https://doi.org/10.17163/abyaups.49.380

Proposal of an Insulated System for Recharging Electric Vehicles and Lighting

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This document presents the results of a highly efficient standalone system implementation proposal with multipurpose applications along the road. It involves an isolated photovoltaic system that requires a comprehensive analysis of the energy resource in the study area using the Glover and McCulloch method. The lighting poles are deployed according to specific standards and parameters for each type of road, and it is verified using DiaLux software to ensure proper lighting parameters. A photovoltaic design is performed based on the irradiation data obtained from the energy resource analysis, followed by a load analysis and battery bank behavior.

This study proposes the implementation of an isolated photovoltaic system to address the challenges related to electric vehicle charging, lighting, and telecommunications (Romano, 2015). The lack of electrical supply and absence of lighting in different sectors of the country due to sudden blackouts pose a challenge to user safety (Fonseca, 2011). Additionally, the lack of phone signal in many areas is a problem as it is considered an essential basic service in today's society (Patiño *et al.*, 2018; Escobar *et al.*, 2010).

The proposed system aims to primarily fulfill the need for lighting in various types of roadways. To achieve this, an analysis will be conducted using DiaLux software to ensure appropriate lighting parameters. Furthermore, there is a goal to reduce the carbon dioxide emissions produced by fossil fuel vehicles, which constitute the main source of pollution in the country (Nasser & Chehade, 2016; Parra, 2017).

Electric vehicle charging is a crucial service that will be integrated into the multipurpose system. Since electric vehicles have limited range, the lack of charging stations along the roads hinders their usage for long trips (Ormachea & Serna, 2009). Therefore, one of the key issues to address is the availability of distributed charging points along the roadways, which would enable more reliable use of electric vehicles (Cuji & Mediavilla, 2022). To design an optimal system, it is necessary to conduct an analysis of the energy resource using a method that provides accurate irradiation data. This will ensure that the system meets the diverse demands of the applications required by the users (Friedman, 2017) (Tévar Arcos, 2020).

Finally, a comprehensive analysis of the system's characteristics, including power losses, voltage drops, and energy production, is conducted. The system is conceived as a solution to enhance the safety and reliability of lighting systems on roads, as well as to enhance communications and serve as a future option for electric vehicle charging.

Case Study

The main road connecting the Coast and the Sierra, especially Guayaquil and Riobamba, faces issues of truck robberies and frequent accidents due to nighttime fog. While some communities along the road have electricity, others lack of it, especially in the Navag paramo. Implementing a photovoltaic system along this road would benefit the isolated communities that currently lack access to electrical power, while also enhancing safety and reducing accidents overall Figure 1.

Figure 1
Unlit road section of the E487 highway taken from Google Map

Evaluation of the energy resource using the glover & mcculloch method

Global radiation plays a crucial role in the optimal implementation of photovoltaic solar systems, as it is used in calculations to determine panel generation (Sheu *et al*., 2016). The NASA database is used to obtain this data, which provides information on global radiation in kWh/m^2 over a year, as shown in Table 1. This table displays the global radiation of the various studied locations.

Table 1
Global Radiation of the different study locations

Months	E45 (kWh/m2)	E487 (kWh/m2)	E28 (kWh/m²)
January	4.17	4.33	3.91
February	3.97	4.21	3.87
March	4.17	4.58	4.29
April	4.06	4.40	4.12
May	4.01	4.21	3.87
June	3.98	4.18	3.75
July	3.90	4.29	3.97
August	4.20	4.60	4.01
September	4.41	4.59	3.83
October	4.56	4.55	3.81
November	4.77	4.65	3.7
December	4.41	4.38	3.63

The evaluation of the energy resource is a monthly assessment, using the values shown in the following Table 2 (Shukla *et al.*, 2020). Display the values for the Glover & McCulloch method (Álvarez, 2017; Salamanca, 2017).

