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Independent Power System for Traffic Lights Through Solar Energy in Ecuador-Manabí-Portoviejo

Jiorge Rolando Moreira-Mendoza
Empresa Municipal de alcantarillado y agua potable de Pedro Carbo
Corresponding author email: jrolando160899@gmail.com

María Rodríguez-Gámez
Universidad Técnica de Manabí, Facultad de Ingeniería y Ciencias Aplicada, Carrera de Ingeniería eléctrica, Portoviejo, Ecuador
Email: maria.rodriguez@utm.ed.ec

Andy Ariel Guerrero-Vélez
Independent engineer, Portoviejo, Ecuador
Corresponding author email: andyguerrero399@gmail.com

Jorge Daniel Mercado-Bautista
Universidad Técnica Luis Vargas Torres de Esmeraldas
Email: jorge.mercado@utelvt.edu.ec

Andrés Marcelo Hernández-Bazurto
Independent engineer, Portoviejo, Ecuador
Email: hernandezmarcelo040199@gmail.com

Abstract---*The need for sustainability solutions promotes the use of renewable and distributed energy sources in urban and rural applications, the energy situation in Ecuador promotes the search for alternatives for the energization of traffic lights in urban areas, the objective of the research was to analyze and design an autonomous power system for traffic lights using solar energy. It was used as an investigative, descriptive and analytical methodology. The result was that solar energy can be used to power traffic lights, guaranteeing greater autonomy and reduction in maintenance costs. Furthermore, the implementation of this technology in urban areas could be an efficient and sustainable alternative to conventional systems that depend on the electrical grid.*
Keywords---*autonomous systems, energy efficiency, renewable sources, solar energy, traffic lights.*

Introduction

Ecuador, a country with great potential in natural resources, has begun to prioritize the use of renewable energy, especially in areas such as solar energy, due to its geographical location and the availability of solar radiation throughout the year. The province of Manabí, located on the country's central coast, is an area with high potential for using this energy source due to its warm and sunny climate (Giler-Barcia & Gorozabel-Chata, 2022).

Portoviejo is the capital of the province of Manabí, a city with considerable urban growth in recent years (Reyna Garcia et al., 2017). However, due to the problems that Ecuador has faced in recent times due to energy problems, it is important to implement new energy generation sources, especially in urban areas. Reliance on traditional electrical systems and the vulnerability of the grid to power outages are common problems in many Ecuadorian cities, including Portoviejo and other areas of Manabí. This can generate interruptions in the operation of traffic lights, which negatively impacts traffic and road safety (Rodríguez et al., 2018).

The transition towards the use of renewable energy and sustainability in the field of urban transport is key to the development of more efficient and environmentally friendly cities. Implementing a solar power system for traffic lights in Portoviejo would not only solve traffic interruption problems but would also serve as a demonstration of technological feasibility for other cities in Ecuador, especially those with similar characteristics in terms of climate and energy needs (Burton et al., 2020).

According to solar radiation studies in the region, Manabí has an average annual radiation of approximately 4.88 kWh/m²/day, which makes it an ideal area for the use of photovoltaic solar energy (Gámez et al., 2017). In the case of solar traffic lights, photovoltaic panels replace the conventional electrical grid, autonomously powering the lighting and controller system. These traffic lights work in a similar way to conventional traffic lights, but with the advantage of being self-sufficient (Kabir et al., 2018).

Materials and methods

For the investigation, the problem that the country was currently going through was first analyzed, and how it affected road circulation within the city of Portoviejo. An analysis of a solution was carried out, with which it was intended to improve road circulation, although there are energy outage problems. The investigative, descriptive and analytical method was applied, so the design of an alternative energy generation system through photovoltaic energy is proposed to be used in road control equipment within the city of Portoviejo, taking into account that the proposal provided is supported with all the information that has been obtained through bibliographic review of various sources (Palacios-Intriago et al., 2024).

Analysis and Discussion of the results

System Design Description

The solar power system for traffic lights was carried out considering both the energy requirements of the traffic light and the specific characteristics of solar radiation in the region of Portoviejo, Manabí. Figure 1 shows the process to follow.

