Engineering and Technology Journal e-ISSN: 2456-3358
Volume 11 Issue 09 September -2026, Page No.- 11451-11463
DOI: 10.47191/etj/v11i09.08, I.F. – 8.595

Design and Construction of a Solar-Powered Street Lighting Prototype for the University of Garoua- Cameroon Campus

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ABSTRACT
Introduction: Lighting is an essential basic need because it ensures the safety, comfort and well-being of citizens. Several means of lighting have been developed by man, the most recent of which are autonomous photovoltaic lighting systems. It is becoming possible to design lighting systems that can operate without a power grid. The objective of this work is to design and construct a solar system adapted for a public lighting need of the University of Garoua's campus.
Method: After evaluating the weather conditions of the installation site using the PVGis software and the daily energy requirement, the components were dimensioned using calculation methods based on the least sunny month.
Results: The prototype consists of a 170 Wp monocrystalline photovoltaic panel that will be tilted at an angle of 15° during installation, a 20A PWM controller, a 100 Ah GEL battery, a 50W LED floodlight, a 32 A DC circuit breaker, a 10 A LDR-DC switch, a 20 KA DC Surge Arrester, and a 6m stainless steel pole. Charging cables have a cross-section of 4 mm^2 while discharge cables have a cross-section of 1.5 mm^2. The total cost of the scheme is 365,000 (three hundred and sixty-five thousand) CFA francs.
Conclusion: An efficient and reliable and economically solar streetlight is designed and implemented in the University of Garoua campus. Further work will be conduct to evaluate the performance of the prototype.

KEYWORDS: Design**,** Solar Energy, Public Lighting, solar streetlight, University of Garoua.

List of abbreviations

AC	Alternating current
C	Battery Capacity (Ah)
C_i	Unit cost of element i (FCFA)
C_T	Total Cost of the System (FCFA)
DC	Direct Current
DoD	Battery Discharge Depth (%)
Gh	Horizontal overall sunshine (KWh/m^2)
K_i	Short-circuit current temperature correction coefficient (-)
K_u	Temperature correction coefficient of the open circuit voltage.
I	Current flowing through the cable (A)
I_r	Daily solar irradiation (KWh/m^2/d)
$I_{cs,max}$	Maximum Output Current of the Photovoltaic Field (A)
I_{max}	Maximum Allowable Current by Regulator (A)
L	Total length (round trip) of the cable (m)
LDR	Light Dependent Resistor
LED	Light Emitting Diode
m_i	Number of element i
N	Number of days of autonomy (j)
N_m	Number of days in the month
N_P	Number of panels in parallel (-)
N_S	Number of Panels in Series (-)
PC	Peak Power (Wc)
P_i	Irradiation in STC (1000W/m^2)
PWM	Pulse Width Modulation

P_N	Nominal power of the lamp
PR	Performance Ratio (-)
P_{reg}	Regulator Power (W)
S	Cable cross-section (mm²).
STC	Standard Test Conditions
h	Equipment Run Time (Hours)
E_s	Solar energy available (KWh/m^2.d)
E_c	Daily consumption (Wh)
E_B	Daily energy requirement (Wh)
V_A	Reference voltage at the origin of the cable (V)
V_S	System Voltage (V)
$U_{oc,max}$	No-load voltage of the photovoltaic system (V)
ρ_1	Resistivity of the cable (Ω.mm²/m)

I- INTRODUCTION

Lighting is a fundamental element for human activity. The lighting of public places, traffic routes, monuments and sites in cities and countryside has now become a major concern for electrical energy distributors and administrative and political authorities [1]. The means used have evolved over time. From the oil lamp used in the 18th century to the new LED lamps, the devices used in lighting have seen a notable increase [1]. With the help of the global energy crisis, the use of autonomous lighting systems by exploiting photovoltaic solar energy is emerging as an essential solution [2] due to its sustainability and its adaptation to the context of developing countries such as Cameroon. In Cameroon, challenges related to the availability and reliability of electric supply make the search of decentralized energy solutions based on renewable resources particularly relevant. This need is further intensified by the frequent power outages which have become a structural constraint that significantly affects daily life and economic activities. Autonomous lighting systems, which combines a photovoltaic panel, a storage battery and an LED light source, makes it possible to produce and consume clean energy locally without depending on the conventional electricity grid. The city of Garoua, located in the north region of the country, benefits from permanent sunshine throughout the year. [3], [4] and [5] reported average solar radiation levels of approximately 5.8 kWh/m^2/day and thus offers a sustainable potential for the deployment of solar streetlights. By its position on the outskirts of the host city, the University of Garoua offers a favourable setting for the deployment of solar streetlights that contribute to the energy transition. Several solar streetlight installation projects have been implemented in different localities of the region with requirements concerning waterproofing, panel orientation and maintenance. Most of those streetlights have low performance and a short lifetime due to likewise, dust deposition, humidity, heavy rainfall and mechanical stresses. To maximize its efficiency, the design of a photovoltaic system should be adapted to specific climatic conditions of the installation site [6] as recommended by international guidelines. Thus, how can an autonomous, efficient, reliable and economically affordable solar streetlight be designed and implemented specifically for the climatic and solar conditions of the University Garoua’s campus? To address this question, the main objective of this study is to design and construct an autonomous streetlight adapted to the climatic conditions of Garoua’s University Campus. Specifically, the study aims to characterize the solar and climatic conditions of the study area, assess the energy requirements for public lighting, size the main components of the system and implement the prototype.

