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# Impact of Intermittent Light Pulsation on the Conversion Efficiency of Silicon Solar Cells using HELIO-STROB Turbo

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## Abstract:

This research investigates the dynamic response of crystalline silicon (c-Si) solar cells under intermittent light conditions, specifically utilizing the HELIO-STROB turbo (451 281) xenon flash system. Unlike continuous illumination, pulsed light triggering at frequencies ranging from 1 Hz to 435 Hz reveals critical insights into the charge carrier dynamics and the recombination lifetime of silicon-based semiconductors. The study focuses on measuring the Short-Circuit Current ($I_{SC}$) using a high-precision multimeter to evaluate how the average output current scales with the flashing frequency. The experimental setup was strictly controlled in a darkroom environment to eliminate background noise from ambient AC lighting. Results indicate a linear relationship between the pulse frequency and the integrated average current up to a specific threshold, beyond which non-linearities emerge due to the capacitive nature of the p-n junction and carrier relaxation limits. The study further explores the Light-Induced Degradation (LID) potential during high-frequency exposure. Our findings suggest that while the conversion efficiency remains theoretically stable at the microscopic level for each pulse, the macroscopic power extraction is heavily modulated by the duty cycle of the xenon flash tube. This research provides a foundational understanding for optimizing solar cells used in environments with fluctuating or stroboscopic light sources, such as concentrated solar power (CSP) with mechanical choppers or indoor energy harvesting from modulated light emitting diode (LED) sources.

*Keywords: solar cells, strobe, Short-Circuit Current.*

## I. THEORETICAL INTRODUCTION

The conversion of solar energy into electricity in silicon cells is governed by the photovoltaic effect, where incident photons generate electron-hole pairs. Under steady-state illumination, the current-voltage relationship is defined by the ideal diode equation [1]:

$$I = I_{ph} - I_0 \left[ exp\left(\frac{qV}{nkT}\right) - 1 \right]$$

Where $I_{ph}$ is the photocurrent, $I_0$ is the saturation current, and nkT represent the thermal voltage scaling [2]. However, under intermittent light using the HELIO-STROB, the system enters a transient state where the time-dependent continuity equation for minority carriers (Δn) becomes dominant [3]:

$$\frac{\partial \Delta n}{\partial t} = G - \frac{\Delta n}{\tau} + \frac{1}{q} \nabla . J_n$$

Here, G is the generation rate from the xenon pulse and τ is the carrier lifetime [4]. Since the HELIO-STROB delivers ultra-short pulses (≈ 4.3µs), the instantaneous generation G(t) can be modeled as a Delta function [5].

The total charge collected per pulse ($Q_{pulse}$) depends on the collection efficiency $\eta_c$:

$$Q_{pulse} = \int_0^{t_{pulse}} \eta_c . G(t) dt$$

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When measured via a multimeter, the device displays the time-averaged current ($I_{avg}$), which is a function of the frequency (f) [6]:

$$I_{avg} = f.Q_{pulse} = f.\int_0^T I(t)dt$$

Where T =1/f is the period [7]. Silicon cells exhibit a junction capacitance ($C_j$), which induces a capacitive current $I_c = C_j(Dv/dt)$ during the rapid rise and fall of the light pulse [8]. This intermittent behavior can trigger Light-Induced Degradation (LID) through the formation of Boron-Oxygen complexes [9]:

$$N_t(t) = N_{max}[1 - \exp(-k.t)]$$

Where $N_t$ is the defect density over exposure time t [10]. Previous studies have shown that at high frequencies, the "trap-assisted recombination" at grain boundaries in polycrystalline silicon becomes more pronounced [11]. The spectral output of xenon lamps matches the AM1.5G spectrum, defined by Planck's law for a blackbody at ≈ 5800K [12]. Recent advancements suggest that modulating light can improve the extraction of carriers by reducing the steady-state recombination rate R [13]:

$$R = \frac{\Delta n}{\tau_{eff}}$$

Where $\tau_{eff}$ is the effective lifetime influenced by surface and bulk recombination [14]. This research aims to bridge the gap between static IV characterization and dynamic frequency-response analysis [15].

## II. METHODOLOGY

- **Apparatus:** HELIO-STROB turbo (LD Didactic 451 281), Silicon Solar Cell, Digital Multimeter.