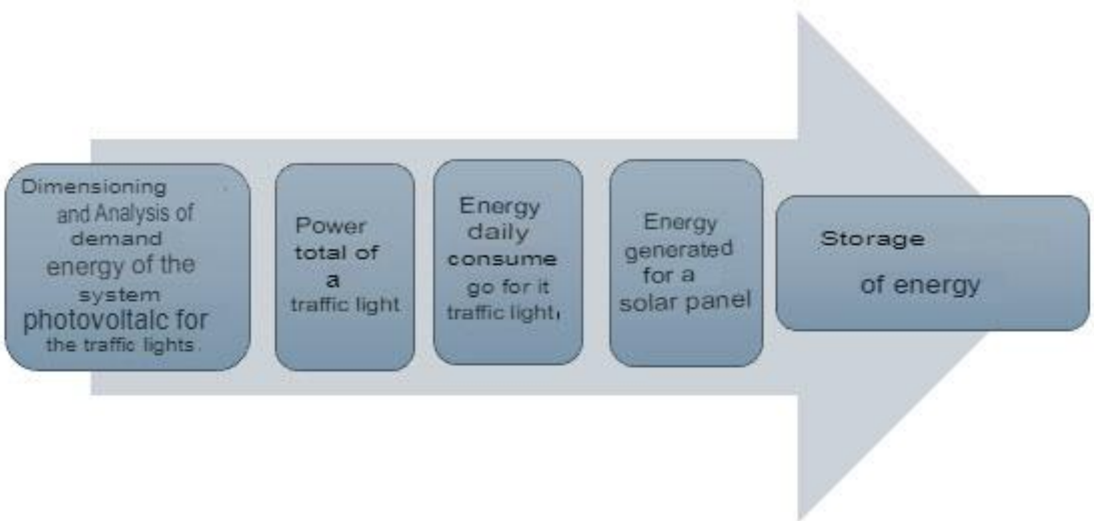

Figure 1. Process to be carried out

Sizing and analysis of energy demand of the photovoltaic system for traffic lights. A modern traffic light that uses LEDs has low energy consumption, for example, a typical traffic light with the following characteristics:

- Red, green and yellow LEDs: 3 lights in total.
- Daily duration of operation: 24 hours a day, 365 days a year.

Total power of a traffic light:
If a traffic light has 3 lights and each light consumes approximately a certain amount of watts, the total power consumed by the traffic light was calculated with equation 1.

$$PTS = CLL \ x \ CL \qquad (1)$$

Where:
PTS→Total Traffic Light Power
CLL→ Led Light Consumption
CL→Number of Lights
Source: (Salamanca Ávila, 2017)

The daily energy consumed by the traffic light, when it operates 24 hours a day, can be calculated with equation 2.

$$ED = PT \ X \ HO \qquad (2)$$

Where:
ED→Daily Energy
PT→ Total Power
TO→ Hours of operation
Source: (Salamanca Ávila, 2017)

Solar energy calculation

It is calculated how many solar panels would be needed to power this traffic light, knowing the average solar radiation in Portoviejo, which is approximately 4.88 kWh/m²/day (Rodriguez et al., 2017), which means that each m2 of solar panel receives that amount of energy daily (Vazquez Pérez, 2022). Figure 2 shows the solar radiation in Portoviejo, Manabí.