MATERIAL AND METHOD

II-1 Material

II-1-1 Presentation of the project site (Djoumassi-Garoua)

Djoumassi-Garoua, is located in the North Region of Cameroon, within the Bénoué Division. Its geographical coordinates are approximately 9.40°N latitude and 13.38° E longitude, at an elevation of about 240m above sea level. Figure 1 gives the map of the North region.

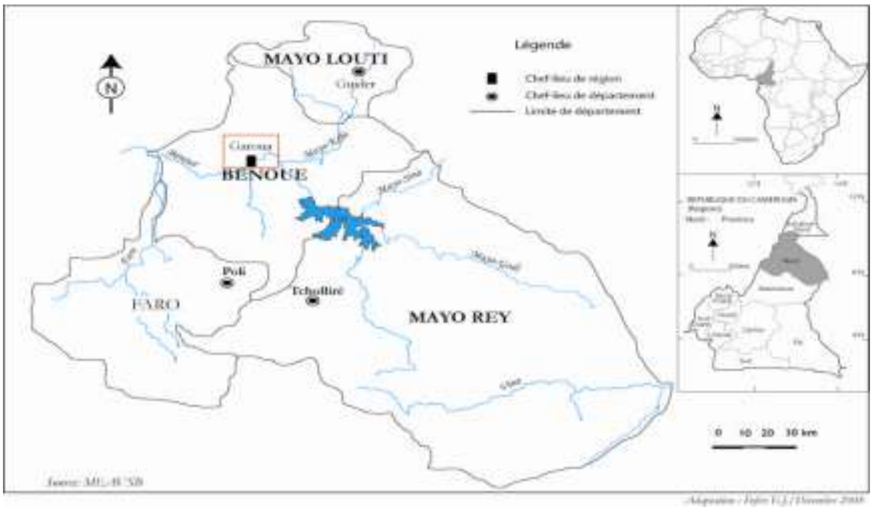

Figure 1: Presentation of the North Region

Djoumassi-Garoua belongs to the northern sudanian ecological zone of Cameroon with a landscape characterized by Savana vegetation and relatively flat terrain.

The climate is the same as that of Garoua, headquarter of the north Region. According to the Köppen classification, Garoua has a tropical Savana climate (Aw), characterized by a distinct rainy season and pronounced dry season.

The average daily irradiation is around 5.7 Kwh/m^2/day as it can be seen in figure 2; a maximum of sunshine in April (6.20 Kwh/m^2/day) and a minimum of sunshine in August (4.75 Kwh/m^2/day). The month of August is the coldest with an average temperature of 25.52 °C while March is the warmest, with an average temperature of 32.90°C. The monthly average temperature is about 32.90°C. The average annual relative humidity is 52.33%. The winds are light to moderate, their speeds vary from 1.81 m/s (September) to 4.24 m/s (February).

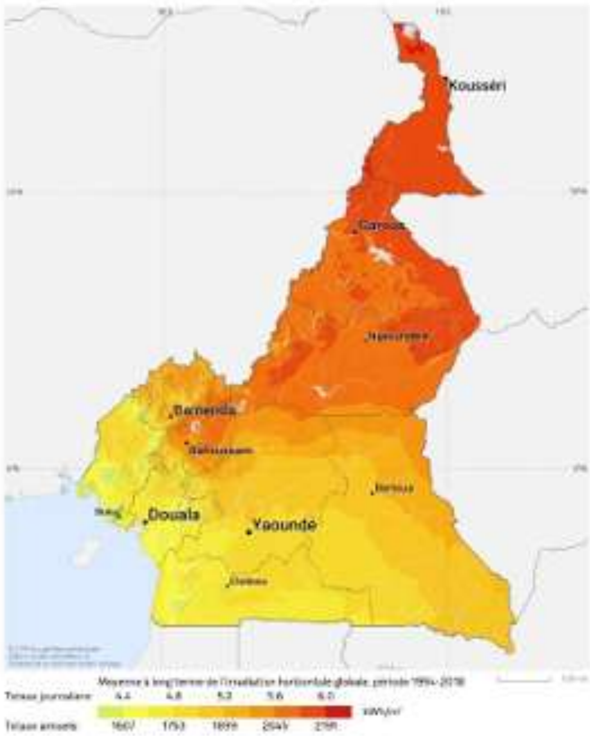

Figure 2: Solar irradiation Map of Cameroon [7]

II-1-2 Presentation of the University of Garoua:

Created by Decree No. 2022/003 of January 05, 2022, the University of Garoua is located in Djoumassi, about ten kilometers from the headquarter of the North Region, in the district of Garoua I, Bénoué division. The university site covers a vast area of about 185 hectares. Figure 3 presents the location of the University of Garoua.