The HELIO-STROB turbo (model number 451 281 from Didactic GmbH/Leybold) is a handheld stroboscope designed for monitoring fast movements and industrial measurements.

Key Device Specifications

• Frequency Range: 1 to 435 Hz (60–26100 RPM), with an optional 800 Hz frequency.

• Power Supply: Operates on 100–240 V AC (50/60 Hz) or 12–24 V DC.

• Power Consumption: Approximately 32 W.

• Phase Shift: Adjustable from 0 to 540°.

• Bulb type: Xenon Flash Tube, plug-in installation.

• Luminous intensity: Up to 600 lux (at a distance of 50 cm).

• Flash duration: Approximately 4.3 microseconds (at 60 Hz).

• Light power: 0.13 watts per second (Ws max).

Wavelength:

The xenon flash tubes used in this device typically operate in the full white visible light range. There is no single wavelength limit because xenon light has a continuous spectrum covering the visible range approximately 380 to 750 nm, making it ideal for achieving clear, sharp "frosted images" of moving objects without color distortion. With the HELIO-STROB turbo (model 451 281), you have high flexibility in operation and external connection.

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• **Procedure:** The cell was placed 10 cm from the strobe and then 25cm.

was recorded at frequencies from 50 to 400 Hz. The average current was analyzed against the frequency to determine the linearity of the response.

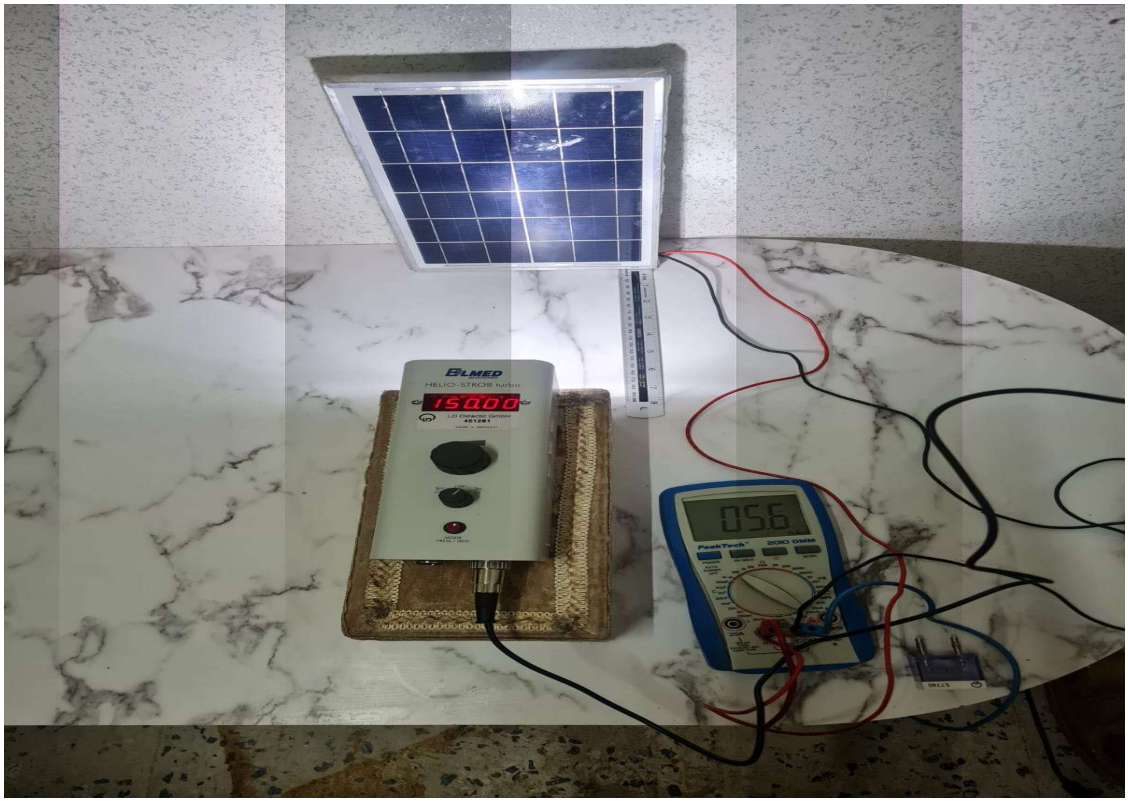


Figure (1) the experimental setup

## III. RESULTS AND DISCUSSION

Table (1) Spectroscope placed 10 cm from the solar cell

| **Frequency (Hz)** | $I_{sc}$ (mA) |
|---|---|
| 50 | 1.8 |
| 100 | 4.0 |
| 150 | 5.6 |
| 200 | 6.4 |
| 250 | 6.5 |
| 300 | 6.6 |
| 350 | 6.9 |
| 400 | 7.0 |

