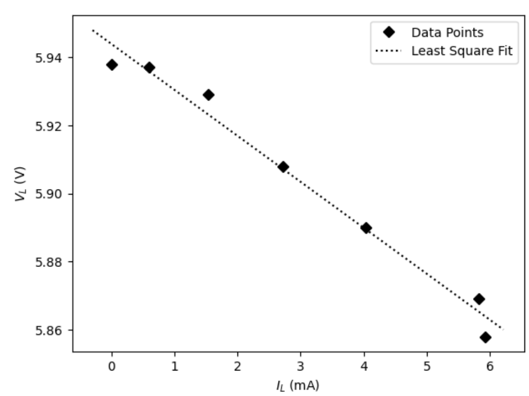

FIG. 3: Output voltage vs output current plot for different values of loads (R_L) for a fixed input voltage

As current across the load, I_L decreases (for increasing values of load resistance), the current across the zener diode, I_Z increases to keep I_S constant. Thus, there is no change in voltage across R_S and thus V_L ideally remains constant. In reality, due to the presence of output impedance or wire resistances, the voltage at the power supply pin on the load device simply behaves according to Ohm's Law. To fix this, feedback loop control systems are used in real circuits.

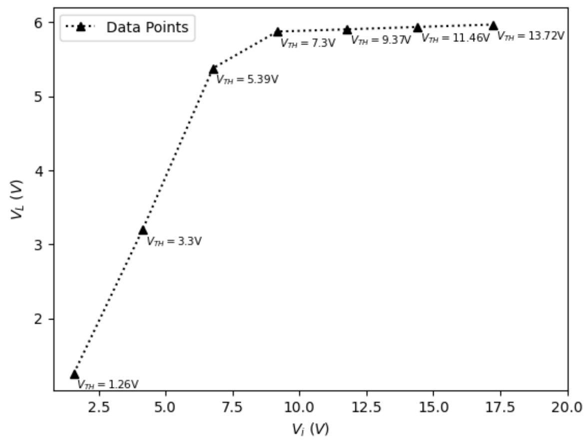

FIG. 4: Output voltage vs input voltage for a fixed load resistance ($R_L = 2.179$ kΩ)

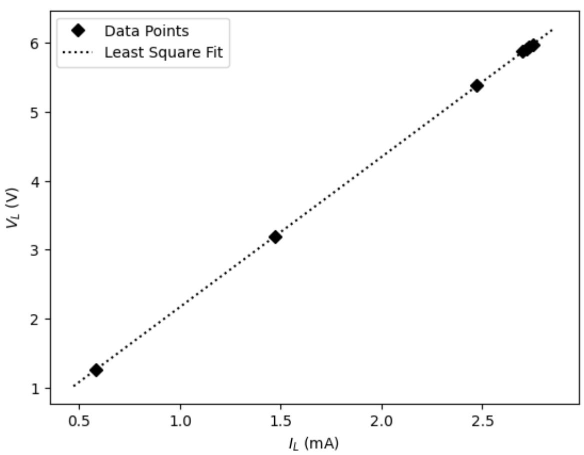

FIG. 5: Output voltage vs output current for a fixed load resistance

Line Regulation

With the load resistance fixed at $R_L = 2.179\,\text{k}\Omega$, plot V_L vs V_i (Fig. 4).

As the load input voltage increases, we can see that load voltage also increases until it becomes roughly constant after a certain V_i. We can observe is this point is right after V_{TH} crosses the zener breakdown voltage (5.6V). Hence, we can take V_{LL} as the output voltage after V_{TH} just crosses the zener breakdown, i.e. $V_{LL} = 5.875$ V (at $V_{TH} = 7.299$).

Additionally, for this setup, $V_{HL} = 5.970$ V (at $(V_i)_{\max} = 17.24$ V. Therefore, percentage line regulation (Eq. 7),

$$\begin{aligned}\text{Line Regulation} &= \frac{5.970 - 5.875}{5.875} \times 100\% \\ &= 1.617\%\end{aligned}$$

Additionally from Fig. 5, we can see that V_L and I_L increase proportionally (following Ohm's law), until V_L roughly stabilises (after V_i crosses the zener breakdown). After that the value of I_L is also roughly constant.

IV. ERROR ANALYSIS

For percentage load regulation, from Eq. (6), propagated error can we written as

$$\begin{aligned}\frac{\Delta LR_{\text{load}}}{LR_{\text{load}}} &= \sqrt{\left(\frac{\partial LR_{\text{load}}}{\partial V_{NL}}\Delta V_{NL}\right)^2 + \left(\frac{\partial R_{\text{load}}}{\partial V_{FL}}\Delta V_{FL}\right)^2} \\ &= \sqrt{\left(\frac{\Delta V_{NL}}{V_{FL}}\right)^2 + \left(\frac{-V_{NL}\Delta V_{FL}}{V_{FL}^2}\right)^2} \\ &\implies \Delta LR_{\text{load}} = 0.024\%\end{aligned}$$

Using $\Delta V_{FL} = \Delta V_{NL} = 0.001$ V, the least count of the multimeter. Similarly, error in percentage line regulation can be calculated using Eq. (7),

$$\begin{aligned}\frac{\Delta LR_{\text{line}}}{LR_{\text{line}}} &= \sqrt{\left(\frac{\partial LR_{\text{line}}}{\partial V_{HL}}\Delta V_{HL}\right)^2 + \left(\frac{\partial R_{\text{line}}}{\partial V_{LL}}\Delta V_{LL}\right)^2} \\ &= \sqrt{\left(\frac{\Delta V_{HL}}{V_{LL}}\right)^2 + \left(\frac{-V_{LL}\Delta V_{LL}}{V_{LL}^2}\right)^2} \\ &\implies \Delta LR_{\text{line}} = 0.017\%\end{aligned}$$

V. RESULTS AND DISCUSSION

Load Regulation: For an unregulated D.C. voltage of ∼11.6 V, we have observed that the load voltage also increases until a certain R_L, after which it becomes roughly constant, i.e. regulated.

By measuring V_L at full and no load current situations, we have calculated the percentage load regulation in the circuit as (1.366 ± 0.024) %.

Line Regulation: We have observed that as the load input voltage increases, load voltage also increases until it becomes roughly constant after V_{TH} crosses the zener breakdown. This is when the zener diode becomes active.

Hence, by measuring V_L at at high and low input lines (when zener is activated), we have calculated the percentage line regulation as (1.617 ± 0.017) %.

Typical well-regulated power supplies have load regulations of less than 1%, meaning that the output voltage will change by a maximum of 1% over the supply's load current range. The values we have achieved are quite close to well-regulated.

Hence we have succesfully constructed a power suppy using zener diode as the voltage regulator.

VI. PRECAUTIONS

1. The transformer must be handled carefully.
2. Switch on the circuit only after verifying the connections to be proper.
3. Do not change the resistor or the capacitor while the circuit is switched on.

[1] SPS. Lab manual. *Website*, 2023. https://www.niser.ac.in/sps/sites/default/files/3-b-zener%20regulator.pdf.