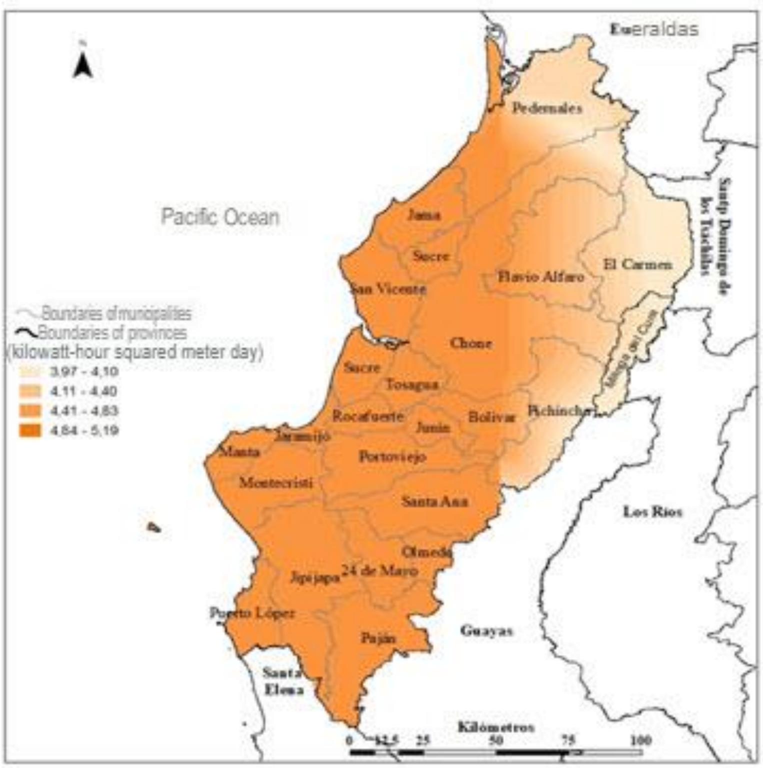

Figure 2. Solar Radiation Ecuador-Manabí-Portoviejo
Source: (Vazquez Pérez, 2022)

As seen on the map, Portoviejo is located in the areas with the greatest coloration, noting that the radiation is between 4.84 and 5.10. kWh/m²/day among the highest in the province.

Energy generated by a solar panel

The daily energy generated by a solar panel in Portoviejo with solar radiation of 4.88 hours per day can be calculated according to Aguilera et al. (2011), using equation 3, (Salamanca Ávila, 2017).

$$EDP = PPS\ X\ HSP \qquad (3)$$

Where:
EDP→ Daily energy per panel
PPS→ Solar panel power
HSP→ Average solar hours
Number of solar panels needed

To cover the kWh/day demanded by the traffic light, it is necessary to calculate how many panels and what power (Wp) are needed (Herrera et al., 2013). Equation 4 shows how to calculate the number of panels.

$$NP = \frac{Edrs}{Edp} \qquad (4)$$

Where:
E.G→ Number of panels
Edrs→ Energy required by the solar traffic light
Egp→ Energy generated by solar panel
Source: (Salamanca Ávila, 2017)

After having the previous results, the accumulation system must be calculated to allow the sustainability of the system and to be able to work without interruptions, even if there is no electrical system service.

Energy storage (batteries)
To ensure that the traffic lights work at night or on cloudy days, an energy storage system is necessary. Its capacity must be sufficient to supply the traffic light throughout the day and at times when there is no power (Panwar et al., 2011). To calculate the capacity of the batteries, the daily energy consumed by the kWh traffic light was clear. It is recommended to have at least 2 days of autonomy in energy storage, in case of unfavorable weather conditions, it could be calculated with equation 5.

$$CB = CDS\ X\ DA \qquad (5)$$

Where:
CB→ Battery capacity
CDS→ Daily consumption of Traffic Lights
DA→ Days of autonomy
Source: (Salamanca Ávila, 2017)
With all the analyses carried out, it was necessary to make a selection of components and materials necessary for the solar traffic light system. High-efficiency photovoltaic panels were selected to maximize solar energy capture. These will be sized according to the solar radiation in the area and the energy consumption of the traffic lights (Abella, 2005). Figure 3 shows some of those types.

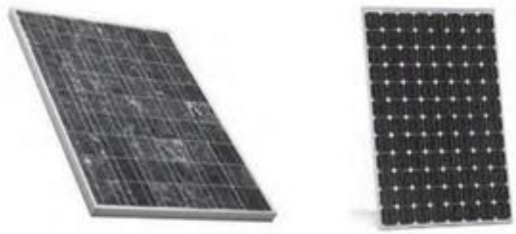

Figure 3. Solar Panels
Source: (Styles, 2012)

Storage batteries will be chosen with sufficient capacity to store energy during the day and guarantee the night operation of the traffic lights. Both lead-acid and lithium batteries will be evaluated based on their cost, durability, and storage capacity (Lamigueiro, 2013), some examples shown in Figure 4.

Figure 4. Batteries for energy storage
Source: (Styles, 2012)

The traffic light system has different elements such as inverters and controllers. In this context, the inverters fulfill the function of transforming the direct current (DC) generated by the solar panels into alternating current (AC) to power the traffic lights. The controllers will manage the charging of the batteries and the distribution of energy (Guasch Murillo, 2003), these are shown in figures 5 and 6.

Figure 5. DC to AC power inverter　　Figure 6. Charge Controller
Source: (Styles, 2012)

Figure 7 shows the 3D design and single-line diagram of the solar system for powering traffic lights.