Table 2
Global Radiation of the different study locations

Delta	Ws	H RADIAN	Ho	N	n	Global radiation (kWh/m2)	H/Ho	n/N
–22.930	90.811	1.5849	35.386	12.10	4.57674	4.33	0.1223	0.3779876
–17.245	90.595	1.5811	36.479	12.07	5.31333	4.21	0.1154	0.4398658
–7.9149	90.266	1.5754	37.494	12.03	4.08133	4.58	0.12219	0.3391057
4.4139	89.851	1.5682	37.315	11.98	3.77366	4.4	0.11796	0.3149907
15.210	89.478	1.5616	35.746	11.93	4.583	4.21	0.11777	0.3841440
22.174	89.217	1.5571	34.059	11.89	4.641	4.18	0.12272	0.3901410
23.049	89.183	1.5565	33.811	11.89	4.726	4.29	0.12687	0.3974398
17.650	89.389	1.5601	35.214	11.91	6.075	4.6	0.13062	0.5097086
7.3423	89.752	1.5664	37.018	11.96	5.8356	4.59	0.12399	0.4876455
–4.611	90.154	1.5734	37.616	12.02	4.35233	4.55	0.12095	0.3620715
–15.363	90.527	1.5800	36.762	12.07	4.6713	4.65	0.12648	0.3870100
–22.23	90.7	1.5844	35.538	12.14	5.50333	4.38	0.12324	0.4550596

Table 2 presents the fit of the linear regression using the values on the X-axis, representing the Hours of the Sun divided by the Photoperiod, and the values on the Y-axis representing the Global Radiation divided by the Extraterrestrial Radiation (Shukla *et al.*, 2020). The linear regression provides the values of a and b, which are essential for calculating irradiation using the Glover & McCulloch method, as shown in Table 3 (Shukla *et al.*, 2020). These results are significant for evaluating and analyzing the available energy resource.

Methodology

Table 3
Irradiation values by the Glover & McCulloch method

Months	a	b	Glover & McCulloch (KWh/m^2)
January	0.0336	0.109	4.30441489
February	0.0336	0.109	4.51319667
March	0.0336	0.109	4.51176309
April	0.0336	0.109	4.46004918
May	0.0336	0.109	4.3555989
June	0.0336	0.109	4.15691534
July	0.0336	0.109	4.13492711
August	0.0336	0.109	4.43931525
September	0.0336	0.109	4.63933282
October	0.0336	0.109	4.55552896
November	0.0336	0.109	4.48296791
December	0.0336	0.109	4.41490018

Table 3 displays the regression coefficients a and b for each month, obtained from the Glover & McCulloch method, which are used to calculate the irradiation values (Shukla *et al.*, 2020). Based on these values, Figure 2 is generated, comparing the data from the NASA database with the results of the method proposed by Glover & McCulloch (Auquilla & Tapia, 2019).

Figure 2
G & M Model vs NASA Data vs PVSYST Data

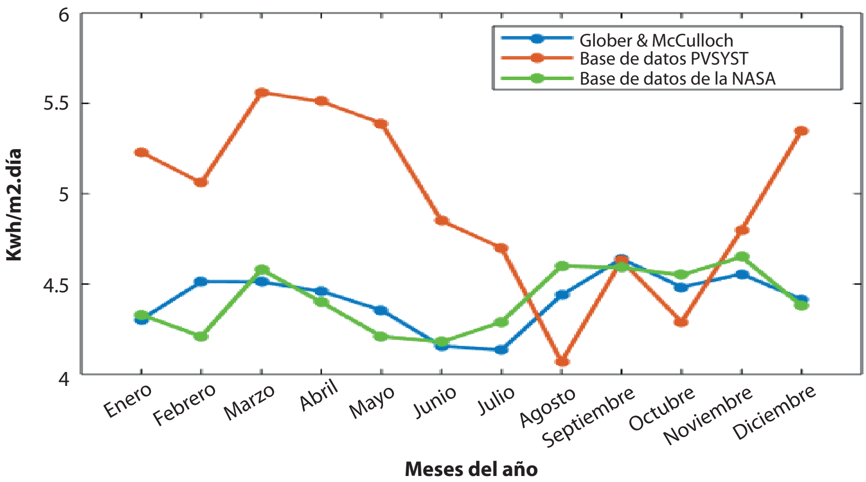


Figure 2 illustrates a comparison between the irradiation recorded in the NASA, PVSYST, and Glover & McCulloch databases (Cóndor & Águila, 2018). It can be observed that the PVSYST database shows favorable irradiation for the specific case study, making it a viable option for the installation of a photovoltaic system (Cuasapaz, 2004). PVSYST is a widely used commercial program, further supporting its suitability in this context (Carbo & Mendoza, 2017; Panimboza & Ormeño, 2020).

