An IoT based on Smart CPV Units Composed of a Hyperbolic Optical Element

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ABSTRACT The first part of the study refers to the development of a 3D solar concentrator composed of two optical elements; a flat circular Fresnel lens associated with a hyperbolic concentrator. This research is conducted to provide better insight into the concentrator optical performance. The concentrator optical performance system is evaluated for the acceptance angle, achieved concentration, fresnel lens tolerances in secondary element placement, and flux distribution on the secondary optic output. Results show the optical efficiencies of the circular apertures and the square apertures of hyperbole as a function of the heights. We noticed that the circular apertures of hyperbole present high optical efficiency for lengths of 30 to 55mm. Still, beyond this length, the square apertures of the hyperbole exhibit higher optical efficiency. Comparison of these optical elements as secondary optical elements with the elements studied in the previous work (pyramid, compound parabolic concentrator, cone, crossed compound parabolic concentrator). We found that pyramid remains the best secondary optical element for a Fresnel lens as a primary optic. The second part is based on deploying a new cost-effective method using IoT to remotely monitor and assess a photovoltaic plant operation. Using technology to supervise concentrated solar generation can significantly improve plant performance, monitoring, and maintenance. This will make preventive maintenance, defect detection, historical plant analysis, and real-time tracking easier. The follow-up program successfully collected all the data from morning till evening. The mean transmission time is 52.34 seconds, with 30 and 102 seconds the shortest and greatest transmission times.

INDEX TERMS remote monitoring; IoT, Fresnel lens; Concentrated Photovoltaic (CPV); Primary Element; Secondary Element; Acceptance angle, optical efficiency, hyperbole

Nomenclature

| Symbol | Definition |
|--------|------------|
| a      | Radius of exit area |
| A      | Radius of the entrance area |
| A_in   | Area of the entrance aperture |
| an     | The difference in width between the exit and the entrance |
| a_ext  | Exit of receiver area |
| F      | Fresnel lens Focal distance |
| N      | Reflections Number |
| L      | Pyramid height |
| PO     | Primary Optic |
| SO     | Secondary Optic |
I. INTRODUCTION

Due to developments in the wireless network and Internet-connected mobile devices, wired technologies such as smartphones and tablets are becoming more widespread. As a result, the Internet of Things (IoT) evolved as a new idea [1-2], was created and has acquired significant emphasis in recent years. The Internet of Things, in general, is a data-sharing network that connects common objects in relation to wired and wireless networks. It is now employed in a variety of industries, in addition to consumer products and appliances, smart cities, healthcare, smart homes, intelligent automobiles, energy systems, and industrial safety.

Currently, a concentrated photovoltaic (CPV) system is a promising technology that is increasingly being incorporated into the existing grid. There is increasing demand to examine real-time data from concentrated photovoltaic plants [3] to enhance the solar plant of power overall performance and ensure grid stability. However, the onsite monitoring is impractical during installation, all solar power facilities must rely on remote monitoring. The use of digital technology and increasingly powerful computer facilities to utilize the potential of IoT to monitor solar power plants is looking promising right now.

Concentrated long-term photovoltaic power is one of the most likely methods of generating electricity from solar energy (CPV). It is a successor for the flat plate module that is more efficient [5]. This strategy drastically minimizes the quantity of space needed for cells. Unfortunately, due to the current cessation of activities, producing a given amount of electricity at a lower cost through high efficiency and prudent spending has become difficult. This business failure is in stark contrast to the scientific achievements, with efficiency rates exceeding 40% [6]. In a previous work [7], four HCPV systems composed of a Fresnel lens as PO fabricated of PMMA and four SO shapes were tested: CPC, cone, CCPC, and pyramid, made of several materials. The authors found that the pyramid can give the best flow distribution, higher efficiency of optics, and larger angle of acceptance.

In this work, the first part is dedicated to investigating another non-imaging secondary optic made of B270, the hyperbolic with two circular and square forms related to the PMMA-based Fresnel lens. We will first be dedicated to correcting Equations (1-4) that define the hyperbola. Then we show the optical performances of the two shapes for photovoltaic application as SO. In addition, the ideal placement for each SO in terms of the FL is established in order to identify the best positioning. Finally, we compare their performance with the other SO studied previously. Following that, using a conceptual approach proposed in this study to employ an IoT-based network to monitor and regulate the condition of a solar system, the data collected by our plant will be monitored and controlled for the first time for the CPV system. While the facility is being updated to a new monitoring system, the monitoring concerns must be addressed, the improvement over an existing solution in the literature is quantified. A mobile radio network is used to transmit sensor data. The data is sent to the remote server via a GPRS module.