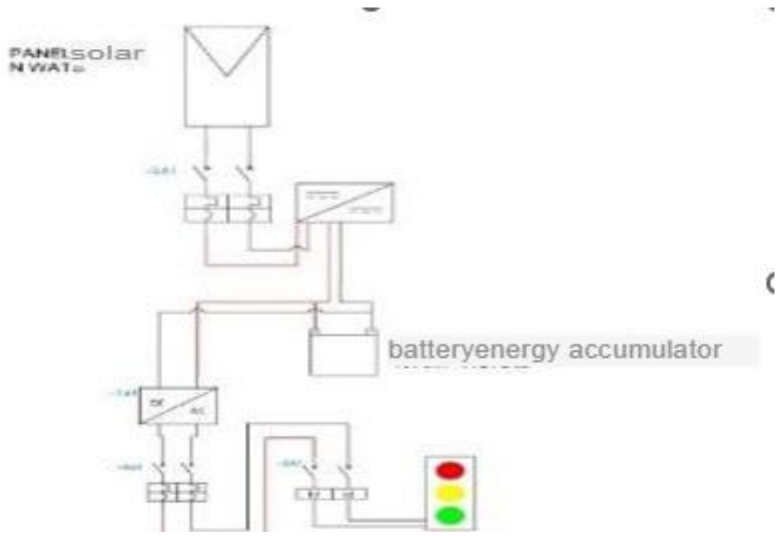

Figure 6. Single-line circuit diagram of the solar system

Figure 7 shows the Board in 3D solar system equipment and in the 8th the 3D design independent power system for traffic lights energized with solar energy in Ecuador-Manabí-Portoviejo.

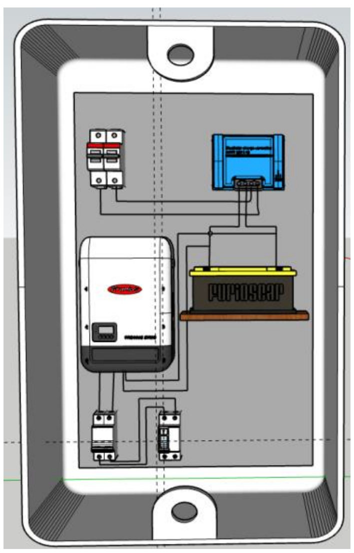

Figure 7. 3D dashboard solar system equipment

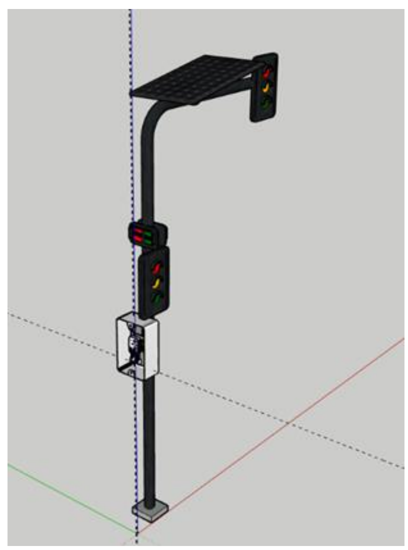

Figure 8. 3D Design Independent Power System for Traffic Lights through Solar Energy

The research was designed based on the emergence of blackouts (Flores Taipe, 2011) in the province that did not allow a correct flow of urban transportation, here the importance of taking advantage of renewable energies and not depending on a single source of energy generation is reiterated, it is based on installing a photovoltaic system to transform solar radiation into electrical energy through equipment already studied such as solar panels, which allow capturing solar radiation and transforming it into electrical energy and storing it in batteries so that it exists. an operating autonomy of several days even in conditions that are not favorable for energy generation, which passes to an inverter to transform from DC to AC and the appropriate voltage to power the equipment and a voltage regulator to prevent the batteries from discharging continuously and not wasting the stored energy (Ortiz, 2013).

Conclusions

The installation of photovoltaic systems to power the traffic lights in the city of Portoviejo is viable due to the solar radiation found in the territory and the storage of energy in the batteries allows the autonomy of their operation even in critical moments for the system. With the implementation of the power system through solar energy, the operation of the traffic lights continues even if there are problems in the conventional electrical network, not structurally affecting the system already installed

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