Figure 3: Location of the University of Garoua.

The campus combines teaching and research facilities (four faculties and four schools) with administrative, social and sports infrastructures. To ensure safety on campus, streetlights FL-P2 (ALL IN ONE) are installed at the entrance of the existing buildings, with the rest of the space in darkness once night falls. Figure 4 provides an overview of the campus.

Figure 4: Eastern façade of the Garoua's University Campus

II-1-3 Equipment used

The solar system will consist of a photovoltaic solar panel to transform solar energy into electricity, a battery to store the energy produced, a regulator to manage the battery charge, a LED lamp to illuminate, an LDR DC to turn automatically the lamp on and off, a metal pole to serve as a support for the panel, the lamp and the battery, a combiner box to fix the battery, the regulator and the circuit breaker, a surge protector and earth stake to protect the system and also wires, wire connectors, connector strips to connect the different parts of the system.Those devices are presented in figure 5.

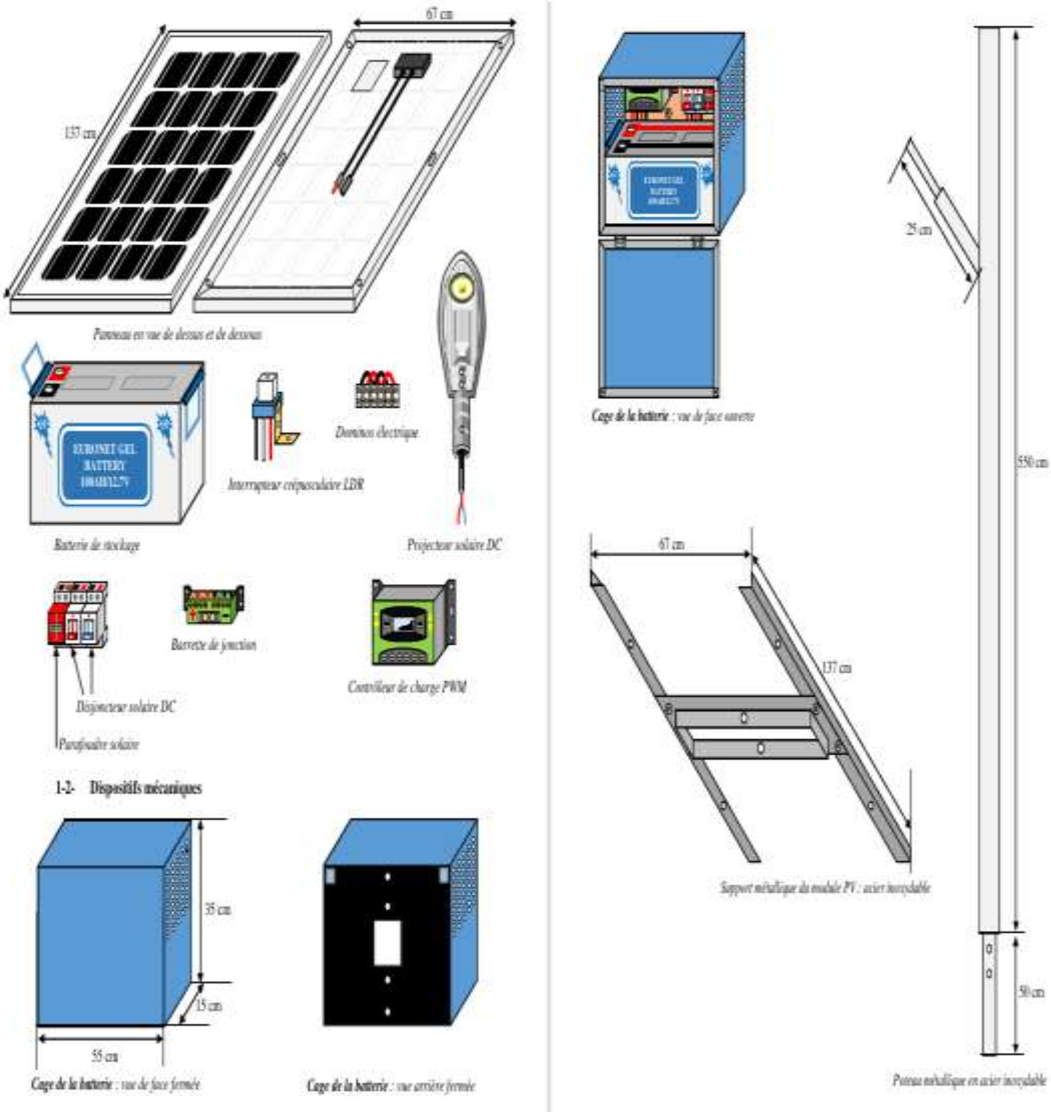

Figure 5: Mean devices used for autonomous streetlight

II-2 Method

The dimensioning of different components will consist of determining the peak power of the photovoltaic array, the capacity of the storage battery, the characteristics of the regulator, and the cross-section of the cables. In the absence of sufficient data on solar deposits over a long period, the intuitive method that takes into account the random nature of the solar radiation was used. It is based on the following steps [8]:

- Estimation of consumption;
- Estimation of the solar energy received;
- Sizing of the photovoltaic array;
- Sizing of the storage battery;
- Charge/discharge controller sizing;
- Cable sizing;
- System cost estimate.