Section 2 follows the introduction and details the prototype constructed and the adjustment of equations found in the literature. Section 3 reports the positioning of the secondary optic concerning the Fresnel lens and Section 4 describes a potential IoT-based solar monitoring system and the last section concerns the conclusions.

II. RELATED WORK

Concentration optics may be constructed using single or multiple optical components. Several researchers have applied several Fresnel lens [7-22], mirror [26], and complex parabolic inverts [27, 28]. We can locate rectangular and flat circular shapes researched by A. Davis [23] in the literature on Fresnel lenses. The discovered round lens has little greater transmittance (82 percent) than the lens that is squared in a analysis of several shaped Fresnel lenses with CPV systems (80 percent). Languy et al. [24] offered a comparison of performance of a doublet Fresnel lens’ theoretical design with the goal of taking use of the achromatic advantage in mirrors and plastic lenses. Due to the low chromatic aberration, the optical efficiency of the double-groove lens approached 90%. Another Fresnel lens for CPV systems was designed by Zhuang et al. [17]. This lens is made up of two sections, the first with standard prisms on the outside and TIR prisms on the inside. According to their findings, the created system features a 0.23 and the acceptability aspect and a 95 percent optical efficiency. Ryu and colleagues invented a new form of the Fresnel lens [25]. It comprises a Fresnel lens that is modular. A superposition of many Fresnel lens blocks is the central concept. The usually incident solar flux is redirected to the solar cell region by a system of modular Fresnel lenses. With an optical efficiency of more than 65 percent, the flux distribution on the cell has improved. Pham et al. [20] proposed another Fresnel lens form. In a manner, it looks like two overlaid linear FLs with perpendicular...
grooves. The lens has two groove surfaces; each one directs sunlight in a single direction allowing whole lens to gather and disperse sunlight to two dimensions and enhance the concentration ratio. Simulations of a 10x10 mm PMMA prototype indicated that the acceptance angle of this lens was 0.84° and it had a high optical efficiency of 82.4 percent, a high concentration ratio of 576 times and uniform irradiance.

In [29] developed a moulded parabolic concentrator capable of producing a consistent flow distributive over a square with a smooth surface of many inches. Five concentric circular pieces were used to create this concentrator. Each segment was positioned parallel to the optical axis and described as a curvature spherical optic with a radius of 1/2f, denote 20% (1/5) of the total opening area. A collection opening with a diameter of roughly 1.5 m might directly achieve concentration levels of 100 to 200 Suns. In [30] have indicated that a parabolic mirror (no secondary element) is simply appropriate at a low concentration rate of approximately 70x, with an optical efficiency around 80%. Chong et al. [31] developed a non-imaging mirror-based planar concentrator. The Sunrays are collected and focused onto a target surface using several flat square mirrors measuring 40 mm x 40 mm. The focus length determines the concentration ratio. However, as the focal length increases, the size of the light spot shrinks according to the authors. Indeed, increasing the distance length from 50 to 100 cm increases the concentration from 270 to 310, as decreasing the lighted area from 13.43 cm² to 10.24 cm².

Wang et al. [32] also presented a solar concentrator with mirrors to develop a CPV system with excellent concentration uniformity. Linear Fresnel Reflectors (LFR) of various widths was used. The new design's performance was compared to that of a hollow parabolic mirror with a geometric concentration of 31.31x. According to simulation data, the homogeneity of the flux density generated by the LFR is superior to that generated by using a parabolic trough concentrator. With a 1° acceptance angle, the optical efficiency was 62%.

The findings reveal that the single stage used for CPV systems fails to meet overall performance standards; either the system is exceptionally efficient, but the flow distribution in the cell is not uniform, or the inverse is true. After that, concentrators with many stages, which are concentration systems containing two optical components, The Primary Optic (PO) and Secondary Optic (SO), often known as the Primary and Secondary Optics, may be more effective. According to the literature, we identified different systems based on the Fresnel lens for a 1000 sun ideal concentration ratio, with secondary systems like as the CPC, Dome, Pyramid, and Hyperbole, which were examined by Rodriguez et al [33, 34]. Although, according to the simulation findings, the four concentrators have an acceptance angle of less than 1° and an optical efficiency of more than 80%, the pyramid may achieve the best flux uniformity. Experiments back up these claims, with angle of acceptance falling to 0.8° and optical efficiency dropping to 73%.