Multipurpose system design

The sizing of the system is carried out considering half of the road, as the same system is planned to be replicated on the other half. In terms of solar panel sizing, it is necessary to determine the consumption of each component present in the poles, such as lamps and signal repeaters for telecommunications, as well as the consumption of electric vehicle charging stations (Alvarado & Carvajal, 2014; Flores & García, 2016).

$$Epole = (822 \times 90W \times 12h) + (1 \times 10W \times 24h) = 888\ kWh/day$$

$$StationChargingElectric = (3 \times 7.3\ kW \times 20h) + 7.376kW = 445.376\ Kwh/day$$

$$Total\ Load = \frac{888\ kWh}{dya} + \frac{445.376Kwh}{day} = 1333.376\ Kwh/day$$

The technical specifications of the solar panel necessary to calculate the quantity required in the system, are detailed in Table 4. This table presents the specific technical characteristics of the solar panel intended for electric vehicle charging stations.

Table 4
Technical specifications of the solar panel

400 W Monocrystalline Panel		
Power	405	Wp
Vmax	176.87	V
Vnom	150	V
Imax	2.287	A
Voc	216.8	V
Isc	2.520	A
Efficiency	17.86	%

Note: *Parra, 2017*

Simulation and results of the multipurpose system

Once the calculations are obtained, the simulation is performed using Etap software. First, the batteries, charge controller, and inverter are configured for each pole, as illustrated in Figure 3.

Figure 3
Design of the array for every 10 poles

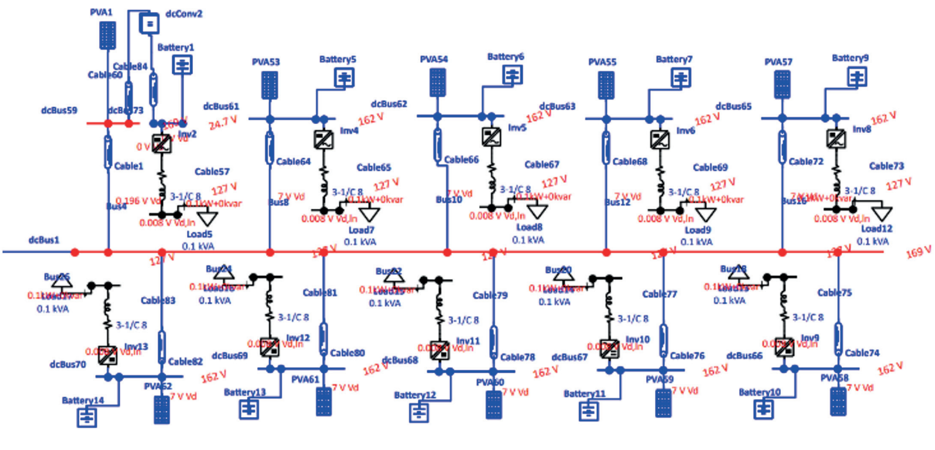


Figure 3 illustrates a set of 10 poles, each equipped with independent systems for communications and lighting. The excess generated energy is directed towards the electric charging stations through a collection bus, represented in Figure 3. It is important to note that due to the distances involved, voltage losses occur. Table

5 provides information on the amount of energy contributed by each pole to the bus, as well as the corresponding voltage losses in the array of the 10 poles.

Table 5
Voltage drops of the array of 10 poles

Distance (m)	Voltaje (V)	Voltage loss (V)	Total voltage (V)
39	160.8	1.93	158.90
78	160.8	3.87	156.96
117	160.8	5.80	155.03
156	160.8	7.74	153.09
195	160.8	9.67	151.16
234	160.8	11.61	149.22
273	160.8	13.54	147.29
312	160.8	15.47	145.36
351	160.8	17.41	143.42
390	160.8	19.34	141.49

The Table 5 presents the voltage loss values in the conductors based on the distances between each pole. These values are expressed in volts, and the nominal voltage of the panel is used as a reference to obtain the total voltage in the conductors. It can be observed that the loss in the last pole is 19.34 V. Based on this, a new configuration in the connections is required. Therefore, the 10 poles are connected in series to increase the voltage, especially due to the greater distances involved. This new configuration allows for a higher voltage that can reach the charging stations.