II-2-1 Estimation of the solar energy available at the site

The solar energy available for the months of the year at the site is shown in figure 6 below.

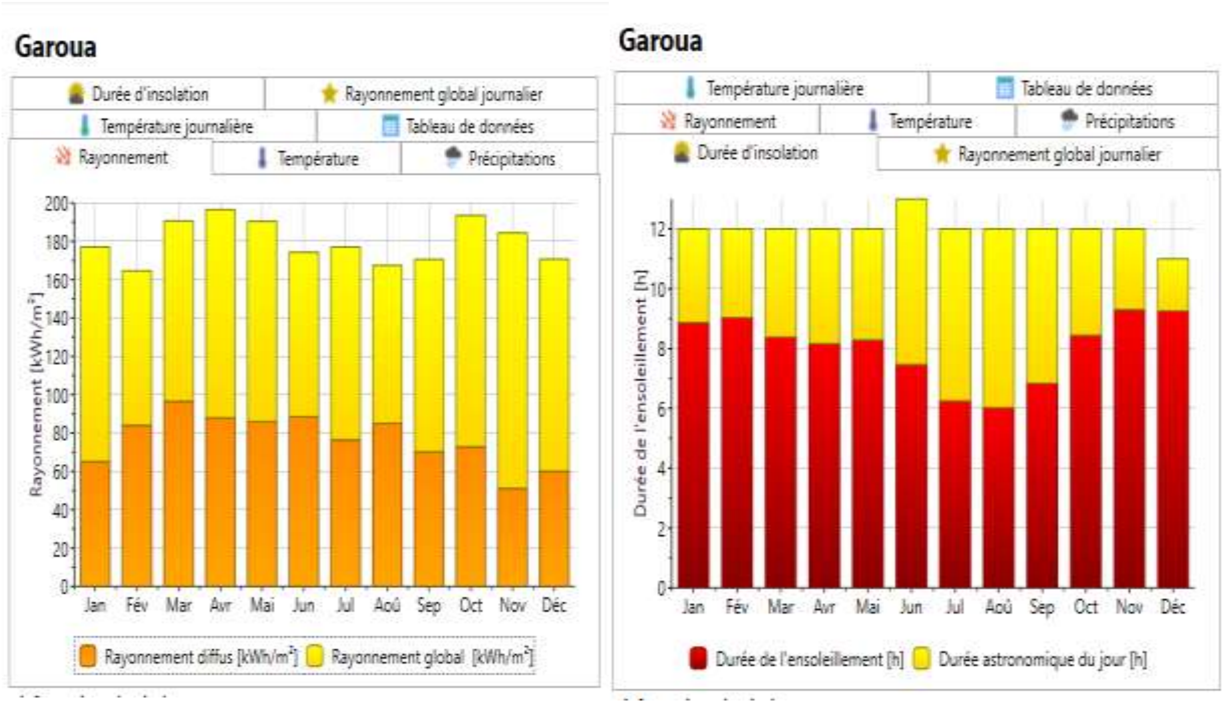

Figure 6: Horizontal global radiation and duration of sunshine in Garoua

The analysis of this figure shows that the least sunny month is February with a value of 165 KWh/m^2. It also gives the number of hours of sunshine. From this month onwards, the daily solar energy received is estimated by equation (1) and the duration of sunshine is 9 hours.

$$E_s = \frac{Gh}{N_m} = \frac{165}{28} = 5,89\ KWh.m^{-2}.d^{-1} \qquad (1)$$

II-2-2 Estimation of daily energy requirement

The streetlight will operate from 6 p.m. to 6 a.m., i.e., a duration of 12 hours per day. The daily energy consumption (Ec), expressed in Watt-hours per day (Wh/d), is given by the following equation (2):

$$E_C = P_N \times h \qquad (2)$$

Taking into account the estimated system losses of 25%, the daily energy requirement is calculated by equation (3):

$$E_B = (1 + 0,25) \times E_C \qquad (3)$$

II-2-3 Sizing of the photovoltaic array

The power of the photovoltaic array to satisfy the need is determined using equation (4):

$$P_c = \frac{E_B \times P_i}{PR \times I_r} \qquad (4)$$

II-2-4 Battery sizing

The capacity of the battery bank, expressed in Ampere-hours (Ah), is given by equation (5):

$$C = \frac{E_B \times N}{DoD \times V_S} \qquad (5)$$

II-2-5 Load Regulator Sizing

The regulator is sizing according to the following four criteria:

- The rated power of the regulator (P_{reg}) must be compatible with the maximum power of the PV panel (P_C) and check equation (6).

$$0,8P_C \leq P_{reg} \leq 1,2P_C \qquad (6)$$

- The maximum allowable current by the regulator (I_{max}) must be greater than the maximum output current of the PV field ($I_{cs,max}$) as indicated by equations (7) and (8).

$$I_{max} > I_{cs,max} \qquad (7)$$

$$I_{cs,max} = I_{cs,STC} \times K_i \times N_p \qquad (8)$$

- The regulator voltage must be compatible with the battery bank voltage;
- The maximum allowable voltage by the regulator (U_{max}) must be higher than the no-load voltage of the PV panel ($U_{oc,max}$) so verifies equations (9) and (10).

$$U_{max} > U_{oc,max} \qquad (9)$$

$$U_{oc,max} = U_{oc,STC} \times K_u \times N_s \qquad (10)$$

II-2-6 Cables sizing

The cross-section of the cable is chosen according to the amperage and distance as shown in table 1 below.