El Himer et al. [35] used just simulation to analyze and appraise four systems built on four secondaries components (CPC, Cone, Pyramid, and CCPC) coupled to lens for a 1000x concentration rate. Furthermore, they showed that the pyramid as SO provides the largest acceptance angle (1.4°), the most uniform illumination in the solar cell, and the maximum optical effectiveness regardless of the material used (83%). Several authors [36-37] have investigated the efficacy of parabolic mirrors as primary or secondary optics. According to research, the usage of a parabolic mirror is a key optical element, particularly when mixed with a flat mirror, produces remarkable optical effects. It is the most cost-effective with an optical efficiency of 85 percent. When two concentrating optical elements are used, the CPV system is more effective due to its high-level optical proficiency, high intensity, and wide acceptance angle. Sellami et al. [38] created a square elliptic hyperboloid concentrator for solar photovoltaics (SEHC). They showed SEHC with a concentration ratio of 4, optical component has an acceptance angle of 120 degrees and a constant optical efficiency of 40 percent. This arrangement collects direct and diffuse radiation every day. The different sizes of the SEHC concentrator only allow for an acceptance angle of 50° and an optical efficiency of 70%. Imhamed et al. [30] investigated a solar elliptic hyperboloid concentrator with the same design (EHC). Their design was developed using formula (1-4) [14]. According to the simulation results, the best shape factor (a/b) for HEC is twice that of a circular profile. The effective concentration of EHC enhances as the concentrator's height increases. Optical efficiency fluctuates as geometry transforms from circular to elliptical with changing aspect ratio (a/b).

The optical efficiency and concentration ratio achieved in the case of a 30° acceptance angle and an estimated height of the hyperboloid concentrator of 0.4m are, respectively, 27% and 20%.

Reflecting optic (mirror), refracting (lens), TIR, and luminescence or any other device that collects a vast area of solar energy on a small receiver surface, can be utilized to focus light on solar cells in one-stage designs. We may infer from this literature review, as indicated in Table 1, that there are several factors to consider when choosing an SO for a Fresnel lens such as a PO. The mirror kaleidoscope has a larger acceptance angle; however the pyramid has the highest optical efficiency. The latter also exhibits the most uniform flux distribution in the solar cell. Therefore, with a Fresnel lens such as a PO, the pyramid appears to be the best secondary element at present. Using a parabolic mirror as a primary optic produces notable optical capabilities, mainly when used in conjunction with a flat mirror (see Table 2), highlighting optical systems that use a parabolic mirror, because it has the maximum possible optical efficiency of 85%.
### Table I

| Fresnel lens associated with | Optical efficiency (%) | Acceptance angle (°) | References |
|-----------------------------|------------------------|---------------------|------------|
| HYPERBOLA                   | 81                     | 0.96                | [37]       |
| CONE                        | 78.38                  | 1                   | [37]       |
|                             | 29.1                   |                     | [43]       |
|                             | 80.85                  | 0.5                 | [37]       |
| CCPC                        | 77.51                  |                     | [42]       |
|                             | 83.6                   | 1.03                | [37]       |
| DOME                        | 81.8                   | 1.11                | [44]       |
| CPC                         | 82.3                   | 1                   | [37]       |
| Pyramid                     | 83.4                   | 1.13                | [37]       |
|                             | 87.52                  | 0.96                | [40]       |
|                             | 87                     |                     | [41]       |

### Table II

| Mirror associated with | Optical efficiency (%) | Acceptance angle (°) | References |
|------------------------|------------------------|---------------------|------------|
| Hyperbole              | 77                     | 0.44                | [51]       |
| Cone                   | 82                     | 1.03                | [49]       |
| CCPC                   | 77.5                   |                     | [46]       |
|                        | 77                     |                     | [47]       |
|                        | 68.3                   |                     | [48]       |
| Flat Mirror            | 85                     |                     | [50]       |
| Pyramid                | 84.24                  | 1.03                | [45]       |

## III. MODELING OF THE SECONDARY OPTIC STUDIED

### A. Basic Solar Concentrator Concepts

1. **Imaging and Non-Imaging Optics**

Baranov [4], Ploke [6], and R. Winston [7] formulated this concept in the 1960s in Germany and the United States, respectively, and it is also the most widely used nowadays. The goal of anidolic optics is to improve a source's illumination while preventing the development of an image of the source on a target.