Results

Figure 4 represents the complete system for half of the E485 road, which is replicated to cover the entire length of the road.

Figure 4
Multi-purpose Photovoltaic System

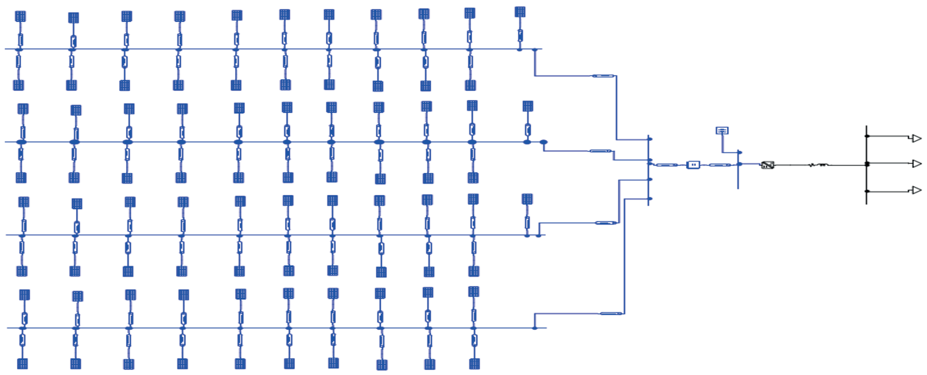
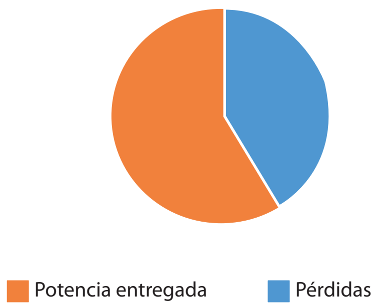


Figure 4 illustrates the complete system, where each panel represents a set of 10 posts. This allows the simulation of a total of 822 posts covering half of the road, each with its respective electric charging station. Table 5 presents the voltage losses in the system due to distances.

Using the values obtained in the simulation, Figure 5 shows the total power losses in the system due to distances.

Figure 5
Power Losses in the System



Technical summary of the multipurpose system

The system extending along the road to supply 2 electric vehicle charging stations will require a panel area of 13,160 m^2, which is approximately one and a half hectares. Table 6 presents the specifications of the isolated photovoltaic system.

Due to power losses in the conductors, it is necessary to add more panels to meet the demand. The existing losses highlight the need to increase the number of panels to meet the power demand without issues. It is important to note that this system is replicated on the other half of the road to have 2 electric vehicle charging stations along the entire road. Each post array includes a DC/DC converter due to the high voltage of the panels, which requires the use of converters.

Table 6
Characteristics of the standalone photovoltaic system

Description	Value	Units
Nominal Power	666225	W
Installed power	158295.875	W
Panel area	13160	m2
Daily energy production	1608822.96	Wh
Annual energy production	587220380	Wh
Installed modules	1645	u

Conclusions

- When implementing a photovoltaic system along a road, the available space is efficiently utilized, as these systems do not require additional land areas. In the case study, the system occupied an area of 13,160 m^2, allowing for optimal use of space.
- The installed power of the system is considerably lower than the nominal power, approximately 4.2 times lower. This is due to losses caused by distances and the irradiation of the area, even considering that the temperature does not exceed 25 °C.
- The average irradiation in the study area is 4.5 kWh, which is low compared to the irradiation used by commercial programs such as PVSYST, which tend to consider more favorable conditions. However, when compared to methods like Glover & McCulloch, a significant difference in the area's irradiation is evident. Therefore, for a photovoltaic design, it is recommended to use the scenario with lower irradiation.
- Out of the energy generated by the panels in their primary bus, a loss of 42 % was recorded, meaning that only 58% of the energy reaches the use in the charging stations. Although the demand is met, the losses are too high, despite the adjustments made to increase the voltage and reduce losses.
- Photovoltaic solar concentrators have higher efficiency compared to conventional panels. While conventional panels have an average

efficiency of 17 %, photovoltaic solar concentrators achieve an efficiency of 170 %, approximately 10 times higher than conventional panels. This helps overcome the low efficiency of conventional panels.

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