Table 1: Sizing of 12V DC cables

Longueur A+R / Section de cable	2 m	4 m	6 m	8 m	10 m	12 m	14 m	16 m	18 m	20 m
0,75 mm²	6,4	3,2	2,1	1,6	1,3	1,1	0,9	0,8	0,7	0,6
1 mm²	8,6	4,3	2,9	2,1	1,7	1,4	1,2	1,1	1,0	0,9
1,5 mm²	12,9	6,4	4,3	3,2	2,6	2,1	1,8	1,6	1,4	1,3
2,5 mm²	21,4	10,7	7,1	5,4	4,3	3,6	3,1	2,7	2,4	2,1
4 mm²	34,3	17,1	11,4	8,6	6,9	5,7	4,9	4,3	3,8	3,4
6 mm²	51,4	25,7	17,1	12,9	10,3	8,6	7,3	6,4	5,7	5,1
10 mm²	85,7	42,9	28,6	21,4	17,1	14,3	12,2	10,7	9,5	8,6
16 mm²	137,1	68,6	45,7	34,3	27,4	22,9	19,6	17,1	15,2	13,7
25 mm²	214,3	107,1	71,4	53,6	42,9	35,7	30,6	26,8	23,8	21,4
35 mm²	300,0	150,0	100,0	75,0	60,0	50,0	42,9	37,5	33,3	30,0
50 mm²	428,6	214,3	142,9	107,1	85,7	71,4	61,2	53,6	47,6	42,9

Calcul de section : $\frac{\rho \times L \times I}{U'}$ ρ = Résistivité cuivre : 0.021 L = Longueur câble Aller + Retour I = Intensité en Ampères U' = Chute de tension relative en Volts à 3%

II-2.7 Voltage drop estimation

The voltage drop (ε) in a cable is given by equation (11). The maximum allowable voltage drop between the PV panel and the battery is 5%.

$$\varepsilon(\%) = \frac{\rho_1 \times L \times I}{S \times V_A} \qquad \textbf{(11)}$$

II-2.8 Pole selection

The choice of the pole is focused on aspects related to mechanical resistivity, reliability, aesthetics and cost.

II-2.9 Estimation of the Construction Cost

The evaluation takes into account the components required, the labour as well as the indirect costs associated with the installation. The total cost is estimated by the following equation (12). The equipment and materials used for the construction of the streetlight were purchased from the local market in Garoua.

$$C_T = \sum m_i \times C_i \qquad (12$$

II-2.10 Installation of the streetlight

The installation process will be carried out in three stages: 1- concrete casting for the foundation base, 2- solar streetlight assembly and electrical connection, 3- pole erection and anchoring. The second and the third stages are performed at least 48 hours after the first stage to ensure adequate concrete curing and sufficient mechanical strength.

III. RESULTS AND DISCUSSION

For the purposes of this study, two types of streetlights were considered: a single-arm streetlight and a double-arm streetlight**.** The design factors are summarized in table 2**.**

Table 2: Design factors of the streetlight

V_S	DoD	I_r	PR	N	E_B
12V	0,6	5,7 KWh/m².day	0,75	1	1,25 Ec

III-1 Case of a single-arm streetlight

III-1.1 Characteristics and quantities of the different components

The characteristics and quantities of the components used are tabulated in table 3 below. The streetlight consists of several main components selected according to the energy requirements of the lighting unit. The single-arm streetlight includes one 170Wp/18V monocrystalline photovoltaic panel, one 100 Ah-12V battery, one PWM/20A-12V/24V Charge controller and one 50W LED Lamp.

Table 3: Characteristics and quantities of the devices used to construct the single-arm streetlight

No.	Designations	Features	Brand	Qty
1	Projector	IP66/DC50W-12V	WBGT	01
2	Solar Battery	GEL/100Ah-12V	Euronet	01
3	Modules PV	Mono/170Wp/18V	Euronet	01
4	Charge controller	PWM/20A-12V/24V	Euronet	01
5	Solar circuit breaker	DC-32A	DELIXI	01
6	Solar surge arrester	DC-20 KA	DELIXI	01
7	LDR Switch	DC/10A-12V	WBGT	01
8	Ground Stake	Pure copper 120 cm	WBGT	01
9	Discharge cable	Flexible / 2 x 1.5 mm²	WBGT	10
10	Charging cable	Soft / 2 x 4 mm²	WYAN	05

11	Protective cable	Flexible / 1x16 mm^2	WYAN	10
12	Battery lugs	Pure Copper / 60 A	WBGT	08
13	Galva Round Tube	(D=7 cm) / 6m	WBGT	01
14	Galva Round Tube	(D=6 cm) / 6m	WBGT	0.5
15	Perforated angle	(30 mm) / 2m	WBGT	02
16	Metal Foil	1/8th (1x2) m^2	WBGT	0.5

III-1.2 Wiring and assembly plan of the single-arm streetlight

The connection of the component in this single-arm prototype requires the following: 10 m of 1.5 mm^2 cable, 5 m of 4 mm^2 cable and 8 m of 16 mm^2 cable. The wiring plan and concise overview are given respectively in figures 7 and 8.