Rather than generating an image, it is necessary to confirm for extreme rays flowing in extreme directions and locations at the entry aperture of the optical system are directed in extreme directions or positions at the absorber, as indicated in Figure 1.

The radiation emitted from the source (Point F and Point E) has to be focused at the receiver's (Points A and B). According to the optical system architecture, the intermediary zones must fall inside the receiver's entire zone AB. As a result, Equation (1) connects the distance between the optical axis and point P in the object plan, d₀, and the distance between point Q and the optical axis in the image plan, dᵢ:

\[ d₀ = M dᵢ \]  (1)

M is the optical system's magnification. The results for image that accurate represents the item by sustaining the relative sizes of its various components.

According to the previous work, CPV systems are categorized into two classes based on the shape and concentration rate (Figure 2).

On the geometrical side, they can be into concentrators with one or two stages, each produced by a mirror, a lens, or other optical form and/or a combination of two or more. The concentration ratio of low concentration systems under 10 times the Sun (10x) can be differentiated. As a result, they can function without trackers for longer periods and have greater Sun tracking adaptability. To focus the light to the silicon solar cell, some low-concentration systems employ diffuse reflectors or TIR instead of lenses or mirrors [9].

The second class includes systems having a concentration ratio of 10 to 100 Suns are considered medium concentration systems.

These systems frequently employ single-junction silicon or GaAs solar cells, which are inexpensive and represent the primary benefit of this system. Nevertheless, such cells are incredibly heat sensitive, and their efficiency drops dramatically as the temperature rises. Active cooling systems, which require larger heat dissipation fins, have mostly solved this problem.

This raises the system's overall cost and reduces its reliability. The two types of medium concentration system use cylindroid-parabolic concentrators and those that use Fresnel optics (lenses or mirrors). Solar tracking on one or both axes is required for these systems. High concentrator photovoltaic systems (HCPVs) are the third type (HCPVs), which is the most common and promising field of CPV research today. The criteria for optical design and high precision tracking remain the same for effective HCPV systems. The system's surface is always in normal incidence about direct Sun beams to the high-precision two-axis tracking mechanism. We now emphasis on the features of the optical elements employed in the primary CPV systems after distinguishing these concentration levels.

### B. THEORETICAL BACKGROUND

The effective concentration ratio, which is defined by, characterizes the CPV system:

\[ C_{eff} = \eta \times C_{g} \]  (2)

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Figure 2. Classification of CPV systems.

![Diagram showing classification of CPV systems]

Figure 3. Non imaging optic

\[ \eta = \frac{P_{\text{out}}}{P_{\text{in}}} \]  

Where \( C_g \) and \( \eta \) are geometrical concentration and optical efficiency, and is determined by

\[ C_g = \frac{A_{\text{in}}}{A_{\text{out}}} = \frac{n_2 \sin \theta_{\text{out}}}{n_1 \sin \theta_{\text{in}}} \]  

Where \( A_{\text{in}} \) and \( A_{\text{out}} \) are the input and output apertures, and \( n_1 \) and \( n_2 \) are the entry and output medium indexes, respectively, as shown in Figure 3.

C. MODEL ANALYSIS

The suggested CPV system utilizes a Fresnel lens as the primary optic and a hyperbolic concentrator as the secondary optic. The Fresnel lens is one of the most often employed optical elements in CPV, and its F/#, is determined by:

\[ F/# = \frac{f}{d} \]  

as well as its opening angle \( \theta \), which is given by:

\[ \tan \theta = \frac{d}{2f} \]  

The hyperbolic concentrator is a non-imaging concentrator used in solar cells to concentrate sun radiation (see Figure 4). This concentrator employs a virtual focus, which allows numerous reflections of sun rays to reach the receiver. Therefore, a hyperbolic concentrator has been proposed in this study. The concentrator comprises highly reflecting material to transfer the maximum energy to the receiver.