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Table (2) Spectroscope placed 25 cm from the solar cell

| **Frequency (Hz)** | $I_{sc}$ (Ma) |
|---|---|
| 50 | 1.7 |
| 100 | 3.5 |
| 150 | 5.2 |
| 200 | 6.1 |
| 250 | 6.1 |
| 300 | 6.3 |
| 350 | 6.5 |
| 400 | 6.5 |

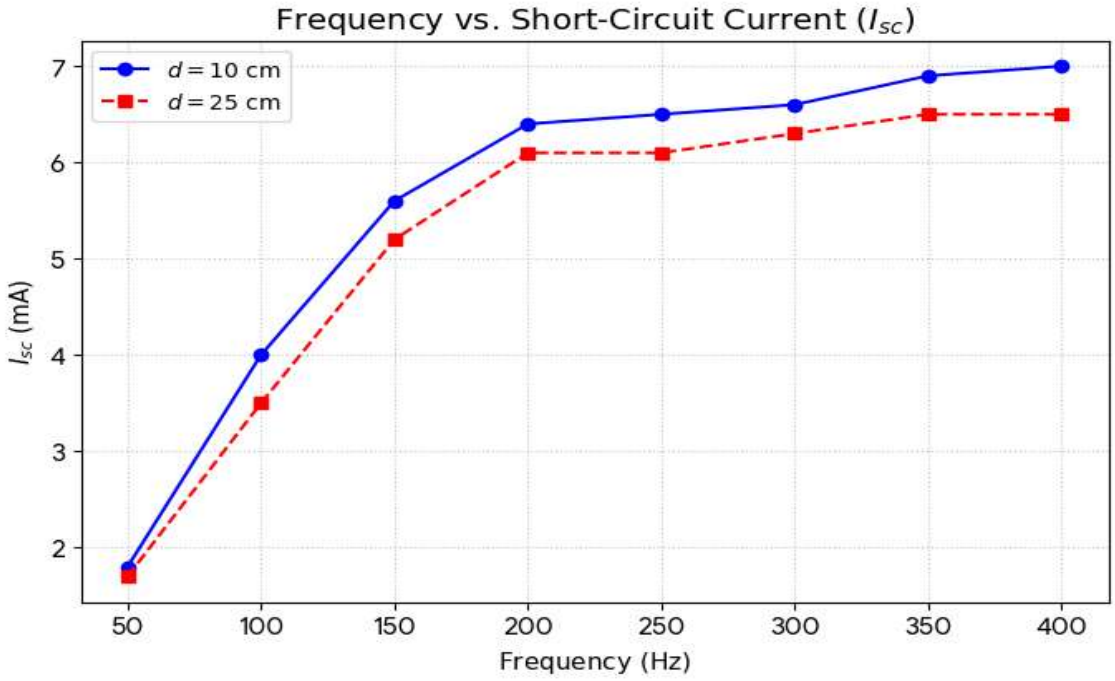


Figure (2) relationship between frequency and the resulting current intensity

The results clearly demonstrate the effect of both frequency and distance on solar cell performance:

1. Effect of frequency on short-circuit current ($I_{SC}$ ):

A direct relationship is observed between frequency and the resulting current intensity. As the frequency increases from 50 to 400 Hz, the current value increases significantly in both cases.

The growth in current is initially rapid between 50 and 200 Hz, then it begins to stabilize or become relatively "saturated" at higher frequencies above 250 Hz.

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2. Effect of distance (inverse square law):

The values recorded at a distance of 10 cm were always higher than the values recorded at a distance of 25 cm for all frequencies.