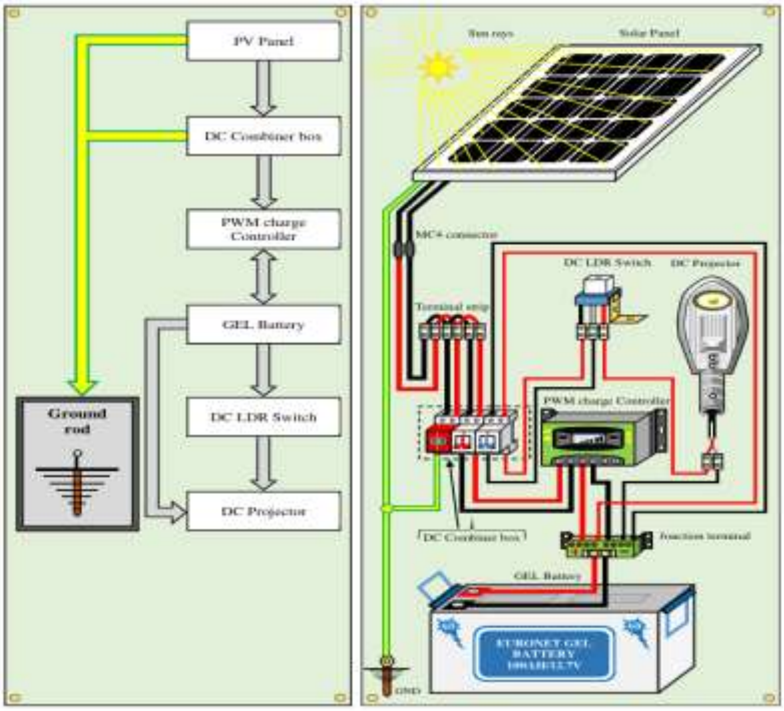

Figure 7: Wiring plan of the single-arm streetlight

Figure 8: Concise overview of the single-arm streetlight

III-1.3 Total implementation cost of the single-arm streetlight

Table 4 presents the detailed breakdown of the implementation cost of a single-arm streetlight including the costs of the main components, materials and installation. The total implementation cost amounted to 410,000 (Four hundred and ten thousand) CFA francs (XAF).

Table 4: Total cost of a single-arm streetlight

No.	Designations	Features	Brand	Unit P. TAX-INC	Qty	Total P.
1	Projector	IP66/DC50W-12V	WBGT	30000	01	30.000
2	Solar Battery	GEL/100Ah-12V	Euronet	90000	01	90.000
3	Modules PV	Mono/170Wp/18V	Euronet	30000	01	30.000
4	Charge controller	PWM/20A-12V/24V	Euronet	15000	01	15.000
5	Solar circuit breaker	DC-32A	DELIXI	10000	01	10.000
6	Solar surge arrester	DC-20 KA	DELIXI	15000	01	15.000
7	LDR Switch	DC/10A-12V	WBGT	5000	01	5.000
8	Ground Stake	Pure copper 120 cm	WBGT	15000	01	15.000
9	Discharge cable	Flexible / 2 x 1.5 mm^2	WBGT	800	10	8.000
10	Charging cable	Soft / 2 x 4 mm^2	WYAN	1000	05	5.000
11	Protective cable	Flexible / 1x16 mm^2	WYAN	1500	10	15.000
12	Battery lugs	Pure Copper / 60 A	WBGT	250	08	2.000
13	Galva Round Tube	(D=7 cm) / 6m	WBGT	55000	01	55.000
14	Galva Round Tube	(D=6 cm) / 6m	WBGT	40000	0.5	20.000
15	Perforated angle	(30 mm) / 2m	WBGT	7500	02	15.000
16	Metal Foil	1/8th (1x2) m^2	WBGT	10000	0.5	5.000
17	Welding Cost	/	/	35000	/	35.000
18	Cost of Cement	/	/	7500	/	7.500
19	Handling Cost	/	/	25000	/	25.000
20	Cost of salt and coal	/	/	2500	/	2.500
21	Sand and gravel	/	/	10000	/	10.000
22	Installation cost	/	/	15000	/	15.000
Total		**Four hundred and ten thousand FCFA**				**410,000F**

III-2 Case of a Double-arm streetlight

III-2.1 Characteristics and quantities of the different components

The characteristics and quantities of the components used are tabulated in table 5 below. The streetlight consists of several main components selected according to the energy requirements of the lighting unit. The double-arm streetlight includes one 200Wp/18V monocrystalline photovoltaic panel, one 120 Ah-12V battery, one PWM/20A-12V/24V Charge controller and two 50W LED Lamp connected in parallel.