For this hyperbola, the basic equation is:

\[ \frac{x^2}{a^2} - \frac{y^2}{b^2} - \frac{z^2}{c^2} = 1 \]  

If \( z=0 \)

\[ y = \sqrt{\left(\frac{x^2}{a^2} - 1\right)b^2} \]  

If \( x=a \) then \( y=0 \)

If \( x= A \), then \( y=H \)

We replace \( x \) and \( y \) by its values on Eq.11, we get:

\[ b^2 = \frac{H^2}{A^2} = \frac{H^2}{(CR - 1)^{-1}} \]

\[ CR = \frac{A^2}{a^2} \]

With

Finally

\[ y_1 = \sqrt{\left(\frac{x^2}{a^2} - 1\right)H^2(CR - 1)^{-1}} \]
The same thing for \( y_2 \), we found
\[
y_2 = \frac{x^2}{b^2} - 1 \quad H^2(CR - 1)^{-1}
\]

The above equations permit us to design the 2D and 3D models for hyperbola, as shown in Figure 4.

### D. SIMULATION RESULTS AND DISCUSSION

**1. Optical Performances**

The output flux distribution and optical efficiency of each SO are compared. As depicted by Figure 5, the SO is positioned at the focal point of a Fresnel lens in each instance. In the simulations, a typical spectrum light source (0.38-1.4m) with a normal angular distribution of sunrays and irradiance of 1000 W/m² was used.

- **CIRCULAR APERTURES OF HYPERBOLIC CONCENTRATOR**

In this first case, a circular PMMA-Fresnel lens is associated with the hyperboloid concentrator's circular apertures. The Fresnel lens is 350 mm in diameter and 3 mm thick, with a focal distance of 265 mm. The triple junction (TJ) solar cell modeled as square with a side length of 10 mm. The geometrical concentration of CPV units is 1000. In terms of the SO, we set the input diameter to 25 mm, the output diameter to 10 mm, and the high to somewhere between 30 and 70 mm. Figure 6 illustrates the optical efficiency versus hyperbola heights. We observe that the optical efficiency lowers as the hyperbolic concentrator heights increase. This is due to the several reflections of the solar rays in the hyperbola, in fact, the number of reflections with a rise in the hyperbola's height. Figure 7 shows the evolution of the receiver's flux distribution as a function of hyperbola length.

We see that the peak with the highest intensity is always at the center of the hyperbola exit, and that the intensity declines as the hyperbola height increases. In this second case, we keep the same optic, but the Fresnel lens is associated with the hyperboloid concentrator's square apertures. Concerning the SO, we will fix the input side to 25 mm, the output diameter to 10 mm, and vary its high from 30 to 70 mm.

**2. SQUARE APERTURES OF HYPERBOLIC CONCENTRATOR**

Figure 8 illustrates the optical efficiency Vs hyperbola height. The optical efficiency improves with a rise in the hyperbola's height up to 48.3 mm and then begins to decline again. The flux distribution evolution in the receiver as a function of hyperbola length is depicted in Figure 9. The flow is evenly dispersed throughout the whole surface of the circular exit; it is homogeneous with respect to the flux concentrated by the hyperbola with the circular openings. The intensity is high for a height of 48.3 mm. This length will be chosen for the next session.

**E. HYPERBOLA POSITIONING FROM THE FRESNEL LENS**

In this section, we will show the performance of the SOs for different positions. We consider three positions chosen according to the focal point without generating any losses: The first one, when the SO is positioned at the point focal, \( z = f \), the second, and the third are defined by the Equation 11-12. Figure 10 illustrates the optical efficiency depending on the position for SOs with lens.

It is evident that the optical efficiency in every case tends to grow and is constant beyond 20 mm for square hyperbola apertures and 15 mm for circular hyperbola apertures, then falls as the distance from the lens approaches the maximum \( z = z_{\text{max}} \). The circular aperture of the hyperbola keeps the higher efficiencies. Considering the acceptance angle, we performed simulations with angles of incidence ranging from 0° (normal incidence) to 1.2°. Figure 11 shows the value of the acceptance angle of the entire system when efficiency is reduced to 80% of its starting value.

These findings reveal that the hyperbola's square apertures have the biggest aperture (1.2°) for all locations Hyperbola's circular aperture only achieves this angle between 250 and 265 mm.
The optical performances of the hyperbola are interesting but as we can see in Table 4 which presents a comparison for the optical efficiencies for circular hyperbola and the square apertures of hyperbola as a function of the heights. We notice that the circular hyperbola presents high optical efficiency for lengths of 30 to 40 mm, but the square aperture of hyperbola presents a higher optical efficiency from this length.