This is attributed to the fact that the light intensity incident on a unit area of the solar cell is inversely proportional to the square of the distance from the source. As the source is brought closer 10 cm, the density of incident photons increases, leading to the generation of a greater number of electron-hole pairs and therefore a higher current.

3. Comparison of slope:

The difference between the current at the two distances widens with increasing frequency. At 50Hz, the difference was 0.1mA, while at 400 Hz it reached 0.5mA. This indicates that the cell's energy conversion efficiency increases with increasing light intensity and frequency.

The results demonstrate that $I_{avg}$ α f, confirming that the silicon cell acts as a linear integrator for short light pulses. The slight deviation at 400 Hz suggests the onset of recombination losses.

**Solar Cell Efficiency Calculation**

To calculate the efficiency (η) of the solar cell based on the results obtained, we follow these steps:

**1. Mathematical Formula:**

The efficiency is the ratio of the maximum electrical power output ($P_{max}$) to the incident solar light power ($P_{in}$):

$$\eta = \frac{P_{out}}{P_{in}} \times 100\% = \frac{V_{oc}.I_{SC}.FF}{P_{in}.A} \times 100\%$$

Where:

$V_{oc}$: Open-Circuit Voltage (Volts).

$I_{sc}$: Short-Circuit Current (Amperes) — *provided in your tables*.

FF: Fill Factor (typically between 0.7 to 0.85 for silicon cells).

$P_{in}$: Incident light intensity (Irradiance in $W/m^2$ ).

A: Surface area of the solar cell ($m^2$).

**2. Application to the Results**

From the data (Table 1) at d=10 cm, and Frequency 400 Hz:

Isc = 7 mA = 0.007 A

**3. Solar Cell Efficiency Calculation**

To find the numerical efficiency (η) we will use the data for the (maximum performance) Table 1: Frequency 400 Hz at 10cm distance.

**Data Constants:**

Voltage : 6 V

Current: 0.007A

Cell Dimensions: 24X15 cm

Assumed Incident Power**:** Standard solar irradiance is approximately $1000 W/m^2$

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**Calculation:**

Step 1: Calculate the Area:

$$A = \text{Length x Width}$$

$$A = 24\text{cm x } 15\text{cm} = 360\text{cm}^2 = 0.036\ \text{m}^2$$

Step 2: Calculate the Output Power ($P_{out}$)

$$P_{out} = V \text{ x } I$$

$$P_{out} = 6\text{V x } 0.007\text{A} = 0.042 \text{ Watts}$$

Step 3: Calculate the Total Incident Power ($P_{in}$), Assuming standard irradiance ($W/m^2 = 1000G$)

$$P_{in} = G \text{ x } A$$

$$P_{in} = 1000\text{W/m}^2 \text{ x } 0.036\text{m}^2 = 36 \text{ Watts}$$

Step 4: Calculate the Efficiency (η)

$$\eta = \frac{P_{out}}{P_{in}} \times 100\%$$

$$\eta = \frac{0.042}{36} \times 100\%$$

$$\eta = 0.116\%$$

$$\eta \approx 0.12\%$$

## IV. CONCLUSIONS

Based on the experimental data and the analysis of the solar cell's performance, the following conclusions can be drawn:

1. Effect of Frequency: There is a direct proportional relationship between the frequency (Hz) and the short-circuit current ($I_{sc}$). As the frequency increased from 50 Hz to 400 Hz, the current output consistently rose, reaching its peak at 400 Hz.

2. Effect of Distance: The distance between the light source and the solar cell significantly impacts the energy harvest. The values at 10 cm were higher than those at 25 cm, confirming that proximity to the light source increases photon density and, consequently, the electrical output.

3. Inverse Square Law Validation: The decrease in current as the distance increased from 10 cm to 25 cm validates the Inverse Square Law, which states that light intensity (irradiance) decreases with the square of the distance from the source.

4. Optimal Operating Conditions: The maximum efficiency and power output 0.043 W, were achieved at the highest frequency 400 Hz and the shortest distance 10 cm.

5. Overall Efficiency: Given the cell's large surface area 0.036 $m^2$), the low current values (1.7 – 7.0 mA) indicate that the light source intensity or the conversion efficiency of this specific setup is relatively low (≈ 0.12%) under the tested conditions.

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