Table 5: Characteristics and quantities of the devices used to construct the double-arm streetlight

No.	Designations	Features	Brand	Qty
1	Projector	IP66/DC50W-12V	WBGT	02
2	Solar Battery	GEL/120Ah-12V	Euronet	01
3	Modules PV	Mono/200Wp/18V	Euronet	01
4	Charge controller	PWM/20A-12V/24V	Euronet	01
5	Solar circuit breaker	DC-32A	DELIXI	01
6	Solar surge arrester	DC-20 KA	DELIXI	01
7	LDR Switch	DC/10A-12V	WBGT	01
8	Ground Stake	Pure copper 120 cm	WBGT	01
9	Discharge cable	Flexible / 2 x 1.5 mm^2	WBGT	10
10	Charging cable	Soft / 2 x 4 mm^2	WYAN	05

11	Protective cable	Flexible / 1x16 mm^2	WYAN	10
12	Battery lugs	Pure Copper / 60 A	WBGT	08
13	Galva Round Tube	(D=7 cm) / 6m	WBGT	01
14	Galva Round Tube	(D=6 cm) / 6m	WBGT	0.5
15	Perforated angle	(30 mm) / 2 m	WBGT	02
16	Metal Foil	1/8th (1x2) m^2	WBGT	0.5

III-2.2 Wiring and assembly plan of the double -arm streetlight

The connection of the component in this double-arm prototype requires the following: 10 m of 1.5 mm^2 cable, 5 m of 4 mm^2 cable and 10 m of 16 mm^2 cable. Figures 9 and 10 present respectively, the wiring plan and the concise overview of the double-arm streetlight.