By comparing these optical elements as secondary optical elements with the elements studied in the previous work [15] (pyramid, CPC, cone, CCPC), we find that for a length of 48.3 mm (Table 4) which is the same length as the four elements, the optical efficiency of the hyperbola circular or the square apertures has important optical efficiency as pyramid and CPC as well as a large acceptance angle (1.2°). We can say that the square hyperbole and the pyramid remain the best choice as SO for a Fresnel lens as PO. For the rest of the work, we take the...
data obtained (Temperatures and powers) of our concentration photovoltaic plant composed of a Fresnel lens of 350mm and a focal length of 265mm attached to a hyperbolic with entry openings and a square outlet of 48.3mm in length.

IV PHOTONOLTAIC MONITORING PROPOSED IOT BASED SYSTEM

A. METHOD RECOMMENDED

Figure 12 shows an idea for the IoT application idea. The sensing layer, which includes voltage sensors, lies at the bottom of the schematic design, current sensor, a pyrometer of irradiance measure, and another sensor.

B. RESULTS AND DISCUSSION

This layer also comprises data process utilizing a microcontroller for data obtained from the sensors. The wireless module connects with the microcontroller to get started and send data to server. The network layer is the second layer, which includes a database for data storage and real-time data processing from the plant. Following the network layer, this information has been processed and saved at the application layer. The data which is collected, evaluated, and stored, this layer generates complicated web-based services. Graphical user interfaces will help in plant operation monitoring. Additionally, console advised to administrator on decisions established on previous data, saving time while making judgments. It is easier to monitor the whole operation of a solar power plant using an IoT-based remote monitoring system and a web-based approach.

This study proposes a smart data collection system for a concentrated solar plant, as depicted in Figure 11. The data collection system can measure all the following: battery voltage, PV voltage, PV current, grid current, solar insolation, battery current, Grid voltage and temperature. A voltage divider circuit senses PV voltage, PV current is measured through a shunt and differential amplifier. The potential transformer with a precision rectification is utilized to measure the grid voltage. The current transformer with precision rectification is utilized to detect current. Insolation of solar is measured using a unit solar cell with a precision amplifier.
The solar system performance was evaluated over three days (8 a.m. to 16 p.m) which is 8 hours. The sensors were able to detect voltage, temperature, current, and light intensity. The formula $P = VI$ used with the watt unit to determine power based on voltage and current data. For the purpose of calculating the environment contribution to the total electricity produced, the panel’s temperature and the amount of light are also monitored. Data for power vs temperature and light vs power intensity are shown in Figures 14 and 15, respectively.

At 13.00, the three-day average power was the highest at 75.2 Watt. The maximum panel temperature obtained at the same time was 30 degrees Celsius, which was directly proportional to the amount of power generated. Increases in solar irradiation or the quantity of sunlight power density obtained location (measure in W/m²) may lead to a rise in temperature. The CPV panel monitoring system and the CPV Monitor application presented in this work can be accessed. The data displayed by both techniques are identical.

The only difference was the data that were shown on the at the website same time, as illustrated in Figure 15. In the CPV Monitor program, the user may choose which data to be displayed and which should be hidden. Figure 14 show the CPV Monitor display.

The proposed IoT solution took advantage of the majority of the benefits of IoT while also addressing some of the usual drawbacks:

- **Interoperability**: The solution has been shown to work with a variety of industrial protocols and communication systems.
- **Management**: A centralized platform monitors IoT devices and allows for maintenance chores such as reconfiguration and upgrade.
- **Communication**: Communication is now encrypted for security. The monitoring system does not require direct external access to the plant because it is software that pushes the data rather than giving remote access to the plant. The 2 minute period for historical data was simply obtained during processing. However, the task of 52 seconds for real time was only fulfilled correctly for a period of 5 seconds. It should be highlighted that plant’s communication infrastructure is mostly to blame for the delay.
- **Scalability**: Data are consolidated on a single platform and new devices are dynamically aggregated (devices self-register on the platform). As the environment changes, the system can be changed to respond to new conditions.
- **Cost**: The solution has lowered maintenance costs, owing to the Open-Source components employed, but
Figure 13. The entire Schematic of the Smart Remote Monitoring System

- CPV plant 1
- CPV plant 2
- CPV plant 3
- CPV plant 4
- Data Logger with modem
- Remote local 1
- Remote local 2
- Internet
- Remote Web Server with logging system

it has also decreased overall device consumption, due to the reduced number of devices and lower individual use.