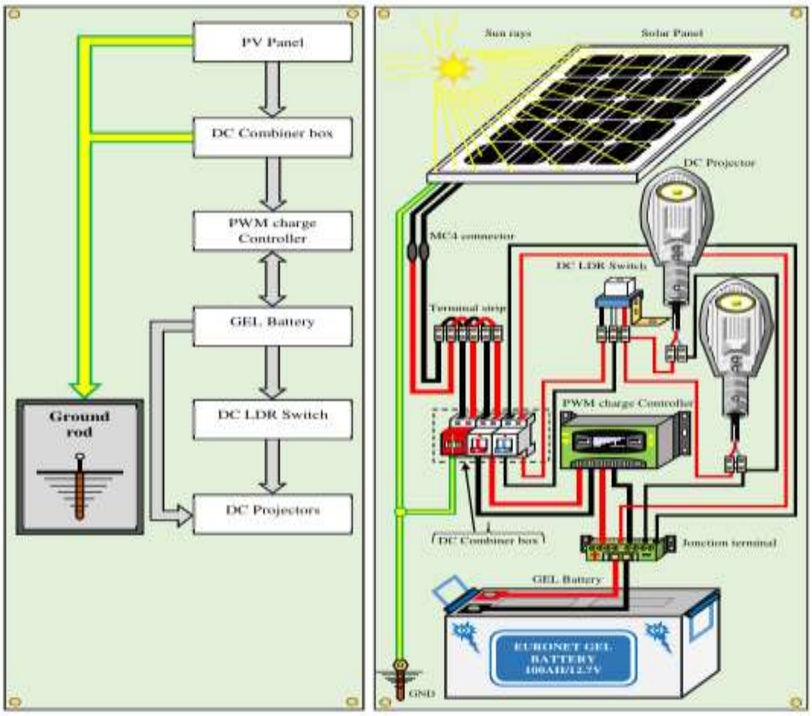

Figure 9: Wiring plan of the double-arm streetlight

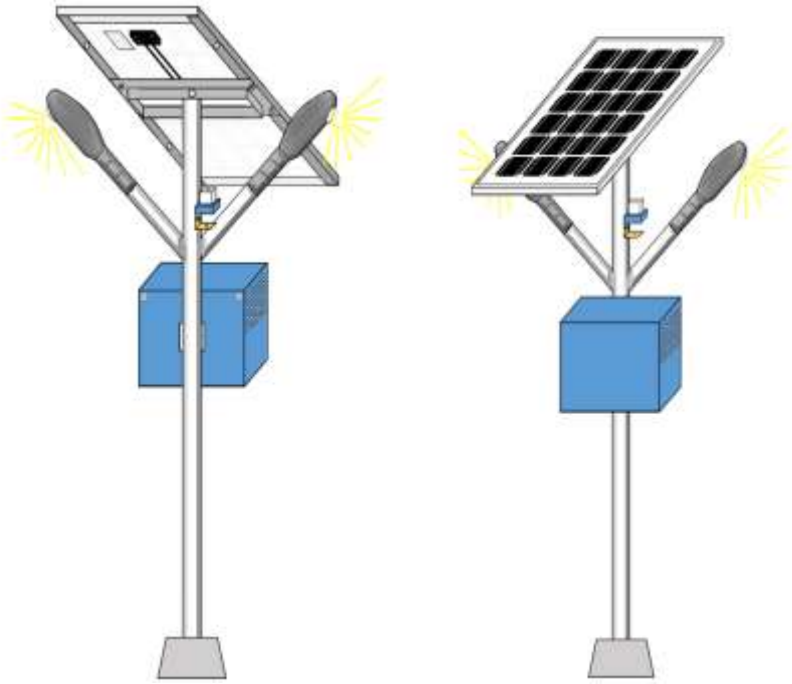

Figure 10: Concise overview of the double-arm streetlight

III-2.3 Total implementation cost of the double-arm streetlight

Table 6 presents the detailed breakdown of the implementation cost of a double-arm streetlight including the costs of the main components, materials and installation. The total implementation cost amounted to 490,000 (Four hundred and ninety thousand) CFA francs (XAF).

Table 6: Total cost of a double-arm streetlight

No.	Designations	Features	Brand	P. Unit TAX-INC	Qty	P. Total
1	Projector	IP66/DC50W-12V	WBGT	30000	02	60.000
2	Solar Battery	GEL/120Ah-12V	Euronet	125000	01	125.000
3	Modules PV	Mono/200Wp/18V	Euronet	45000	01	45.000
4	Charge controller	PWM/20A-12V/24V	Euronet	15000	01	15.000
5	Solar circuit breaker	DC-32A	DELIXI	10000	01	10.000
6	Solar surge arrester	DC-20 KA	DELIXI	15000	01	15.000
7	LDR Switch	DC/10A-12V	WBGT	5000	01	5.000
8	Ground Stake	Pure copper 120 cm	WBGT	15000	01	15.000
9	Discharge cable	Flexible / 2 x 1.5 mm^2	WBGT	800	10	8.000
10	Charging cable	Soft / 2 x 4 mm^2	WYAN	1000	05	5.000
11	Protective cable	Flexible / 1x16 mm^2	WYAN	1500	10	15.000
12	Battery lugs	Pure Copper / 60 A	WBGT	250	08	2.000
13	Galva Round Tube	(D=7 cm) / 6m	WBGT	55000	01	55.000
14	Galva Round Tube	(D=6 cm) / 6m	WBGT	40000	0.5	20.000
15	Perforated angle	(30 mm) / 2 m	WBGT	7500	02	15.000
16	Metal Foil	1/8th (1x2) m^2	WBGT	10000	0.5	5.000
17	Welding Cost	/	/	35000	/	35.000
18	Cost of Cement	/	/	7500	/	7.500
19	Handling Cost	/	/	5000	/	5.000
20	Cost of salt and coal	/	/	2500	/	2.500
21	Sand and gravel	/	/	10000	/	10.000
22	Installation cost	/	/	15000	/	15.000
Total		**Four hundred and ninety thousand FCFA**				**490,000F**

III-4 Installation of the streetlight

A single-arm solar streetlight was constructed and installed at the University of Garoua’s campus and is in perfect operation as the images in figure 7 below shows. The installation involved mounting the photovoltaic panel, fixing the lighting unit, positioning the battery and charge controller, and connecting the different components according to the design configuration. The LED luminaire was mounted on the lighting pole, while the battery and the charge controller were properly positioned in the combiner box and connected to the photovoltaic panel and lighting system. Particular attention was paid to the orientation and inclination of the photovoltaic panel in order to maximize solar energy capture. For the considered site, the optimum tilt angle is 15° and due south orientation.

Figure 11: Some pictures of the installation stage.

IV. CONCLUSION AND OUTLOOK

The main objective of this study was to design an autonomous solar streetlight, intended for the University site in Djoumassi in the city of Garoua. After analysing the energy needs and climatic conditions of the area, the sizing of the system for 12 hours of lighting per night with a 24-hour battery life led to the following choices:

(1) for a single-arm streetlight, a Solar panel 170 Wp-18V, a GEL Battery of 100 Ah-12V, a PWM Regulator 20 A, a DC LED Lamp of 50 W and a pole made up with galvanized steel of 6 m for a total cost of implementation amounted to 410,000 CFA francs (XAF).

(2) for a double-arm streetlight, a Solar panel 200 Wp-18V, a GEL Battery of 120 Ah-12V, a PWM Regulator of 20 A, two DC LED Lamp of 50 W connected in series and a pole made up with galvanized steel of 6 m for a total cost of implementation amounted to 490,000 CFA francs (XAF).

A single-arm streetlight prototype was implemented at the University of Garoua’s Campus and further work must be carried out to evaluate the performance of the device under local operating conditions.

This work provides an opportunity to apply knowledge related to solar photovoltaic energy, energy storage, power electronics, control system and LED lighting from scientific and educational perspective. From a technological perspective, it contributes to the development of a solution adapted to the specific conditions of north Cameroon. Economically, the use of a locally available renewable energy resource may reduce dependence on grid electricity for isolated sites. From an environmental point of view, the project will contribute to the reduction of greenhouse gas emissions and the promotion of renewable energy in Cameroon. Thus, the installation of a standalone solar streetlight within the Garoua’s University site is a technically feasible, economically viable and environmentally sustainable solution.

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