Finally, additional test setups were run to confirm and generalize the study's findings. The first test concerned the focal distance of the lens, and we changed the focal length of FL from 175mm to 700m. The second included adjusting the facet spacing from 0.1 to 1mm in 0.1mm increments. The last test focused on wavelength fluctuations ranging from 0.1 to 1.4m. All the simulation findings reveal the same hierarchy in the performance of the SOEs under consideration.

Although having the highest intensity, we discovered that the circular hyperbole has the lowest homogeneity: nevertheless, the square hyperbole has the highest optical efficiency and the best uniformity compared to the other components.

The CPV Plant is managed using a web-based remote monitoring system and IoT in this study. This type of control is utilized for the first time with CPV plants. The effectiveness of the CPV monitoring program was determined by the amount of time necessary to transmission of data from hardware (data collection) to data gateway and, eventually, the application. The smallest and longest transmission times were 30 and 102 seconds, respectively. Finally, we can state that the follow-up program collected all the necessary data from morning to night. In this work, access is granted to the CPV panel monitoring system and the described CPV Monitor application. Therefore, the information displayed by both methods is the same.

The distinction was that the data was shown concurrently on the website, as seen in Figure 15. The CPV Monitor program allows the user to select which data to display and conceal. Figure 16 shows the display of the CPV Monitor. Additional test configurations were conducted to corroborate and generalize the findings of the study. The focal distance of the lens was changed from 175mm to 700mm in the first test. The second step involved increasing the facet spacing from 0.1 to 1 mm in increments of 0.1 mm. The final test concentrated on wavelengths between 0.1 and 1.4m. All of these simulations reveal a similar hierarchy in the performance of the SOEs examined.

We discovered that while the circular hyperbole has the highest intensity, it has the lowest homogeneity; while, the square hyperbole has a high optical efficiency as CPC and the best homogeneity compared to the other components. In the conclusion of this study, the CPV plant is managed using a web-based remote monitoring system and IoT. This type of control is applied for the first time with a CPV plant. The CPV performance monitor software is measured by the time expected to transfer data from the hardware (data collection) to the data gateway and, eventually, the application. The mean transmission time was 52.34 seconds, with 30 and 102 seconds the shortest and greatest transmission times.
Finally, we can say that the follow-up program successfully collecting all the data from morning till evening. Compared to other studies, the paper [52] provides an IoT system for monitoring photovoltaic power plants that are fully based on open-source software. The built IoT solution not only improved the scalability, security, and management capacity of the monitoring system, but also improved the monitoring system of the monitoring period and cost of the monitoring system. The complexity is also decreased because the intermediate devices are no longer required. The paper [53] discusses the implementation of a new cost-effective IoT-based methodology for remotely monitoring and evaluating the operation of a solar PV power plant. This will make preventive maintenance, defect detection, historical installation analysis, and real-time monitoring easier.

On the other side, the solution’s monitoring system has resulted in a number of benefits:

- Improved data refresh time: The data refresh time has been reduced from 10 minutes to 52 seconds. Data can now be handled in real time for analysis and I-V curve anomalies can be recognized.
- Reduced costs: Open-source software eliminates the need for reversal in development. Furthermore, the software does not require the purchase of licenses on a regular basis.

V CONCLUSION

We have studied the development of a 3-D solar concentrator composed of two optical elements: a circular flat Fresnel lens develop from PMMA associated with a hyperbolic concentrator made B270. The performances of these concentrator systems are evaluated and compared according to the acceptance angle obtained, the effective concentration, tolerances in the placement of the SO, and the uniformity of the flux distribution. We found that the optical efficiencies of the circular hyperbola and the
square apertures of hyperbola as a function of the heights, presents high optical efficiency for lengths of 30 to 40mm but from this length the square aperture of hyperbola presents a higher optical efficiency. By comparing these optical elements as secondary optical elements with those studied in the previous work pyramid, CPC, Cone, and CCPC), we found that the pyramid and the square hyperbole remain the best secondary optical elements for a Fresnel lens like a PO. The data completed by our plant will be monitored and controlled by a conceptual approach suggested in this study, which consists of using an IoT-based network to monitor and regulate the state of a solar system. The data from the sensors are sent via a mobile radio network and transfer data to the remote server. Consequently, automation and intellectualization of concentrated photovoltaic plant monitoring will improve the decision making of large-scale solar power plants and grid integration in the future. This study looks at the approach and presents an IoT-based remote monitoring system for solar power facilities.

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